Are the harmful emissions from New Zealand's light duty vehicle fleet improving?

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Executive summary

Vehicle engine control and emissions reduction technologies are continually improving and, as a result, new vehicles tend to discharge less air pollution per kilometre travelled than older vehicles. In theory, as new vehicles replace old in the New Zealand fleet and as fuel quality improves, the amount of pollutants discharged on a *per vehicle* basis should (on average) be reducing. However, it is unknown how much influence (if any) new technology and improved fuel is actually having on the 'real-world' emissions from New Zealand's light duty *vehicle fleet as a whole*. This is a critical piece of information as it determines whether 'business-as-usual' policies and trends will be sufficient to ensure that environmental standards will be met. Gaining an understanding of how real-world vehicle fleet emissions are changing with time could flag that additional vehicle emissions reduction strategies and policies are required.

This project used remote sensing to measure real-world vehicle emissions in Auckland in 2009 and then compared the results with measurements taken at the same sites during comparable road-side monitoring campaigns in 2003 and 2005. The main objective of the project was to address the question:

> *Are the harmful emissions from New Zealand's light duty fleet improving (reducing) under the current business as usual scenario?*

The 2009 road-side monitoring took place at seven sites across the Auckland region in May and November 2009 and yielded a dataset of 22,000 valid readings. Emissions measurements covering 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 were:

- From 2003 to 2009, the mean age of vehicles within the monitored vehicle 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 overall average concentrations per vehicle reduced by 43% for CO, 58% for HC, 39% for NO and 27% for uvSmoke. The introduction of emissions standards for New Zealand new vehicles has significantly reduced the mean emissions of CO, HC, NO and uvSmoke for vehicles manufactured from 2003 onwards compared with vehicles manufactured pre-2003.

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 from the project is that harmful emissions from New Zealand's light duty fleet are generally improving (reducing) under the current business as usual scenario. While this is an encouraging result, there are three issues which will need to be considered and monitored, and in-service interventions/policies may be required.

First, NO emissions improvements may have plateaued (especially from diesel vehicles) which is of concern with many urban environments showing steady or even increasing levels of ambient nitrogen dioxide (NO_2). Second, the aging vehicle fleet is also a concern because much of the improvement observed in the fleet emissions is due to new lower emitting vehicles entering the fleet. Third, while per vehicle average emissions are reducing, the number of vehicles in New Zealand and the distance they are being driven is increasing and driving conditions are becoming more congested, especially in the urban areas. Therefore it is likely that at least some of the individual vehicle emissions improvements are being eroded by the other factors that influence the total amount of emissions being discharged by New Zealand's light duty vehicle fleet.

It is also important to note the study was based only on vehicles measured in Auckland and did not consider emissions from heavy duty vehicles, which are the largest source of particulate pollution from the road transport sector.

The results from this project will be invaluable to the NZ Transport Agency, Ministry of Transport and other stakeholders for:

- assessing the effectiveness of existing legislation, such as the Vehicle Exhaust Emissions Rule
- evaluating the potential benefits of implementing future emissions control strategies
- setting benchmarks for monitoring changes in fleet characteristics of and emissions from vehicles over time
- determining the likelihood that vehicle emissions reduction targets will be met.

The key findings clearly demonstrate the value of regular roadside remote sensing in identifying and assessing the key trends that influence the emissions performance of the light vehicle fleet. The principal recommendation for the future is therefore to continue with regular campaigns every two years to continue to monitor any critical or emerging trends that may require future policy interventions. Future monitoring programmes could also be used to investigate regional differences in vehicle fleets and vehicle emissions profiles.

Abstract

Vehicle emission reduction technologies are continually improving. In theory, as new vehicles replace old ones in the fleet and as fuel quality improves, the amount of pollutants discharged on a per vehicle basis should (on average) be reducing. However, it is unclear how much influence new technology and improved fuel is actually having on the 'real-world' emissions from the light duty vehicle fleet as a whole.

This project used remote sensing to measure real-world vehicle emissions in Auckland in 2009 and then compared the results with measurements taken at the same sites in comparable campaigns undertaken in 2003 and 2005. The main objective of the project was to address the question: *Are the harmful emissions from New Zealand's light duty fleet improving under the current 'business as usual' scenario?*

Emissions measurements (carbon monoxide, nitric oxide, hydrocarbons and uvSmoke as an indicator of fine particulate matter) were stored together with vehicle information (such as fuel type, age, odometer reading and emission standard) enabling the effect of each parameter and any trends to be assessed.

The results confirmed that New Zealand's light fleet emissions are indeed generally improving with current trends. However, three trends of concern were identified and require on-going monitoring.

1 Introduction

1.1 Background

Many locations in New Zealand experience poor air quality, primarily due to home heating during winter but also with a contribution from motor vehicles. Vehicle emissions contribute between 11% and 81% of winter weekday emissions in metropolitan Christchurch (Smithson 2008) and between 27% and 82% in the Auckland region (Metcalfe et al 2006), depending on the contaminant. In addition, unlike home heating, motor vehicles are a year-round source. Air pollution from vehicles alone is estimated to result in 500 premature deaths, more than 260 hospitalisations and 712,000 restricted activity days[1] in New Zealand each year (Kuschel and Mahon 2010).

In 2005, the Ministry for the Environment introduced National Environmental Standards (AQNES) for air quality (MfE 2004). The AQNES have targets which must be met by 2013 and regional councils have been developing management strategies based on predictions of future likely emissions to achieve compliance in their airsheds, largely focusing on emissions from industry and home heating. At the same time, the Ministry of Transport (MoT) and the Ministry of Economic Development (MED) working in concert have significantly tightened controls on vehicle emissions and vehicle fuels through a variety of policy initiatives. Major progress has been made in fuels and technology, with sulphur levels in diesel now at Euro 5[2] (MED 2008) and new vehicles being required to meet a strict schedule of improving emissions standards (MoT 2007).

In theory, as new vehicles replace old in the New Zealand fleet and as fuel quality improves, the amount of pollutants discharged on a *per vehicle* basis should (on average) be reducing. However, it is unknown how much influence (if any) new technology and improved fuel is actually having on the real-world emissions from New Zealand's light duty vehicle *fleet as a whole*. This is a critical piece of information as it determines whether 'business-as-usual' policies and trends will be sufficient to ensure the AQNES and other environmental standards will be met. Gaining an understanding of how real-world vehicle fleet emissions are changing with time could flag that additional vehicle emissions reduction strategies and policies are required.

1.2 Objectives and scope of the research

The primary objective of this project was to address the question:

> *Are the harmful emissions from New Zealand's light duty fleet improving (reducing) under the current 'business as usual' scenario?*

In order to do this and to assess the relative difference in emissions from vehicles of different ages and types the research aimed to:

- undertake roadside vehicle emissions measurements in 2009 to obtain a representative profile of light duty vehicles

[1] A restricted activity day is one where a person is unable to undertake their normal daily activities, such as going to school/work or enjoying their recreation, because they are affected by air pollution.

[2] Sulphur in diesel must not be more than 10ppm by mass or less to allow vehicles to comply with Euro 5 emission standards. This has been a requirement for all diesel sold in New Zealand since 1 January 2009. However, historically, sulphur levels in diesel were much higher and were above 500ppm prior to August 2004.

- collate the 2009 vehicle emissions measurements with similar databases developed in 2003 and 2005
- characterise and compare the features of the monitored light duty vehicle fleet in 2003, 2005 and 2009
- assess any trends in fleet emissions over the period 2003 to 2009
- evaluate the effect of emissions standards on vehicle emissions
- review the effect of odometer readings on vehicle emissions.

Remote sensing was previously employed in New Zealand in three major campaigns in Auckland and Wellington to measure exhaust emissions of a large number of vehicles in 'real-world' situations during the period 2003 to 2006 (Fisher et al 2003; Bluett and Dey 2006; Bluett et al 2010). This project also used remote sensing to measure real-world vehicle emissions in Auckland in 2009 and then compared the results with measurements taken at the same sites in comparable roadside monitoring campaigns in 2003 and 2005.

Measurements were undertaken at seven sites across the Auckland region in May and November 2009 yielding a dataset of approximately 22,000 valid readings. The measured pollutants included carbon monoxide (CO), nitric oxide (NO), hydrocarbons (HC), and uvSmoke as an indicator of fine particulate. The four pollutants monitored align closely with those managed by ambient air quality regulations which set target ambient concentrations of CO, hydrocarbons (benzene), nitrogen dioxide (NO_2) and particulate matter (PM_{10}). Each pollutant measurement was also recorded with information about the vehicle, such as fuel type, age, odometer reading and emissions standard. The vehicle details were linked to the emissions measurements to enable the effects of and trends in each parameter to be assessed. The study mirrored a work programme undertaken by Gary Bishop and Donald Stedman (University of Denver) which used a multi-year on-road emissions measurement programme to assess whether on-road emissions had reduced for vehicle fleets measured in four states in the USA (Bishop and Stedman 2008).

Overall analyses were undertaken to identify critical trends in both the fleet and the emissions monitored in 2003, 2005 and 2009. In addition, specific analyses were undertaken to investigate the effect of emissions standard and the effect of age/odometer reading on actual fleet emissions. These additional analyses were performed to assess the effectiveness of existing emissions legislation (MoT 2007) and to assess the potential of future policies involving interventions such as accelerated scrapping schemes.

The major output has been the development of a framework and baseline, which will facilitate the on-going assessment of the emissions performance of New Zealand's light duty vehicle fleet.

1.3 Project funding

The project was funded by the NZ Transport Agency through the NZTA's 2009/10 Research Programme, with significant contributory funding from the Auckland Regional Council and NIWA. The total project budget was $146,200 (exclusive of GST) comprising:

- $56,200 from Auckland Regional Council ($50,000 for phase 1 of the measurement campaign and $6200 for the detailed analysis of the effect of vehicle mileage)
- $20,000 from NIWA (for phase 2 of the measurement campaign and the general data analyses)
- $70,000 from the NZTA Research Fund (for the balance of the project activities).

1.4 Report structure

This report is structured as follows:

- Chapter 2 outlines the equipment, sites and analysis techniques used in the 2009 measurement campaign, with references to the 2003 and 2005 studies.
- Chapter 3 presents the trends in the vehicle fleets measured in 2003, 2005 and 2009, in terms of vehicle characteristics.
- Chapter 4 discusses the trends in the vehicle emissions measured in 2003, 2005 and 2009, in terms of air contaminants.
- 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 from vehicles built to different emissions standards.
- Chapter 7 summarises the key findings.
- Chapter 8 presents the overall conclusions and recommendations.

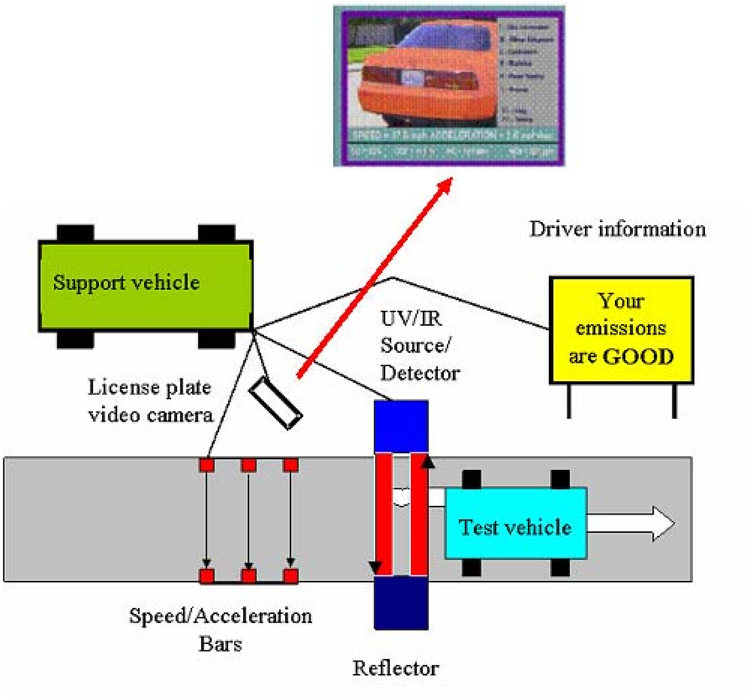
2 Method

This chapter outlines the equipment, sites and analysis techniques used to collect the 2009 dataset. This dataset was then used to compare fleet and emissions trends against the 2003 and 2005 datasets obtained in earlier remote sensing campaigns.

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 and 2009 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). Technical details on the RSD are provided in Stedman et al (1997) (see www.feat.biochem.du.edu/whatsafeat.html). 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).

2.1.1.1 Cautionary note on measuring NO_X emissions

The oxides of nitrogen (NO_X) emissions from motor vehicles principally consist of nitric oxide (NO) and nitrogen dioxide (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. For petrol vehicles the NO:NO_X ratio is 0.9-0.95; for diesel it is 0.75-0.85 (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 (eg 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.

2.1.2.1 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. It is accepted 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.

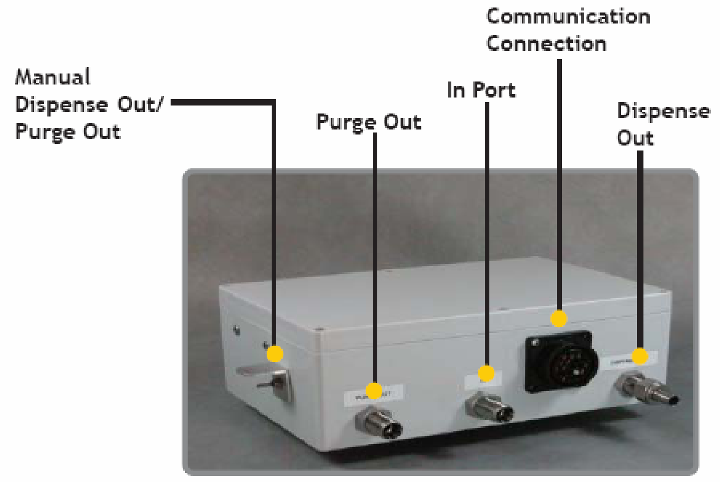
Every time the source detector module (SDM) was switched on and warmed up, the unit was calibrated using a method named cell calibration. A cell which contained a known concentration of calibration gases was placed in the IR beam path and the SDM was then calibrated to the known values of gas within 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 RSD4000EN measures to produce uvSmoke data is UV absorbance at wavelengths ~232. 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 (~2m) 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.

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. A more detailed description of how VSP is calculated is provided in appendix A. The RSD 3000 system did not have the capability to measure vehicle speed or acceleration and therefore VSP data is 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 (eg VSP) to screen out measurements of vehicles operating in enrichment mode.

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

In this study, VSP was used to check that differences in vehicle power output were not responsible for any differences observed in fleet average emissions measured in 2005 and 2009. For example, if the vehicles measured in 2005 had been driven more aggressively (faster and/or higher acceleration) than in 2009, then vehicle power output (as measured by VSP) could be a major factor causing the higher emissions that may be observed in the 2005 fleet. A comparison of emissions from petrol and diesel vehicles measured in the 2005 and 2009 campaigns by VSP bands is contained in appendix A, together with the implications on the findings of this study. The conclusion from the VSP comparison contained in appendix A is that the differences observed in the petrol and diesel fleet average emissions measured in 2005 and 2009 were not a result of changes in vehicle power output over the two campaigns.

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

2.1.6 Vehicle 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[3]) and information obtained for each vehicle. Table 2.1 lists the relevant information obtained for the vehicles monitored in this project.

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.

[3] 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.

Approvals and advice were sought and obtained from all relevant roading and traffic control authorities. These authorities included the relevant city council when monitoring was being 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 is 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 (eg Walsh et al 1996). This may be due to a number of possible factors such as the simulated drive cycles not being representative of actual drive cycles or not accounting for all vehicles. Regardless, 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 the effect of these vehicles adequately in a selected dynamometer testing programme.

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 and up to 2000 vehicles can be monitored each hour. This compares with approximately 30 minutes to complete a single IM240 setup and test. The open path monitoring is also unobtrusive because there is no physical connection to the vehicle and no specific behaviour is required of the driver. The RSD monitoring is therefore very cost effective – typically only $2–$3 per vehicle.

There are, of course, limitations to the vehicle emissions data collected by the RSD compared with the data collected using a dynamometer and analyser setup. It is useful to view the results of any RSD study in light of these limitations.

- 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 (involving not only accelerations but also 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. For this reason, the emissions measured will reflect driving conditions that predominate on these types of roadway and will not necessarily be representative of emissions generated on other roadway types, eg at busy intersections or suburban roads where the emissions of 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. Therefore the particulate data presented in this report should be compared to dynamometer data with caution.
- 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 cannot be measured. However, exhaust systems that discharge vertically are only installed on heavy duty vehicles (gross vehicle mass greater than 3500kg) which were excluded from

this analysis. 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 that 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 RSD technology used to monitor vehicle emissions has advanced significantly since the initial stages of development in the early 1990s when the pollutants that were measured were restricted to CO and HC, and neither the vehicle's speed nor acceleration was recorded. The benefits 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 (eg 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 has 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 2009 at a range of sites across Auckland. The 2009 results were then compared with results for the same sites obtained from previous RSD campaigns conducted in 2003 and 2005 (Fisher et al 2003; Bluett et al 2010).

Details of these campaigns follow.

2.2.1 Sites used in the 2009 campaign

The 2009 RSD monitoring was carried out at seven sites across the Auckland region. These sites were selected based on their ability to meet three criteria:

1. Were (or represented) sites previously used in the 2005 monitoring campaign (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.

Monitoring for this project was undertaken in two stages – the first in May 2009 and the second in November 2009 – as shown in table 2.2. In total, valid results were collected for approximately 22,000 light duty vehicles.

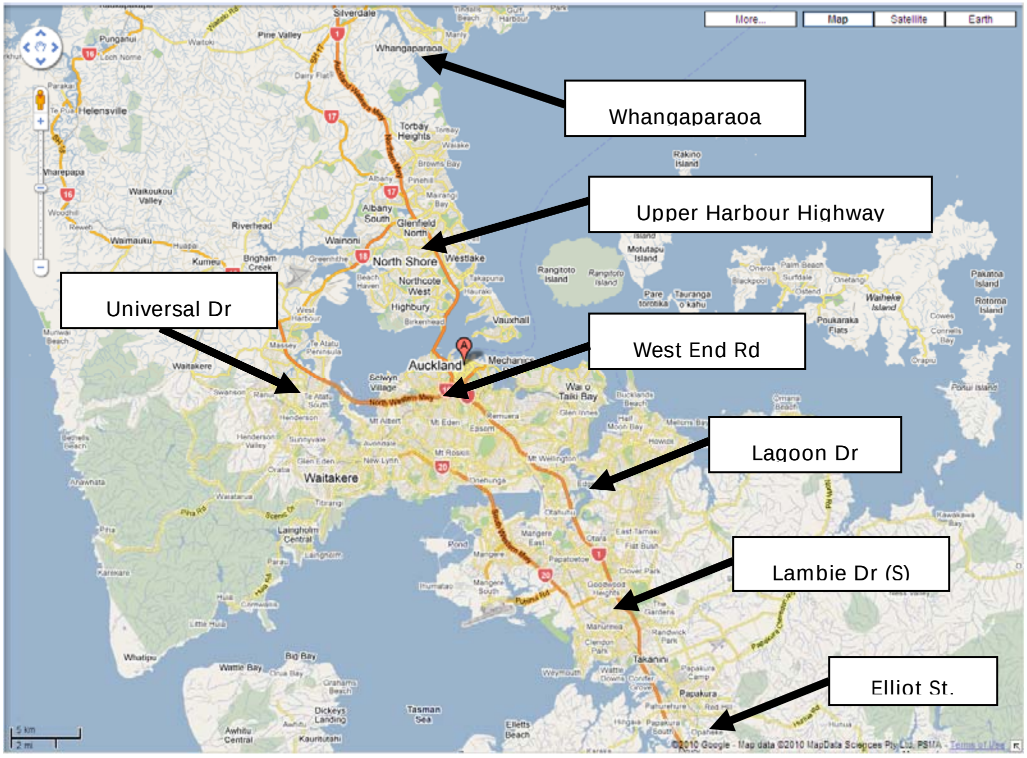
The general locations of the sites are shown in figure 2.8.

Table 2.2 Details of all monitoring sites used in the 2009 remote sensing campaign

Site no.	Site name	Date	Time	Site code	Vehicles tested	Valid tests	Capture rate
1	Lagoon Dr	5 May	06:35-12:35	AUC2	4415	2485	56%
		4 Nov	05:52-12:04	AUC2	4296	2216	52%
2	Lambie Dr (S)	16 May	07:12-13:30	MAN2	2502	1130	45%
3	Universal Dr*	7 May	12:38-17:03	WAI5	1840	607	33%
		19 May	12:41-18:16	WAI5	4345	2274	52%
		3 Nov	12:30-19:01	WAI5	5151	2496	48%
4	West End Rd	13 May	06:19-11:54	AUC8	1671	951	57%
5	Whangaparaoa Rd*	14 May	05:41-07:16	ROD3	1728	724	42%
		20 May	15:19-18:54	ROD3	4677	2263	48%
6	Elliot St	15 May	06:45-12:14	PAP1	2160	1100	51%
7	Upper Harbour Highway	18 May	12:42-17:23	NOR5	3604	1773	49%
		6 Nov	12:45-19:04	NOR5	5772	4109	71%
	Total for 2009				**42,161**	**22,128**	**52%**

* These sites were repeated in the first stage in May because monitoring was cut short on the first day due to inclement weather

Figure 2.8 Map of Auckland indicating locations of all monitoring sites used in the 2009 RSD campaign



2.2.2 Sites common to the 2003 and 2005 campaigns

Table 2.3 highlights which sites used in 2009 were common to the campaigns in 2003 and 2005.

All seven sites used in 2009 were repeats of sites from 2005 but only four were originally monitored in 2003. Unfortunately, many of the sites from the original 2003 campaign were no longer suitable for remote sensing as they either had been upgraded to more than one lane, had been installed with ramp metering signals which interrupt the traffic flow or no longer existed.

However, there was still sufficient commonality to enable trends to be assessed across the three campaign years when the data analysis was undertaken.

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

Site no.	Site name	Site code	2009 sites	2005 sites	2003 sites
1	Lagoon Dr	AUC2	Y	Y	Y
2	Lambie Dr (S)	MAN2	Y	Y	Y
3	Universal Dr	WAI5	Y	Y	N
4	West End Rd	AUC8	Y	Y	N
5	Whangaparaoa Rd	ROD3	Y	Y	N
6	Elliot St	PAP1	Y	Y	Y
7	Upper Harbour Highway	NOR5	Y	Y	Y
	Total valid readings		**22,000**	**21,000**	**11,000**

Y = yes, N = no

2.3 Statistical tools/techniques for data analysis

The emissions data from vehicles did not conform to a normal distribution. It was highly skewed with many low values and relatively few high values. The skewed nature of the vehicle emissions data set collected is further explained in appendix B.

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. However, with large data sets the K-W test can sometimes detect differences that could be considered practically insignificant. To address this issue the positive K-W test results were cross checked using the Mann-Whitney test.

2.3.1 Kruskal-Wallis test for significant differences

Skewed datasets like emissions data (see appendix B) 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% (ie p = 0.05). A set of example results for the K-W test for significant differences is provided in appendix C.

2.3.2 Mann-Whitney test

The Mann–Whitney (M-W) test is a non-parametric test for assessing whether two independent samples of observations have equally large values. It is one of the best-known non-parametric significance tests. The M-W test is virtually identical to performing an ordinary parametric two-sample t test on the data after ranking over the combined samples. The M-W test is very similar to the K-W test except it uses data values rather than the rank of the data.

This routine tests the hypothesis that distributions of both groups are equal against the alternative that probability of an observation from one population (X) exceeds an observation from the second population. The significance level used for all M-W tests in this report was 95% (ie p = 0.05). A set of example results for the M-W test for significant differences is provided in appendix C.

2.3.3 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, eg HC concentrations can be ±6.6 ppm of the value recorded. When measuring pollutant concentrations from lower emitting newer 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.

3 Trends in the fleet – 2003, 2005 and 2009

This chapter presents the major trends in key vehicle parameters measured for the light duty vehicle fleets monitored in 2003, 2005 and 2009. Emissions measurements from heavy duty vehicles (gross vehicle mass greater than 3500kg) were excluded from the analyses. Results are presented for age, year of manufacture, fuel type and country of first registration. Further analysis is done on the age profile for the overall fleet, which is 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 11,285 light duty vehicles in the 2003 dataset, 21,491 in the 2005 dataset and 22,128 in the 2009 dataset. Of these, the vast majority were petrol or diesel vehicles with the remainder powered by other fuels, eg LPG. Given the negligible contribution of the other fuels, the analyses undertaken here were only based on petrol or diesel vehicles.

3.1 Vehicle age and year of manufacture

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. However in New Zealand, due to the relatively recent introduction of vehicle emissions control standards (2003), vehicle age is not a good proxy for the emissions control technology which may (or may not) be installed in a vehicle. In addition, as a vehicle ages its emissions performance tends to degrade as parts and systems wear or fail.

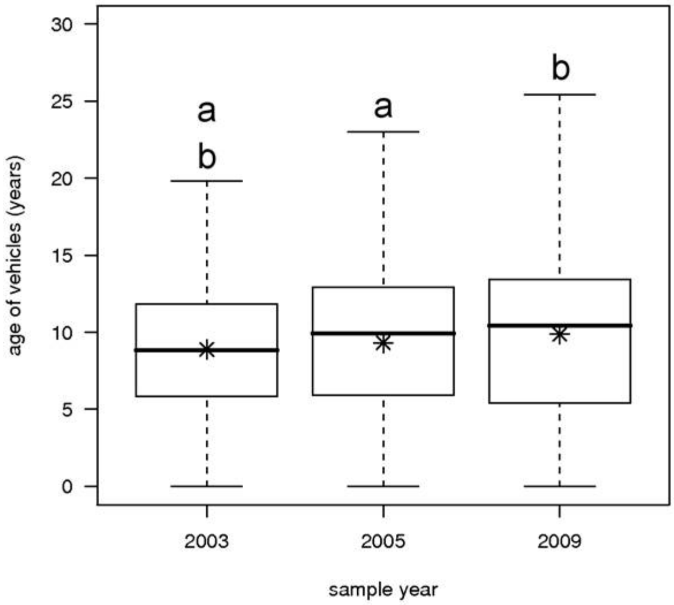
3.1.1 Vehicle age

Table 3.1 and figure 3.1 compare the mean ages of the vehicles monitored in 2003, 2005 and 2009.

Table 3.1 Comparison of the mean and median ages for the 2003, 2005 and 2009 fleets

Campaign year	Age (years)	
	Mean	Median
2003	8.83	8.83
2005	9.31	9.92
2009	9.88	10.42

Figure 3.1 Comparison of the age distributions for the 2003, 2005 and 2009 fleets



In figure 3.1 (and in all other box plots throughout the report), the median values are indicated by the lines that run horizontally through the box. The inter-quartile (25th to 75th percentile) range is noted by the lower and upper edges respectively of the box. The whiskers extend to the 5th and 95th percentile values. Any values outside this range (outliers) are omitted from the plot. The mean values are indicated by the stars.

The mean age of the light fleet steadily increased by just over one year from 2003 to be 9.88 years in 2009. The median age has shown a similar trend.

Figure 3.2 compares the age profiles of the fleets monitored in 2003, 2005 and 2009 to illustrate which sections of the fleet have aged. From 2003 to 2009, the proportion of the fleet less than 10 years old decreased while the proportion of the fleet greater than 14 years old increased, suggesting that people have been keeping their vehicles longer.

Figure 3.2 Comparison of the age profiles for the 2003, 2005 and 2009 fleets

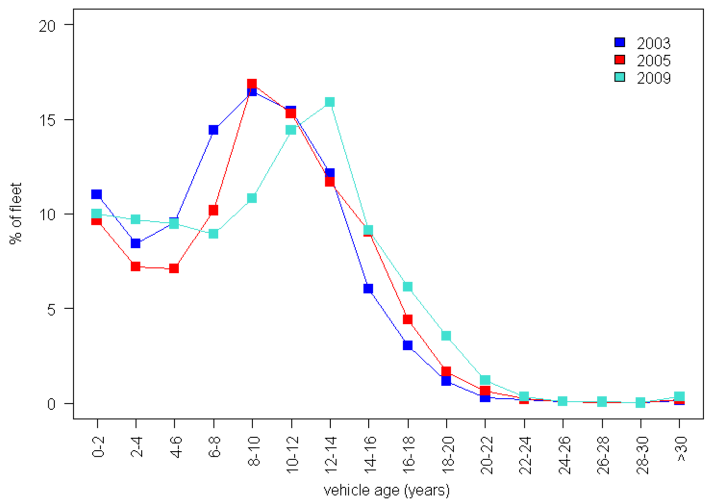


Table 3.2 compares the mean ages for the actual national and the monitored Auckland fleets.

Table 3.2 Comparison of the mean ages for the actual national and monitored Auckland fleets

Campaign year	Actual national light fleet*		Auckland light fleet	Monitored Auckland light fleet
	Average age	Travel weighted average age	Average age	Average age
2003	11.39	10.23	No data	8.83
2005	11.62	10.33	10.88	9.31
2009	12.49	11.01	11.45	9.88

* data from the annual fleet statistics (MoT 2010)

Both the Auckland fleet and the national light fleets have aged since 2003. However the average age of the monitored Auckland fleet has been consistently younger than the actual Auckland fleet.

This finding is not surprising. Newer vehicles tend to be driven a greater number of kilometres each year than older vehicles, hence they have a greater chance of driving through a monitoring site than older vehicles that do fewer kilometres. This is illustrated in table 3.2 where the travel weighted average age for the national fleet is younger than the arithmetic average by up to 1.5 years. Another possible explanation is that monitoring was undertaken in principally urban areas where the average age of vehicles may be lower than the region-wide average which includes smaller towns and rural areas, where older vehicles may be more commonly used. Table 3.3 presents the 2005 and 2009 light passenger vehicle registration statistics for Auckland by territorial local authority confirming a wide variation in average vehicle ages across the region (NZTA 2009).

Table 3.3 Variation in average age of the light vehicles across Auckland in 2005

Average age of light passenger vehicles (years)	Rodney District	North Shore City	Waitakere City	Auckland City	Manukau City	Papakura District	Franklin District
2005	11.9	10.4	12.0	9.9	11.0	12.2	12.4
2009	12.6	11.1	12.9	10.2	11.6	12.9	13.2

Although the remote sensing datasets do not necessarily reflect the *exact profile* of the entire Auckland regional fleet, they do reflect the *most likely effects* of the entire Auckland fleet, which is more important.

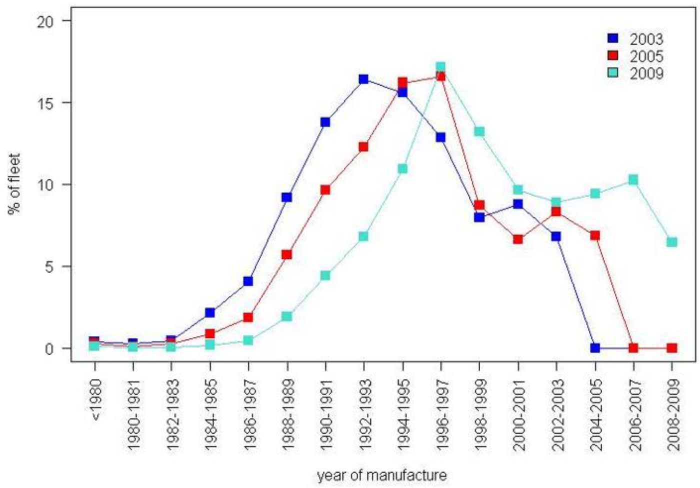
3.1.2 Vehicle year of manufacture

Table 3.4 compares the mean year of manufacture of the monitored 2003, 2005 and 2009 vehicle fleets, with the detailed profiles shown in figure 3.3.

Table 3.4 Comparison of the mean and median years of manufacture and age for the 2003, 2005 and 2009 fleets

Campaign year	Year of manufacture		Vehicle age	
	Mean	Median	Mean	Median
2003	1994	1994	8.83	8.83
2005	1995	1996	9.92	9.31
2009	1999	1999	10.42	9.88

Figure 3.3 Comparison of the year of manufacture profiles for the 2003, 2005 and 2009 fleets



As expected, figure 3.3 and table 3.4 show clear shifts in the mean years of manufacture for each fleet, largely due to the time that elapsed between the monitoring campaigns. However, the differences seen are also important as the year of manufacture is strongly linked to emissions standards. It is noteworthy that there was a reduction in the percentage of the fleet monitored in the last year of each campaign. This was an artefact of the campaigns being undertaken before the calendar year was complete and therefore not all the new vehicles manufactured and sold that year would have been on the road at the time of monitoring.

Overseas emissions standards generally change every five years or so, with emissions usually decreasing by 30% to 50% with each new standard depending on the contaminant. Because the fleet average year of manufacture was five years younger in 2009 than in 2003, fleet average emissions in 2009 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 contaminants in quite different quantities and proportions. Figure 3.4 compares the breakdown of fuel types used by the fleets monitored in 2003, 2005 and 2009.

Figure 3.4 Comparison of the fuel type profiles for the 2003, 2005 and 2009 fleets

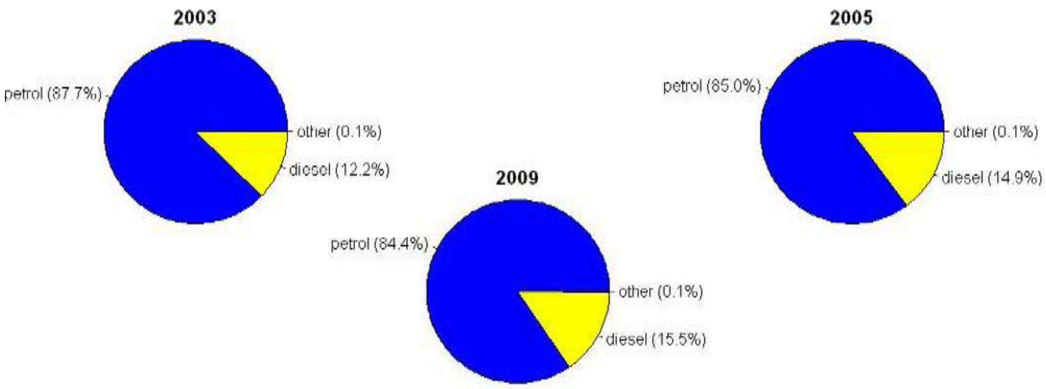


Figure 3.4 shows that between 2003 and 2009, the proportion of the fleet using diesel increased from 12.2% to 15.5%. This is consistent with national trends showing an increase in diesel vehicles from 13.4% of the light fleet in 2003 to 15.7% in 2009 (MoT 2010).

3.2.1 Petrol vehicles

Figure 3.5 and table 3.5 compare the mean ages of the petrol vehicles monitored in 2003, 2005 and 2009. The detailed age and year of manufacture profiles for each of the different petrol fleets are provided in figure 3.6.

The mean age of the petrol vehicles in the monitored light fleet has steadily increased by just over one year since 2003 to be 10.05 years in 2009, with slightly larger increases seen in median age over time.

Figure 3.5 Comparison of the age distributions for the 2003, 2005 and 2009 petrol vehicles

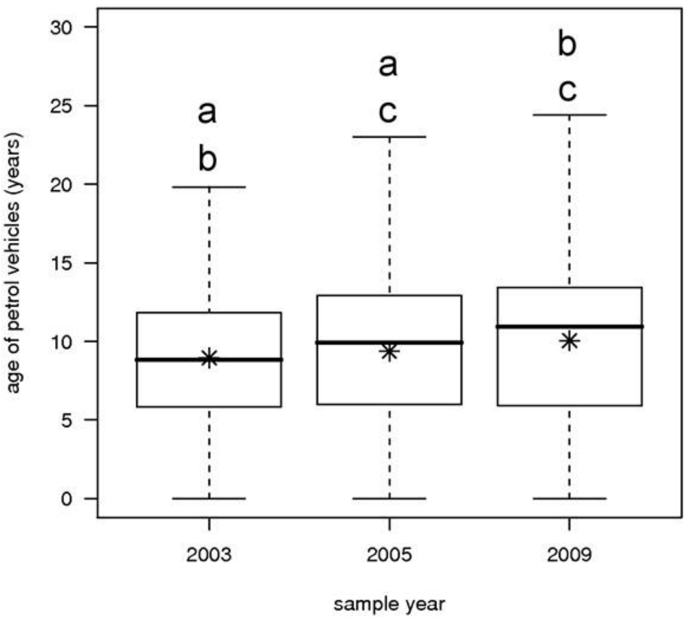
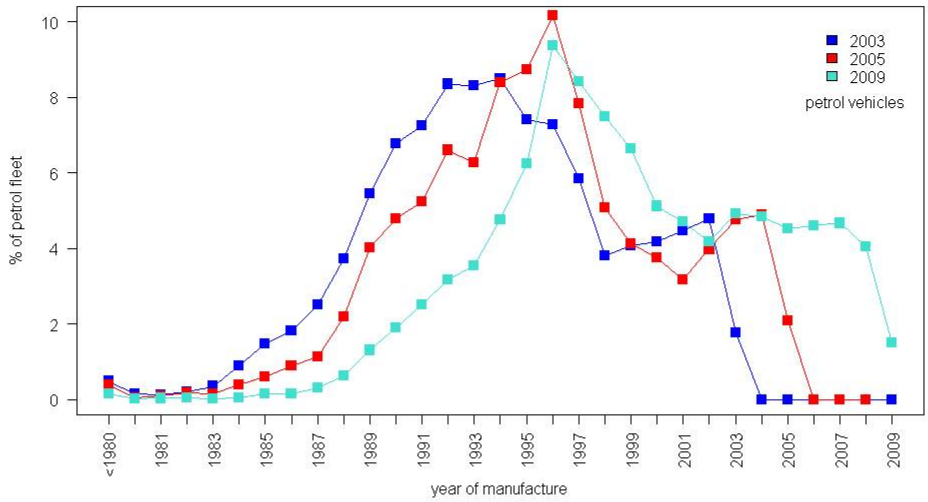
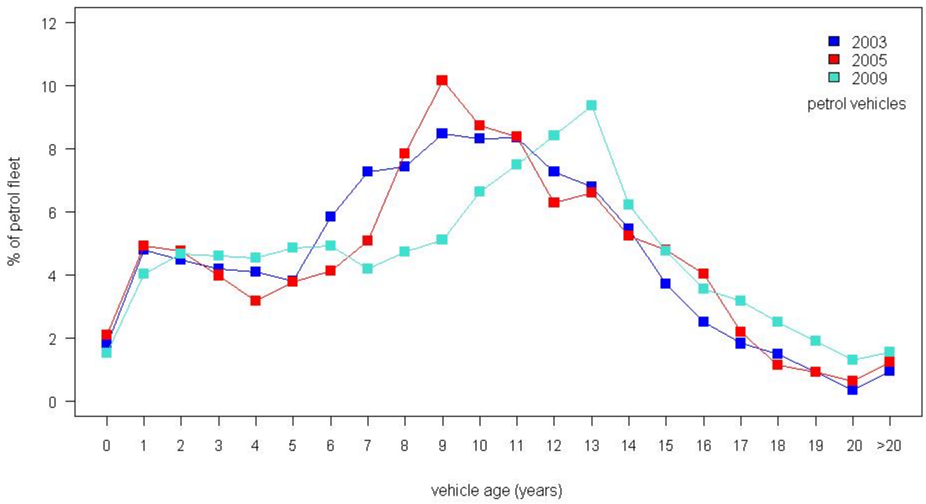


Table 3.5 Comparison of the mean and median ages for the 2003, 2005 and 2009 petrol vehicles

Campaign year	Age (years)	
	Mean	Median
2003	8.95	8.83
2005	9.37	9.92
2009	10.05	10.92

Figure 3.6 Comparison of the year of manufacture and age profiles for the 2003, 2005 and 2009 petrol vehicles





3.2.2 Diesel vehicles

Figure 3.7 and table 3.6 compare the mean ages of the diesel vehicles monitored in 2003, 2005 and 2009. The detailed age and year of manufacture profiles for each of the different diesel fleets are provided in figure 3.8.

The mean age of the diesel vehicles in the light fleet was slightly higher in 2009 relative to 2003 but the trend was less conclusive than that seen for petrol vehicles, with the 2005 results showing higher mean and medians than the 2003 and 2009 results.

Figure 3.7 Comparison of the age distributions for the 2003, 2005 and 2009 diesel vehicles

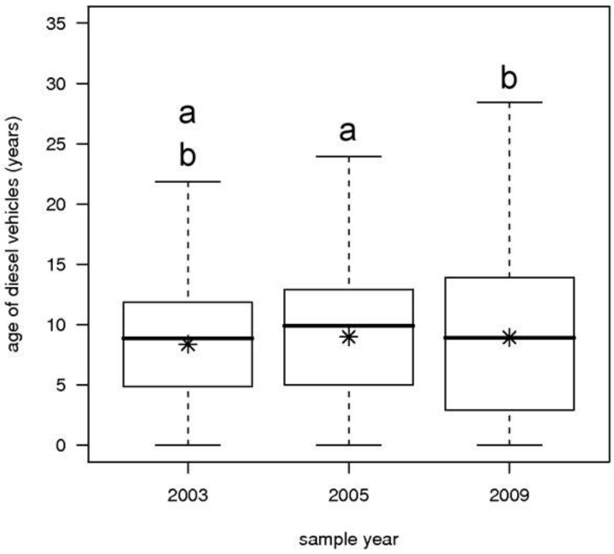
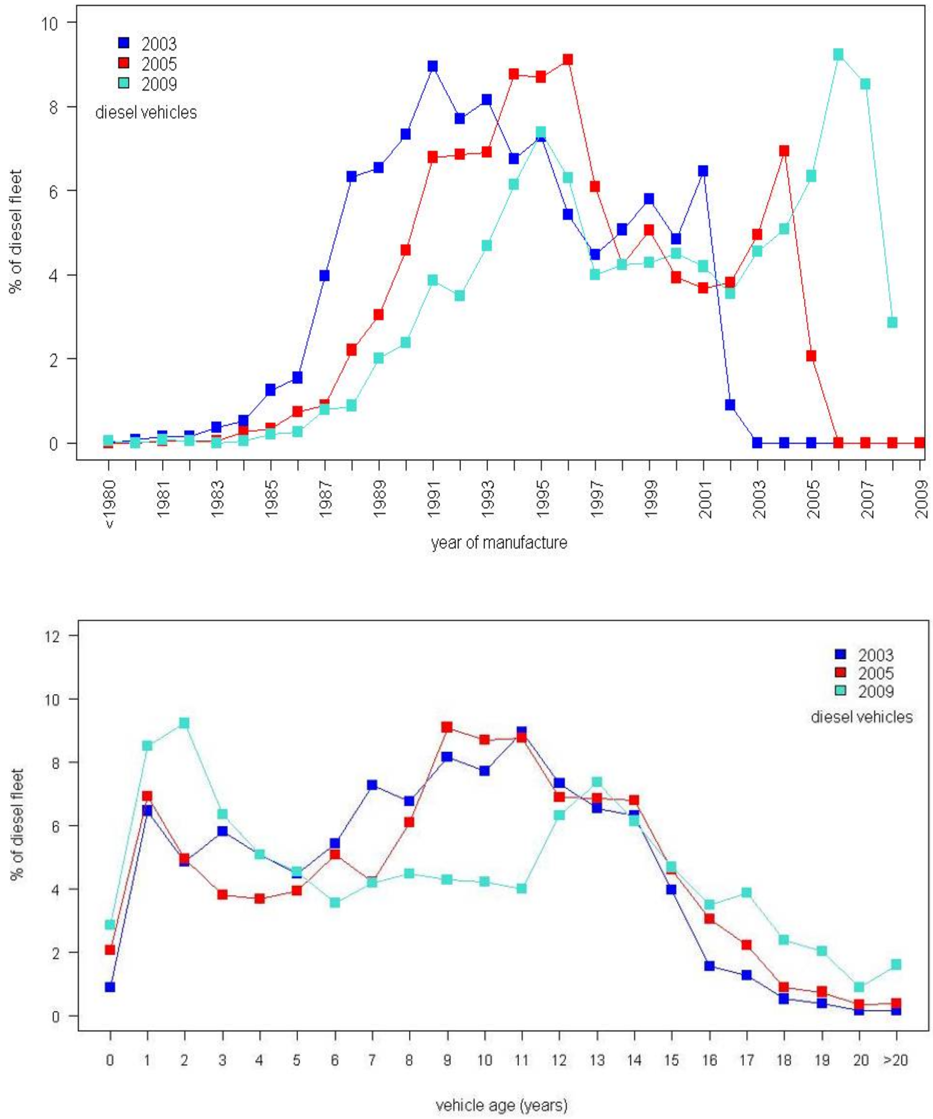


Table 3.6 Comparison of the mean and median ages for the 2003, 2005 and 2009 diesel vehicles

Campaign year	Age (years)	
	Mean	Median
2003	8.37	8.83
2005	9.99	9.92
2009	8.93	8.92

From figure 3.8 the 2009 profile shows a marked increase in the proportion of vehicles aged 1–2 years and a significant drop in the proportion of vehicles aged 9–11 years. The latter may reflect recent emissions legislation which requires more stringent diesel exhaust emissions standards than were in force in 2005 and earlier years (MoT 2007). This should be most evident in reductions in the mean age of used imported used diesel vehicles coming into the New Zealand fleet and is investigated in the next section.

Figure 3.8 Comparison of the year of manufacture and age profiles for the 2003, 2005 and 2009 diesel vehicles

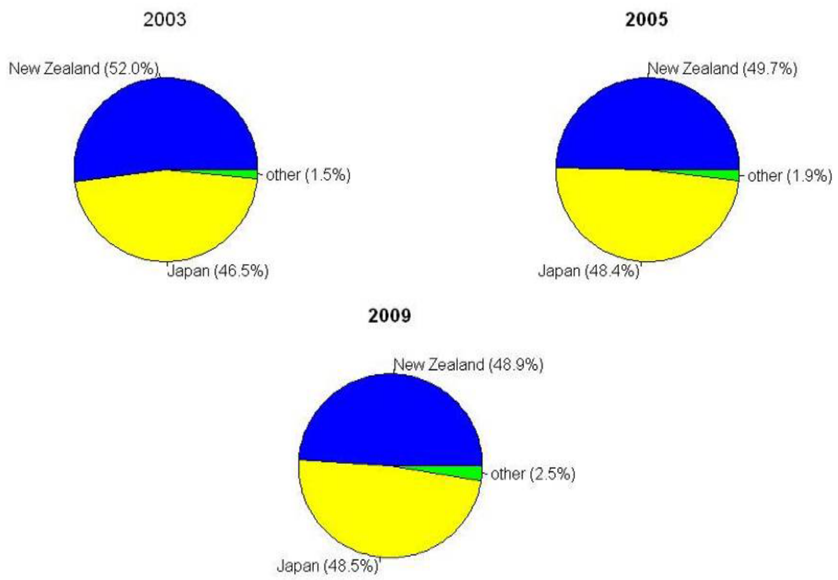


3.3 Country of first registration

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. Consequently, the country of first registration (which is recorded in the motor vehicle register for every vehicle) is a critical parameter in understanding a fleet's emissions performance.

Figure 3.9 shows a breakdown of the fleet by the county of first registration for the vehicles monitored in 2003, 2005 and 2009.

Figure 3.9 Comparison of the country of first registration for the 2003, 2005 and 2009 fleets



Approximately half of the vehicles monitored were New Zealand new and the other half entered the New Zealand fleet as used vehicles imported from other countries (mainly Japan). There was a growth in imported used vehicles within the monitored fleets from 48.0% in 2003 to 51.1% in 2009. The proportion of used vehicles imported from Japan appeared to have plateaued with an increasing number of used vehicles being imported from other countries (1.5% in 2003 to 2.5% in 2009). Regardless of the source of imported used vehicles, the proportion of the monitored fleet which are New Zealand new vehicles is still in decline.

This growth in the proportion of imported used vehicles in the monitored fleet is consistent with that observed in the national fleet which increased from 46.0% in 2003 to 48.6% in 2009 (MoT 2010). However, the Auckland monitored fleets had a slightly greater proportion of imported used vehicles (up to 3% higher than that seen in the national fleet).

4 Trends in the emissions – 2003, 2005 and 2009

This chapter discusses the major trends in vehicle emissions measured for the fleets in 2003, 2005 and 2009. 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 (NZN) and Japanese used imports (JPU)).

Datasets used for the analysis in this section: In total, valid measurements were available for 11,285 light duty vehicles in the 2003 dataset, 21,491 in the 2005 dataset and 22,128 in the 2009 dataset. Of these, the vast majority were petrol or diesel vehicles with the remainder powered by other fuels, eg LPG. Given the negligible contribution of other fuel types, the analyses undertaken in this report were only based on petrol or diesel vehicles.

4.1 Change in the fleet emissions

Figure 4.1 and table 4.1 compare the emissions of CO, HC, NO and uvSmoke from the total light duty vehicle fleets (petrol and diesel vehicles) monitored in 2003, 2005 and 2009.

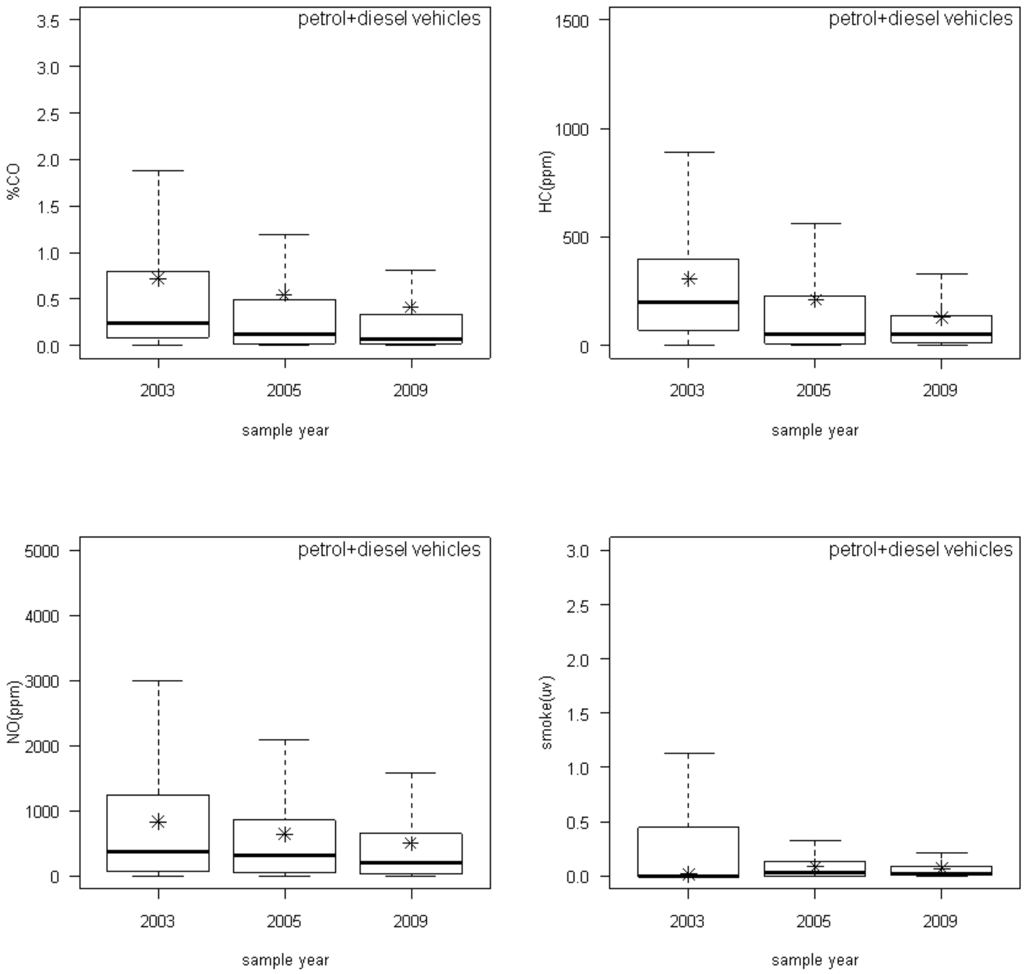
Emissions of CO, HC and NO, on average, decreased significantly from the light fleet between 2003 and 2009. uvSmoke emissions, on average, also showed an improvement but only from 2005 onwards. The 2003 uvSmoke results need to be interpreted with caution as these values were estimated from the RSD3000 opacity measurements, whereas the 2005 and 2009 uvSmoke results were measured directly using the RSD4000EN equipment (see section 2.1.2 for more details). The 2003 RSD3000 estimates of uvSmoke for petrol or petrol vehicle dominated fleets included a significant amount of negative data. It appears that the 2003 estimates of uvSmoke for petrol or petrol vehicle dominated fleets may be unrealistic and therefore have been left out of the analysis.

Table 4.1 Comparison of median and mean emissions for the 2003, 2005 and 2009 fleets

Campaign year	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	0.72	0.24	306	200.	823	369	NA*	NA*
2005	0.54	0.11	211	56	655	333	0.090	0.033
2009	0.41	0.07	129	52	504	197	0.066	0.022

* uvSmoke data for 2003 are estimated from RSD3000 opacity measurements.
For petrol vehicles, uvSmoke data estimates appear to be unrealistically low.

Figure 4.1 Comparison of emissions distributions for the 2003, 2005 and 2009 fleets



4.2 Changes in petrol vehicle emissions

The number of valid measurements made for petrol vehicles monitored in the 2003, 2005 and 2009 campaigns was 9894, 18,260 and 18,452 respectively. The analysis in this section of the report considers the overall petrol fleet emissions. Subsequent sections present analyses of the petrol fleet broken down into NZN and JPU vehicles. The reason for splitting the petrol fleet into these two groups is that 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.

Figure 4.2 and table 4.2 compare the emissions of CO, HC, NO and uvSmoke from all petrol vehicles monitored in 2003, 2005 and 2009.

Figure 4.2 Comparison of emissions distributions for the 2003, 2005 and 2009 petrol vehicles

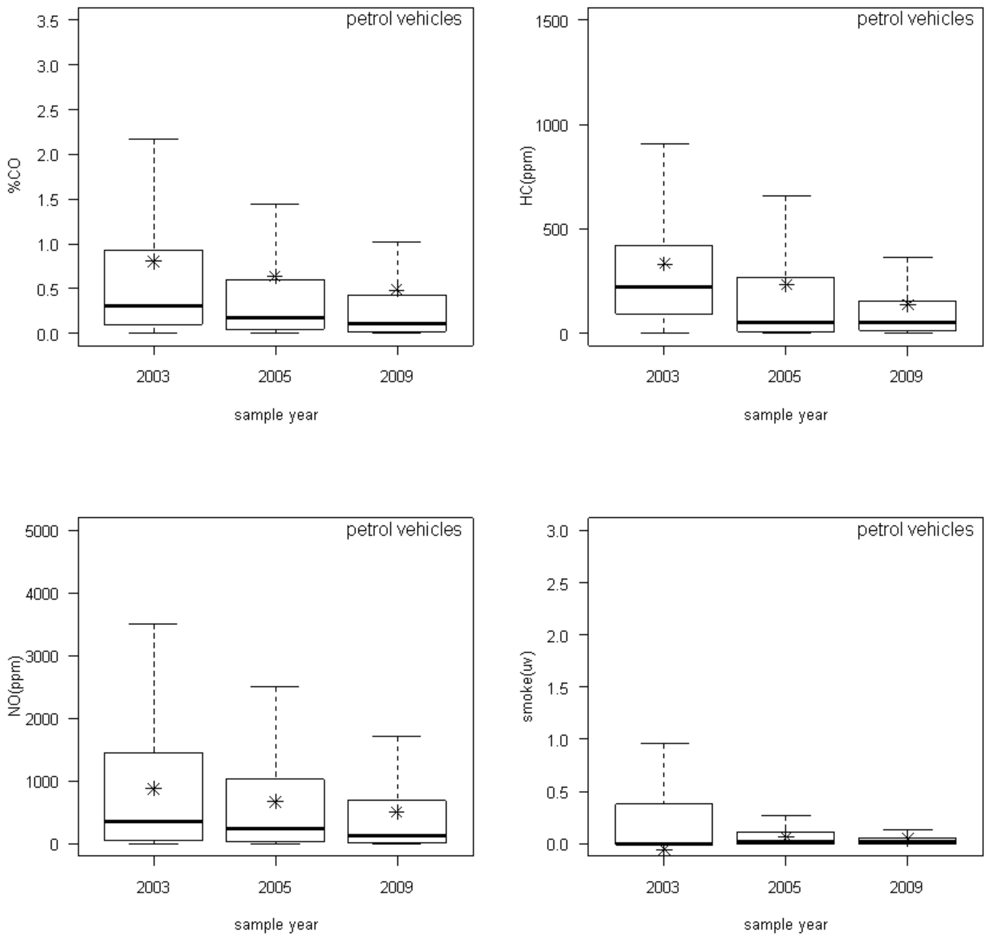


Table 4.2 Comparison of the mean and median emissions for the 2003, 2005 and 2009 petrol fleets

Campaign year	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	0.80	0.31	330	220	880	359	NA*	NA*
2005	0.63	0.17	232	54	671	246	0.064	0.020
2009	0.48	0.11	137	50	511	126	0.050	0.015

* uvSmoke data for 2003 are estimated from RSD3000 opacity measurements.
For petrol vehicles, uvSmoke data estimates appear to be unrealistically low.

Emissions of CO, HC and NO from petrol vehicles, on average, decreased significantly between 2003 and 2009. uvSmoke emissions, on average, also improved but only with some confidence beyond 2005.

As mentioned previously, the 2003 uvSmoke results from petrol vehicles were excluded from the analysis of the 2003 fleet. This exclusion also applied to the analyses of uvSmoke emissions from NZN and JPU petrol vehicles which are detailed in the following sections.

4.2.1 NZN petrol vehicles

The number of valid measurements made for NZN petrol vehicles monitored in the 2003, 2005 and 2009 campaigns was 5337, 8980 and 9063 respectively.

Figure 4.3 and table 4.3 compare the emissions of CO, HC, NO and uvSmoke from the NZN petrol vehicles monitored in 2003, 2005 and 2009.

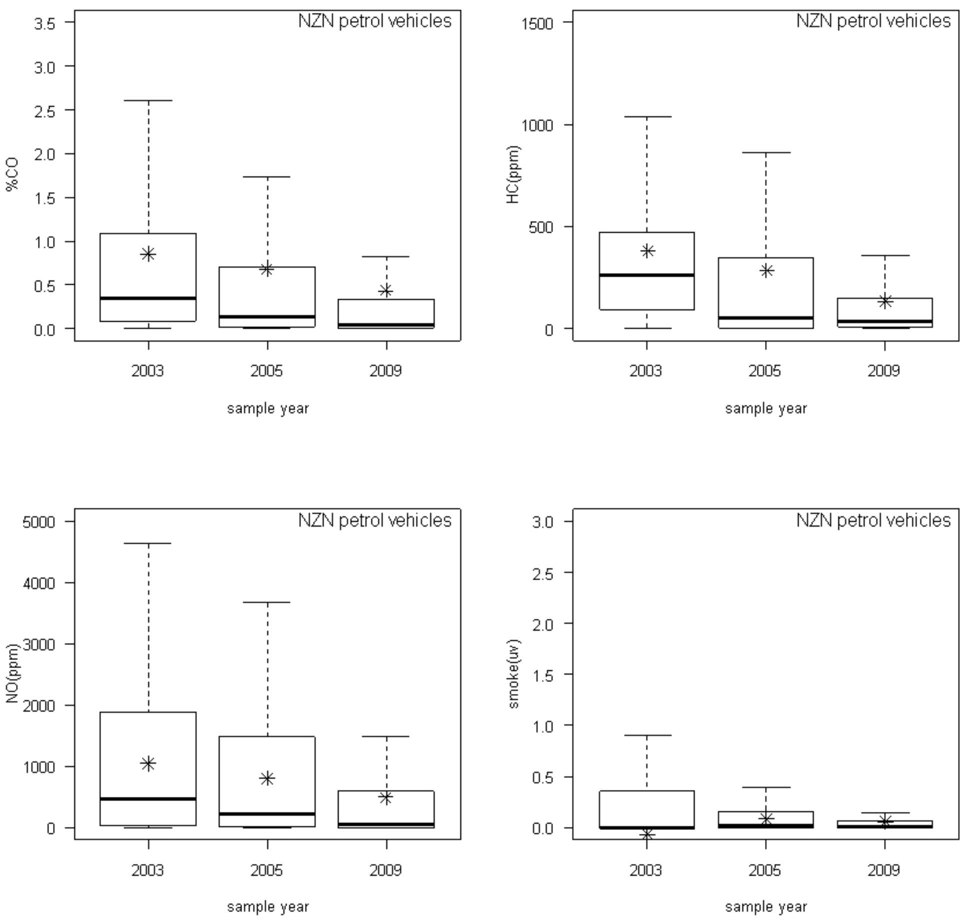
Emissions of CO, HC and NO, on average, from NZN petrol vehicles decreased significantly from 2003 and 2009. uvSmoke emissions, on average, also improved but only with some confidence beyond 2005.

Table 4.3 Comparison of the mean and median emissions for the 2003, 2005 and 2009 NZN petrol fleets

Campaign year	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	0.85	0.34	379	260	1046	472	NA*	NA*
2005	0.67	0.13	282	54	804	213	0.084	0.024
2009	0.43	0.05	132	36	497	55	0.053	0.010

* uvSmoke data for 2003 are estimated from RSD3000 opacity measurements.
For petrol vehicles, uvSmoke data estimates appear to be unrealistically low.

Figure 4.3 Comparison of the emissions distributions for the 2003, 2005 and 2009 NZN petrol fleets



4.2.2 JPU petrol vehicles

The number of valid measurements made for JPU petrol vehicles monitored in the 2003, 2005 and 2009 campaigns was 4557, 9281 and 9389 respectively.

Figure 4.4 and table 4.4 compare the emissions of CO, HC, NO and uvSmoke from the JPU petrol vehicles monitored in 2003, 2005 and 2009.

Emissions of CO, HC and NO, on average, from JPU petrol vehicles decreased significantly from 2003 and 2009. However, uvSmoke emissions showed no obvious trends.

Figure 4.4 Comparison of the emissions distributions for the 2003, 2005 and 2009 JPU petrol fleets

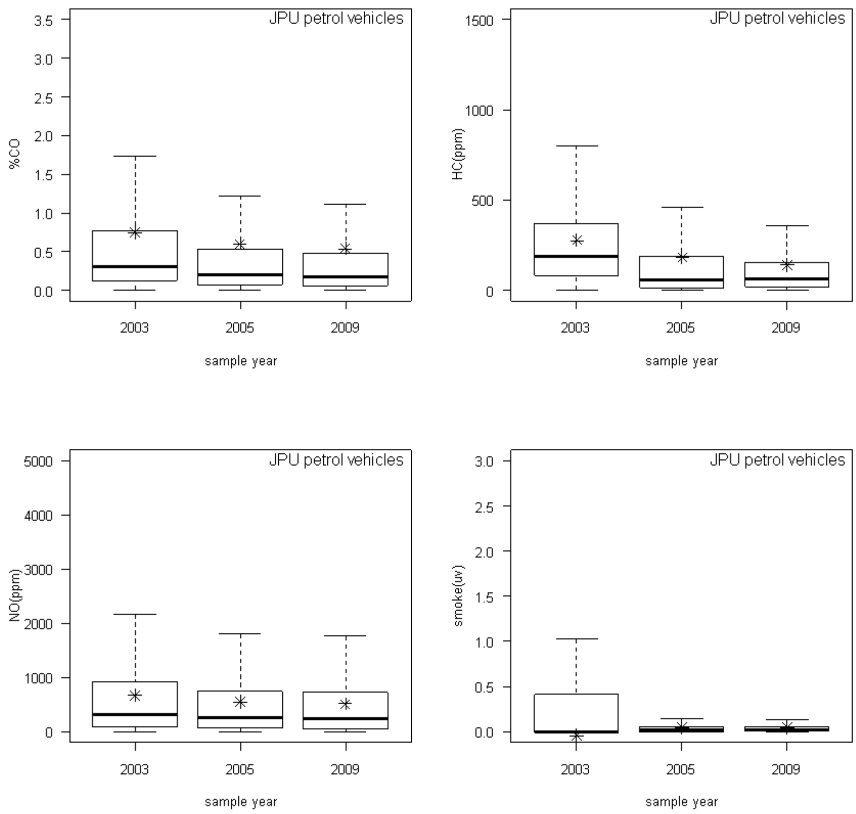


Table 4.4 Comparison of the mean and median emissions for the 2003, 2005 and 2009 JPU petrol fleets

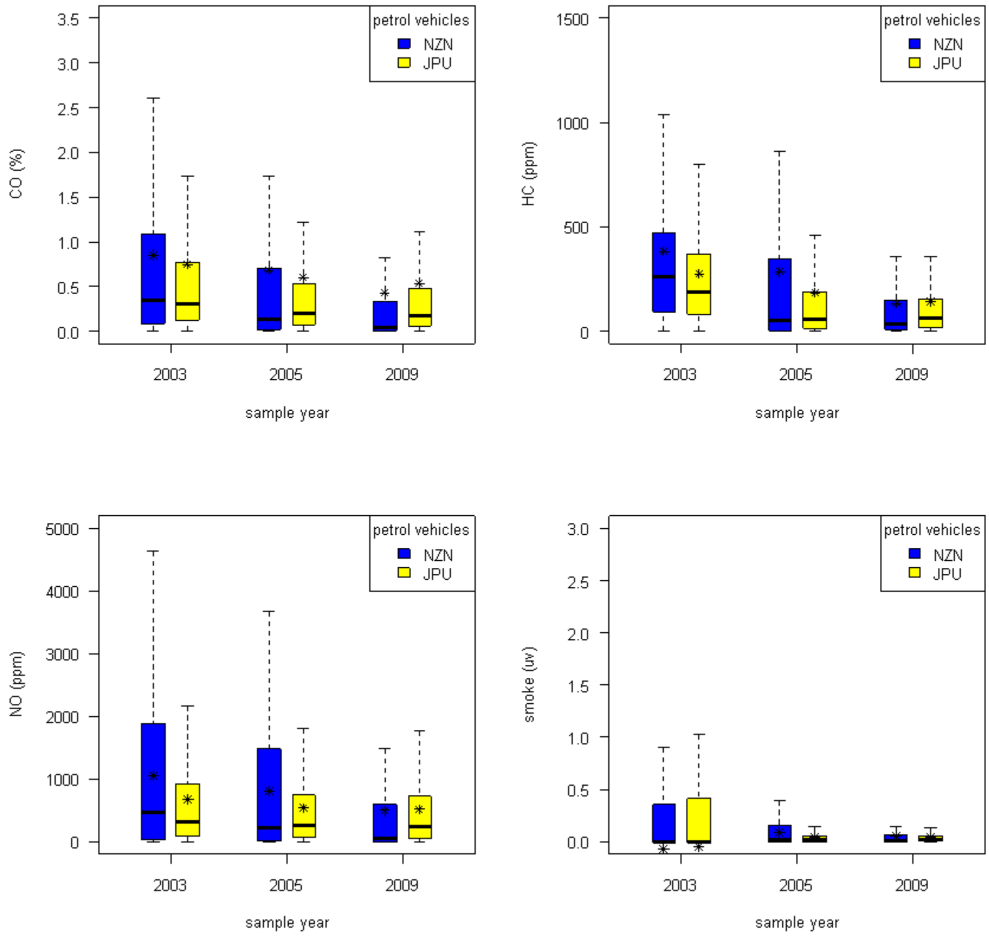
Campaign year	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	0.75	0.30	274	190	672	308	NA*	NA*
2005	0.60	0.20	181	55	545	266	0.044	0.018
2009	0.54	0.18	141	64	520	230	0.046	0.021

* uvSmoke data for 2003 are estimated from RSD3000 opacity measurements.
For petrol vehicles, uvSmoke data estimates appear to be unrealistically low.

4.2.3 Comparison of NZN and JPU petrol vehicles

Figure 4.5 compares the emissions of NZN and JPU petrol vehicle fleets from the 2003, 2005 and 2009 monitoring campaigns.

Figure 4.5 Comparison of emissions for the 2003, 2005 and 2009 NZN and JPU petrol vehicles



In 2003 and 2005, the NZN petrol fleet had higher emissions of CO, HC and NO, on average, than JPU petrol vehicles but this was reversed in 2009. uvSmoke showed similar trends with the NZN petrol vehicle emissions being higher, on average, than those of JPU petrol vehicles in 2005 but lower in 2009.

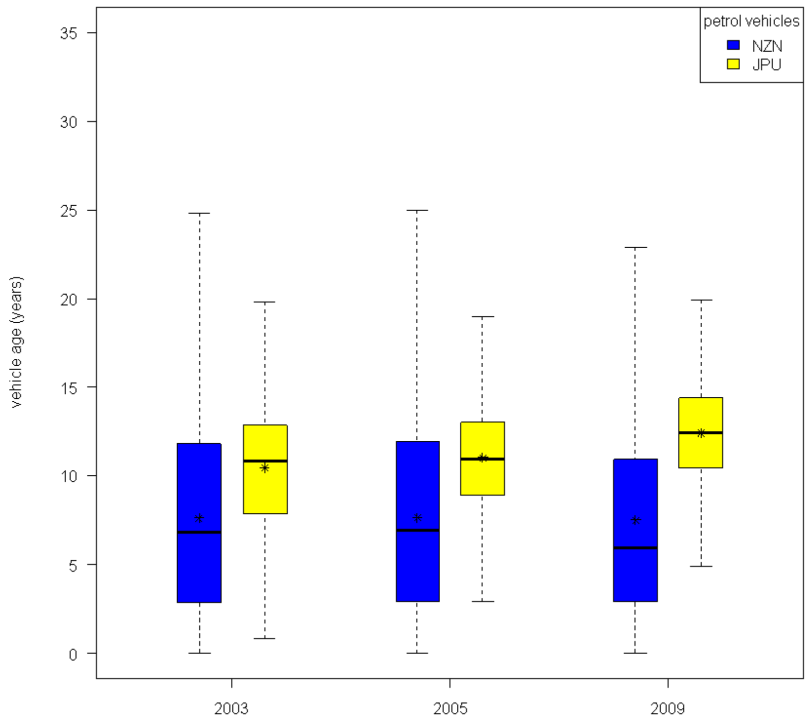
Although the NZN petrol fleet on average recorded higher emissions of CO, HC and NO initially in 2003, its rate of emissions improvement was appreciably faster than the JPU petrol fleet. By 2009, the NZN petrol fleet had lower median and mean emissions of CO, HC and NO than the JPU petrol fleet.

Figure 4.6 and table 4.5 compare the mean and median vehicle ages for the 2003, 2005 and 2009 NZN and JPU petrol vehicle fleets.

Table 4.5 Comparison of the mean and median vehicle ages for the 2003, 2005 and 2009 NZN and JPU petrol vehicles

Campaign year	NZN petrol vehicles		JPU petrol vehicles	
	Age (years)		Age (years)	
	Mean	Median	Mean	Median
2003	7.6	6.8	10.5	10.8
2005	7.6	6.9	11.0	10.9
2009	7.5	5.9	12.4	12.4

Figure 4.6 Comparison of vehicle ages for the 2003, 2005 and 2009 NZN and JPU petrol vehicles



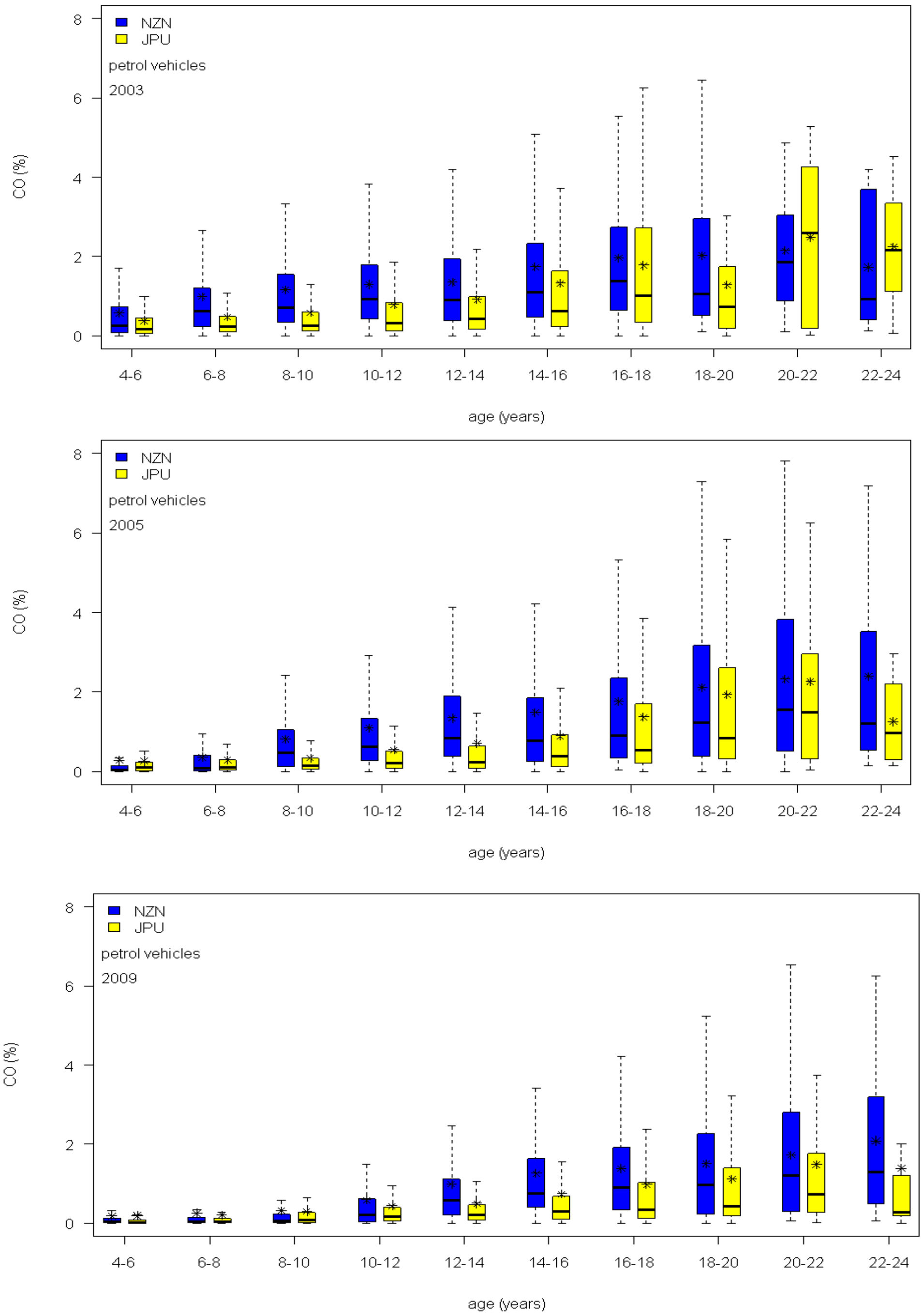
The mean age of the JPU petrol vehicles was considerably older than the NZN petrol vehicles in all three campaigns. From 2003, the mean age of the NZN petrol vehicles was stable at around 7.5 years but the mean age of the JPU petrol vehicles increased from 10.5 years (only three years difference) to 12.4 years (nearly five years difference) in 2009.

Figure 4.7 investigates the consequent effects of vehicle age on emissions by comparing CO emissions by age for the 2003, 2005 and 2009 NZN and JPU petrol vehicles. 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 4.7 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 found its way into the NZN fleet, the difference in emissions performance between younger (<10 years) NZN and JPU vehicles reduced significantly. Older NZN petrol vehicles (>10 years) continued to emit significantly more CO than JPU petrol vehicles of the same age.

Comparisons of HC and NO emissions from NZN and JPU petrol vehicles by age for 2003, 2005 and 2009 showed similar results to those described for CO. For uvSmoke emissions the same trends were evident in the 2005 and 2009 data.

Figure 4.7 Comparison of CO emissions by vehicle age for 2003, 2005 and 2009 NZN and JPU petrol vehicle fleets



4.3 Changes in diesel vehicle emissions

The number of valid measurements made from diesel vehicles monitored in the 2003, 2005 and 2009 campaigns was 1391, 3231 and 3676 respectively. The analysis in this section of the report considers the overall diesel fleet emissions. Subsequent sections present analyses of the diesel fleet broken down into NZN and JPU vehicles. The reason for splitting the diesel fleet into these two groups is that 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.

Figure 4.8 and table 4.6 compare the emissions of CO, HC, NO and uvSmoke from the diesel vehicles monitored in 2003, 2005 and 2009.

Figure 4.8 Comparison of emissions distributions for the 2003, 2005 and 2009 diesel vehicles

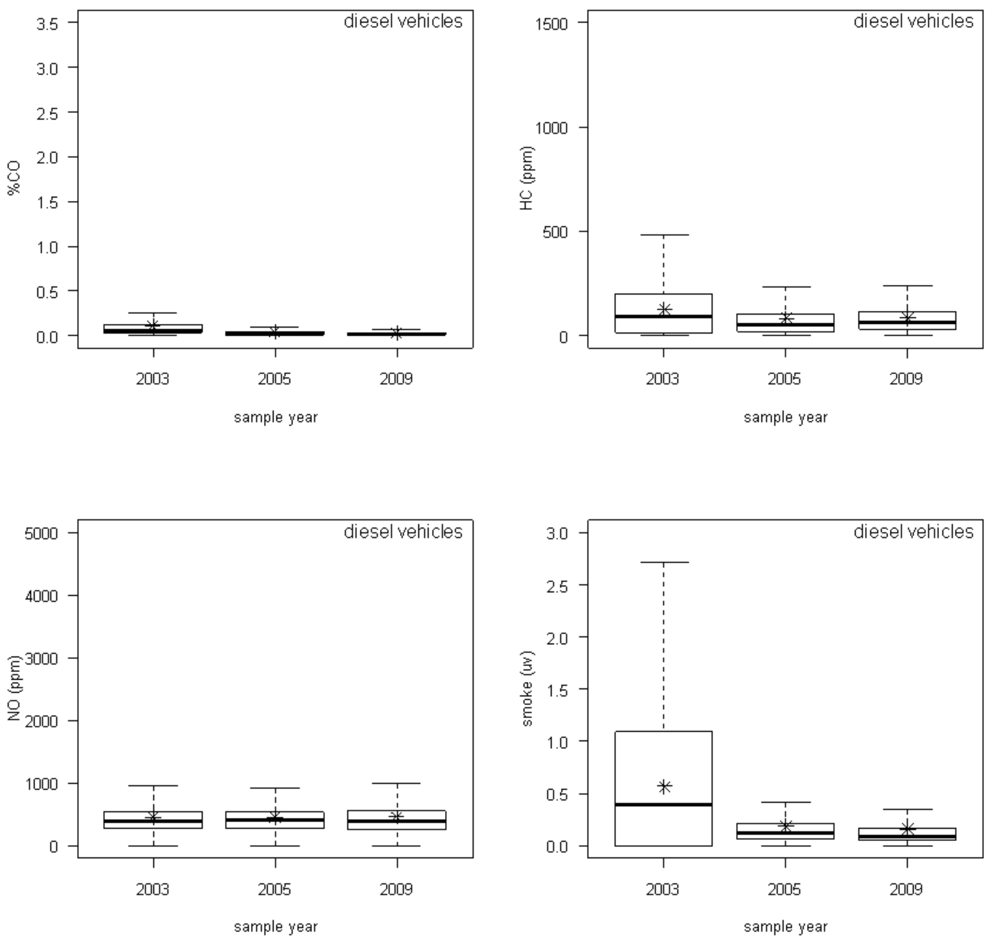


Table 4.6 Comparison of the mean and median emissions for the 2003, 2005 and 2009 diesel fleets

Campaign year	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	0.10	0.06	123	90	450	388	0.571	0.390
2005	0.04	0.02	80	52	453	402	0.187	0.118
2009	0.02	0.01	85	62	466	386	0.156	0.090

Emissions of CO and uvSmoke from diesel vehicles, on average, decreased significantly between 2003 and 2009. HC emissions were also significantly lower in 2009 relative to 2003 but much of this improvement seemed to have occurred prior to 2005. There was no obvious improvement or trend in NO emissions from diesel vehicles.

The trend in emissions of CO from diesel vehicles should be treated with some caution as the emissions of CO from diesel engines are comparatively low and occur toward the lower end of the RSD measurement range. This caution also applies to the analyses of CO emissions from NZN and JPU diesel vehicles which are detailed in the following sections. Also note that the 2003 uvSmoke results were estimated from opacity rather than direct measurements as discussed previously.

4.3.1 NZN diesel vehicles

The number of valid measurements made from NZN diesel vehicles monitored in the 2003, 2005 and 2009 campaigns was 847, 1282 and 2504 respectively.

Figure 4.9 and table 4.7 compare the emissions of CO, HC, NO and uvSmoke from the NZN diesel vehicles monitored in 2003, 2005 and 2009.

Emissions of CO and uvSmoke from NZN diesel vehicles, on average, decreased significantly between 2003 and 2009. HC emissions were also significantly lower in 2009 relative to 2003 but much of this improvement seemed to have occurred by 2005. There was no obvious improvement or trend in NO emissions from diesel vehicles.

Figure 4.9 Comparison of the emissions distributions for the 2003, 2005 and 2009 NZN diesel fleets

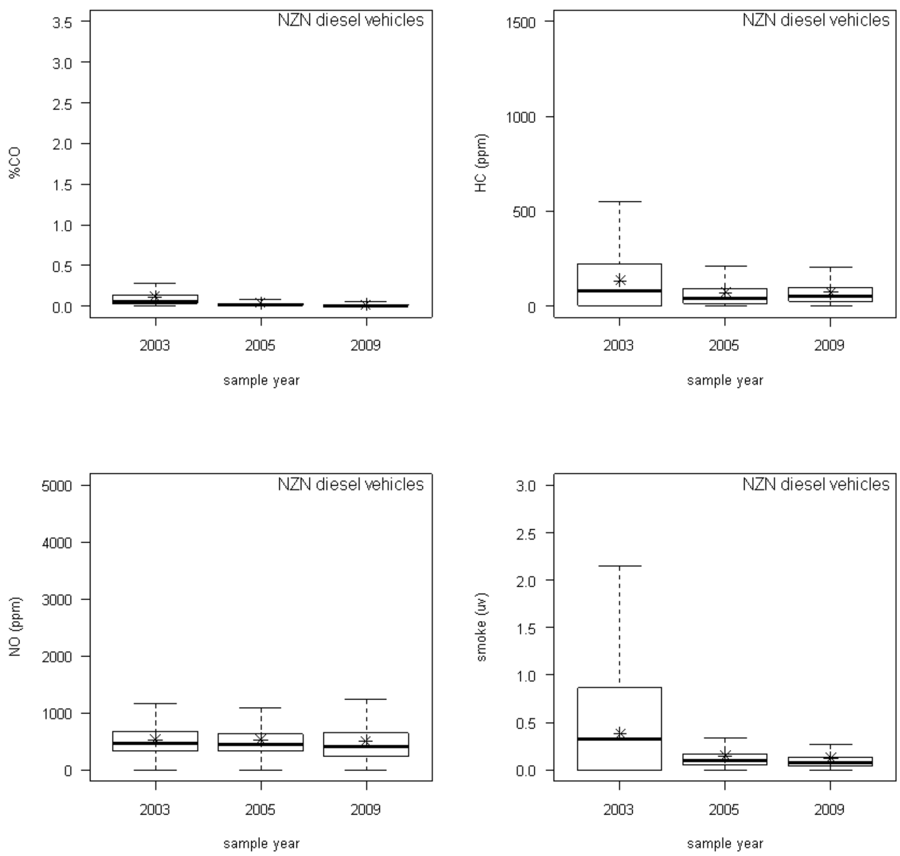


Table 4.7 Comparison of the mean and median emissions for the 2003, 2005 and 2009 NZN diesel fleets

Campaign year	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	0.11	0.06	133	80	529	470	0.385	0.323
2005	0.03	0.01	69	43	528	451	0.148	0.101
2009	0.02	0.004	73	52	506	410	0.122	0.073

4.3.2 JPU diesel vehicles

The number of valid measurements made from JPU diesel vehicles monitored in the 2003, 2005 and 2009 campaigns was 544, 1949 and 1621 respectively.

Figure 4.10 and table 4.8 compare the emissions of CO, HC, NO and uvSmoke from the JPU diesel vehicles monitored in 2003, 2005 and 2009.

Emissions of CO, HC and uvSmoke from JPU diesel vehicles, on average, decreased significantly between 2003 and 2009 but much of this improvement seemed to have occurred prior to 2005. There was no obvious improvement or trend in NO emissions from diesel vehicles.

Figure 4.10 Comparison of the emissions distributions for the 2003, 2005 and 2009 JPU diesel fleets

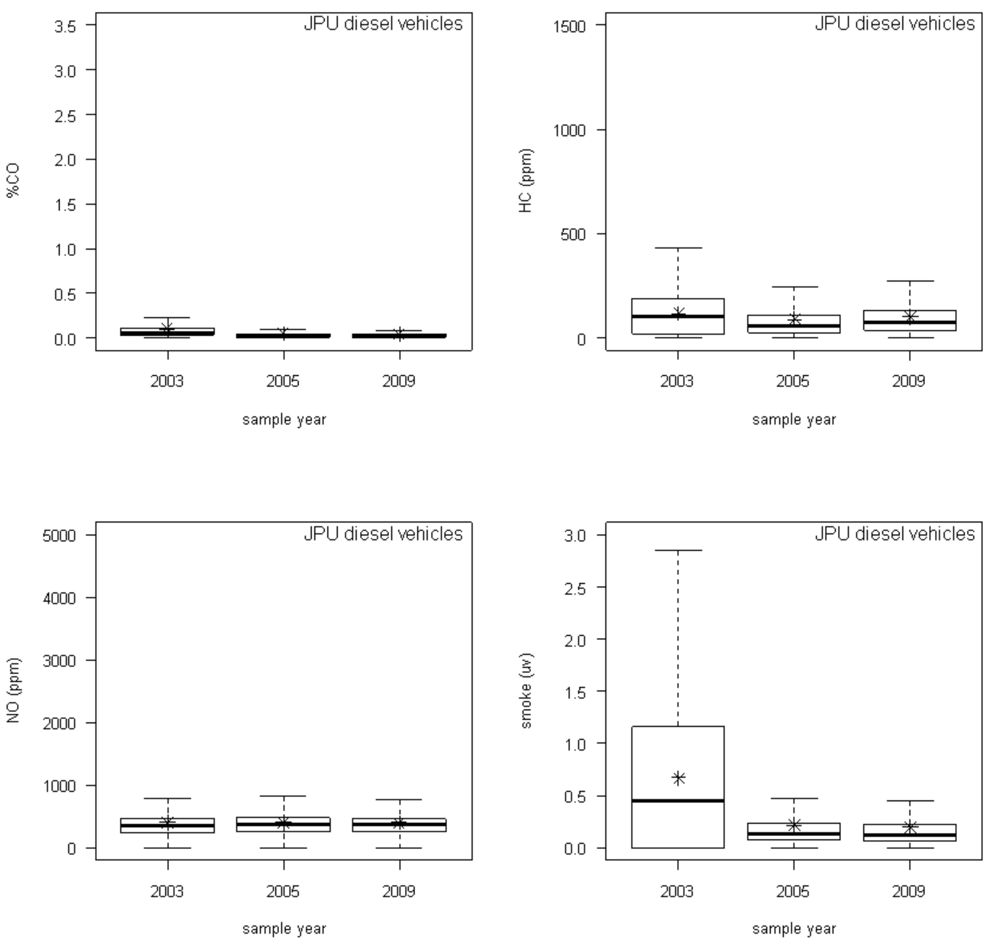


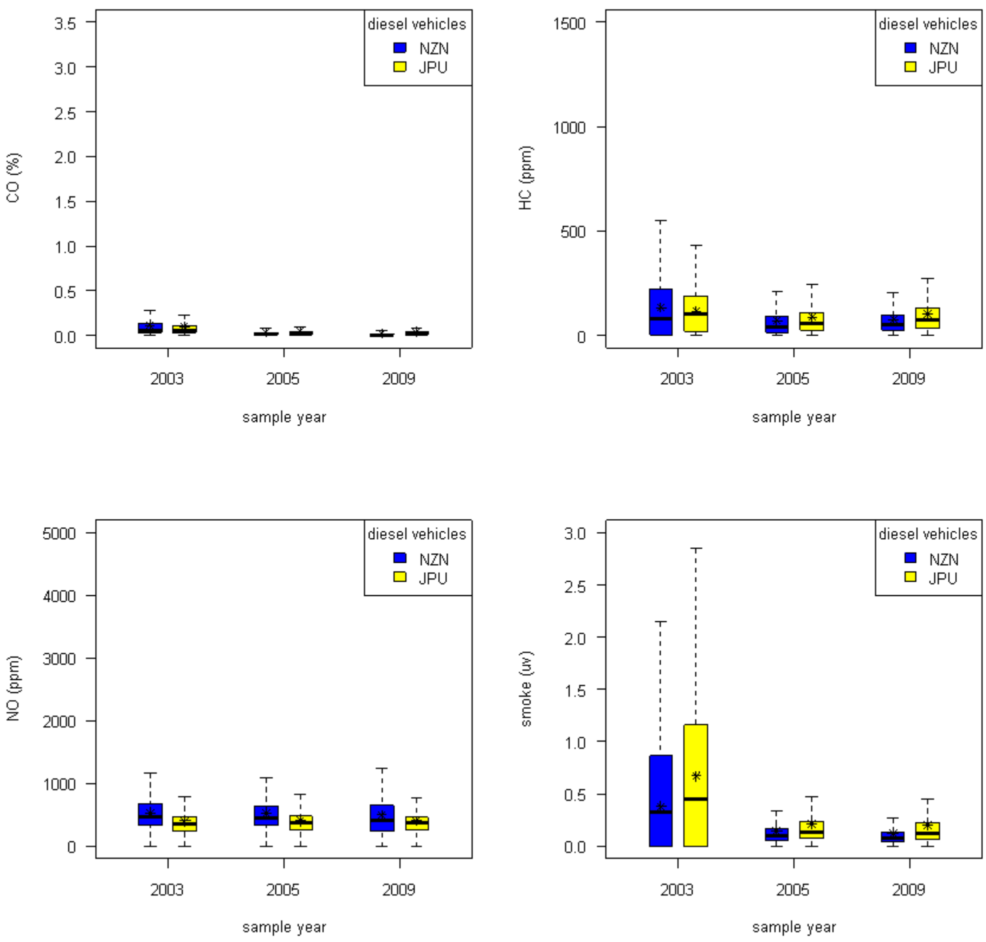
Table 4.8 Comparison of the mean and median emissions for the 2003, 2005 and 2009 JPU diesel fleets

Campaign year	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
2003	0.10	0.06	115	100	399	346	0.673	0.454
2005	0.04	0.02	87	56	401	377	0.213	0.131
2009	0.03	0.02	100	76	408	366	0.198	0.117

4.3.3 Comparison of NZN and JPU diesel vehicles

Figure 4.11 compares the emissions of NZN and JPU diesel vehicle fleets from the 2003, 2005 and 2009 monitoring campaigns.

Figure 4.11 Comparison of emissions for the 2003, 2005 and 2009 NZN and JPU diesel vehicles



The 2003 campaign found very little difference between emissions of CO or HC between the two diesel fleets. In the two later campaigns (2005 and 2009), CO and HC emissions from NZN diesel vehicles tended to be lower than those from the JPU diesel fleet. NO emissions, on average, were significantly higher from NZN diesel vehicles than those from JPU diesel vehicles for all three monitoring campaigns. The reverse was found for uvSmoke emissions, where JPU diesel vehicles tended to be higher than NZN diesel vehicles for all years.

In terms of the rate of emissions improvement, both the NZN and the JPU diesel fleets were comparable on average for reductions in CO emissions. The NZN fleet had relatively high emissions of HC in 2003 but improved at an appreciably faster rate to where median and mean emissions were lower than those for JPU diesel vehicles by 2005. Neither the NZN nor the JPU fleet showed any clear trend in NO emissions from 2003 to 2009. Both NZN and JPU diesel vehicles showed dramatic reductions (~200%) in uvSmoke emissions during the 2003 to 2009 period.

Figure 4.12 and table 4.9 compare the vehicle ages for the 2003, 2005 and 2009 NZN and JPU diesel vehicle fleets.

Figure 4.12 Comparison of vehicle ages for the 2003, 2005 and 2009 NZN and JPU diesel vehicles

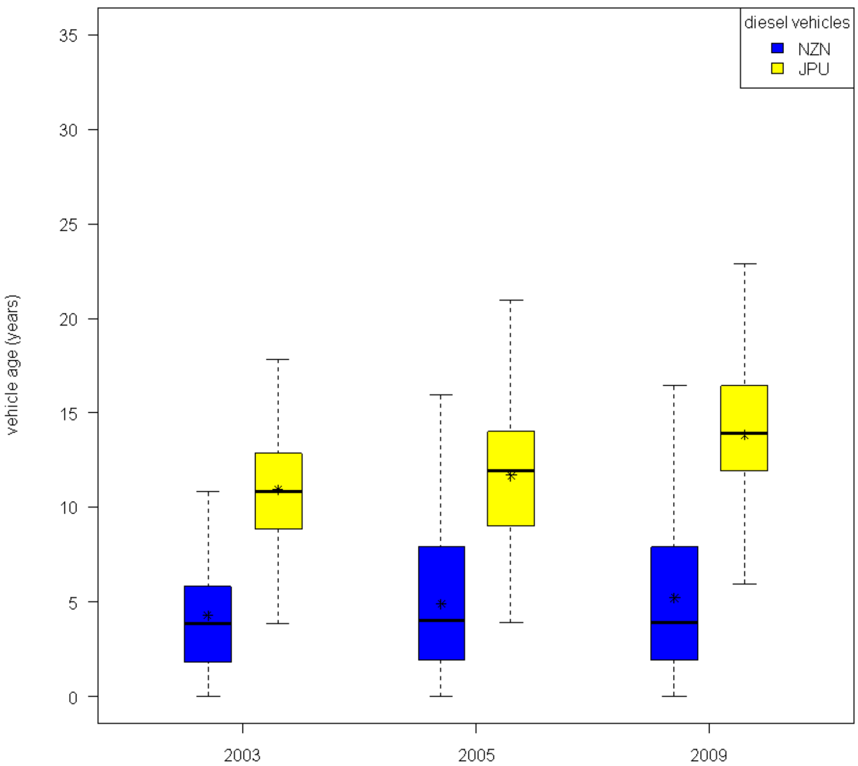


Table 4.9 Comparison of the mean and median vehicle ages for the 2003, 2005 and 2009 NZN and JPU diesel vehicles

Campaign year	NZN diesel vehicles		JPU diesel vehicles	
	Age (years)		Age (years)	
	Mean	Median	Mean	Median
2003	4.3	3.8	10.9	10.8
2005	4.9	4.0	11.7	11.9
2009	5.2	3.9	13.8	13.9

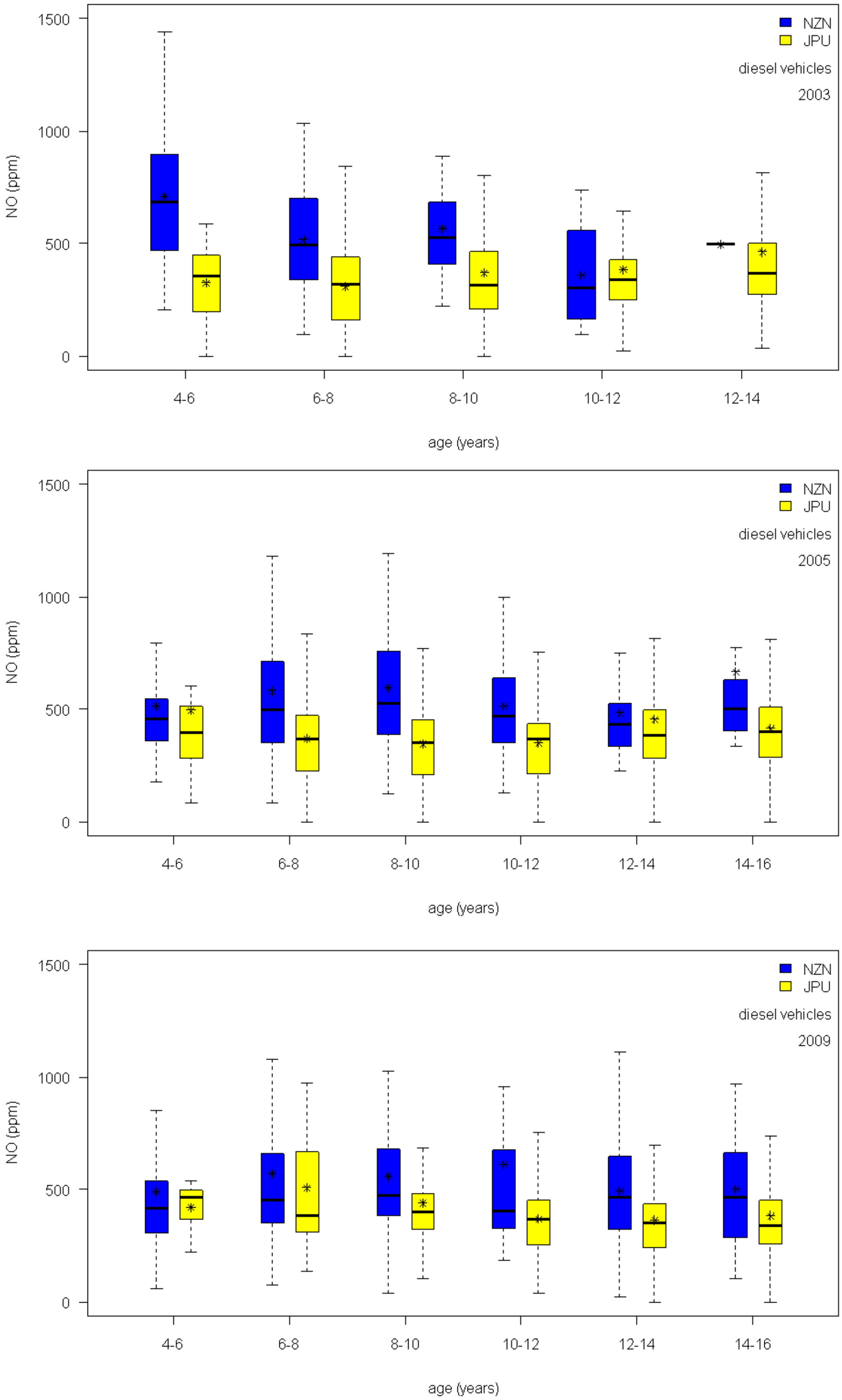
The mean age of the JPU diesel vehicles was considerably older than the NZN petrol vehicles in all three campaigns. Both fleets aged between 2003 and 2009 but the JPU diesel fleet aged faster. The mean age of the NZN diesel vehicles increased from 4.3 years in 2003 to 5.2 years in 2009, while the mean age of the JPU diesel increased from 10.9 years (a 6.7 year difference) in 2003 to 13.8 years (an 8.6 year difference) in 2009.

Figure 4.13 investigates the consequent effects of vehicle age on emissions by comparing NO emissions by age for the 2003, 2005 and 2009 NZN and JPU diesel vehicles. In the first campaign in 2003, NO emissions from JPU petrol vehicles, on average, were significantly lower than those from NZN vehicles of the same age. In 2005 NZN diesel vehicles older than six years had significantly higher NO emissions than JPU vehicles of the same age. By 2009, these significant differences were only seen for vehicles older than eight years.

Figure 4.13 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 emissions control technology found its way into the NZN fleet, the difference in emissions performance between younger (<8 years) NZN and JPU vehicles reduced significantly. Older NZN diesel vehicles (>8 years) continued to emit significantly more NO than JPU diesel vehicles of the same age.

Comparisons of CO, HC, and uvSmoke emissions from NZN and JPU diesel vehicles by age showed very little difference between emissions from NZN and JPU vehicles of the same age.

Figure 4.13 Comparison of NO emissions by age for the 2003, 2005 and 2009 NZN and JPU diesel vehicles



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 (NZN and JPU) and also split for fuel type (petrol or diesel).

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.

5.1 NZN 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 later updated and replaced by the Vehicle Exhaust Emissions 2006 rule and finally by the current Vehicle Exhaust Emissions 2007 rule (MoT 2007). 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 (available at https://motochek.landtransport.govt.nz). The analysis was only undertaken on the 2009 dataset as this was the only one with sufficient numbers of vehicles in a wide range of emissions standard classes. 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 52% of vehicles manufactured post-2003 had a recorded emissions standard. The remaining 48% of vehicles were built to Euro 2, Euro 3 or Euro 4 but it was not possible to say exactly which. These vehicles were binned as a group called '2003+'.

Table 5.1 shows the numbers of NZN vehicles monitored in 2009 by emissions build standards.

Table 5.1 Numbers of NZN vehicles monitored in 2009 by emissions build standards

Vehicle type	Pre-2003	2003+	Euro 2	Euro 3	Euro 4
Petrol	3605	2776	520	1668	495
Diesel	522	711	256	330	235

5.1.1 NZN petrol vehicles

Figure 5.1 and table 5.1 compare the 2009 NZN petrol fleet emissions by emissions 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.

Figure 5.1 Comparison of 2009 NZN petrol fleet emissions by emissions standard

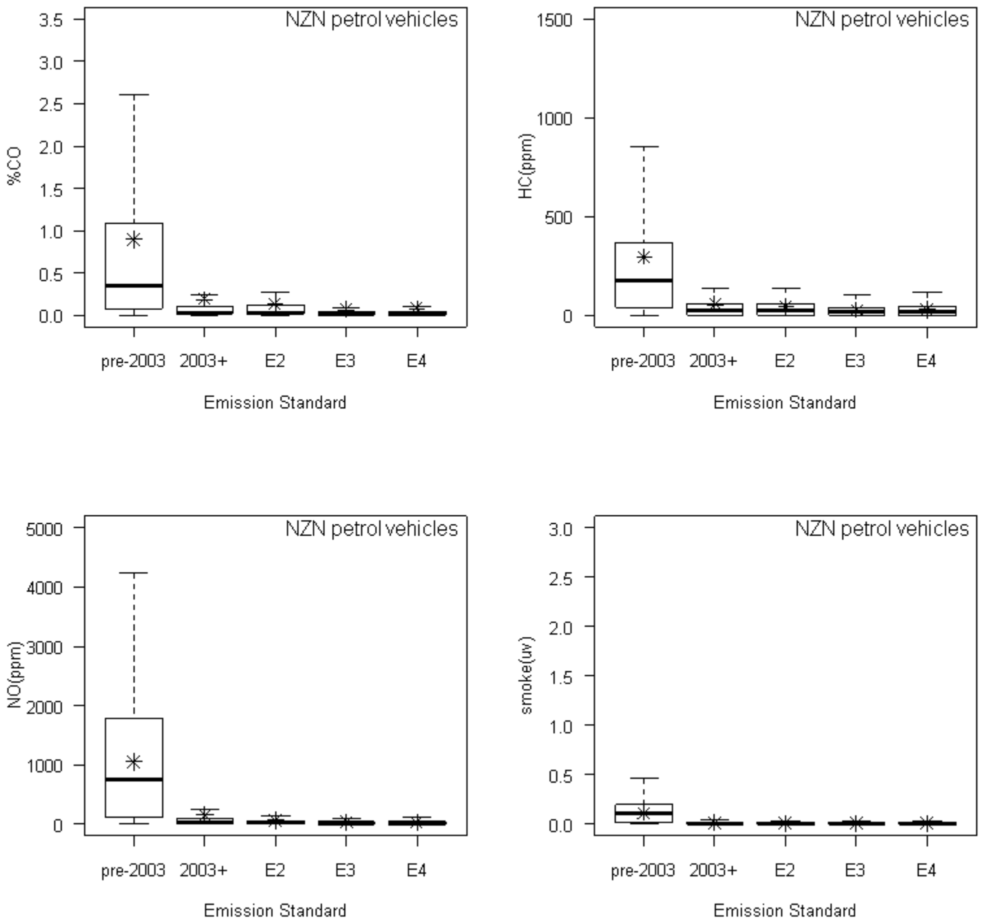
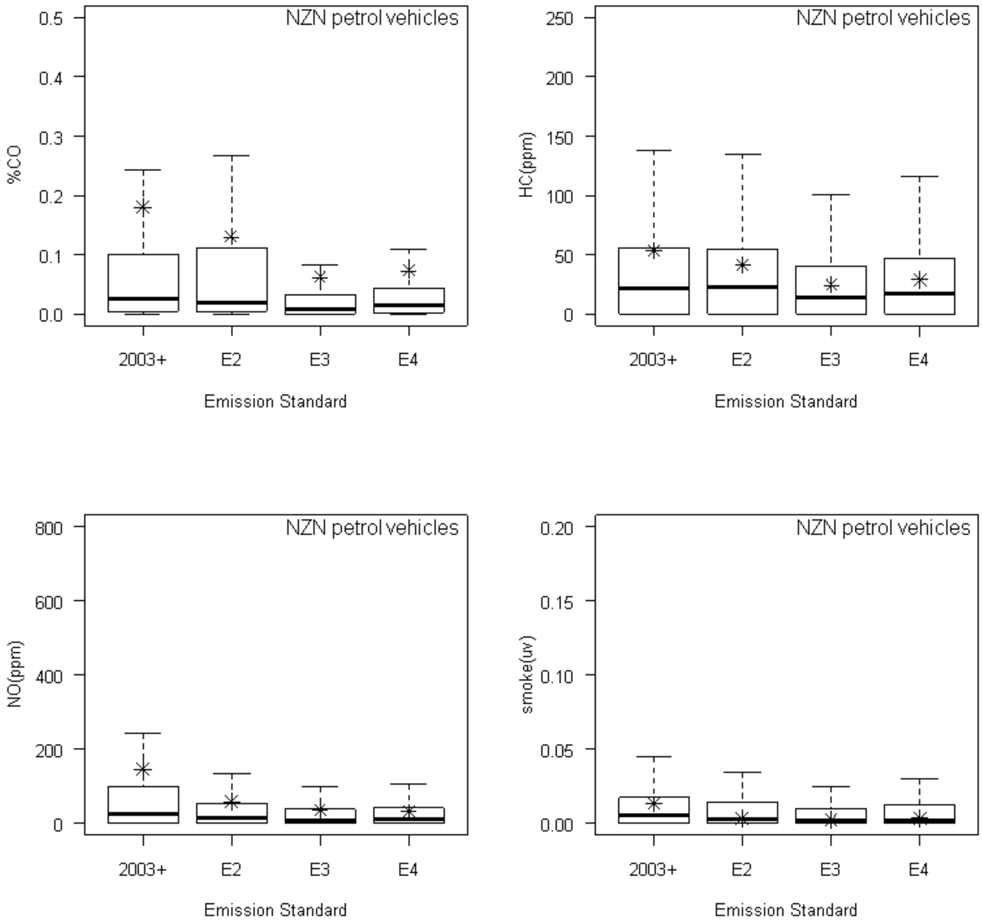


Table 5.2 Comparison of median and mean emissions for the 2009 NZN petrol fleet by emissions standard

Pollutant	Pre-2003	2003+	Euro 2	Euro 3	Euro 4
	Mean (median)	**Mean (median)**	**Mean (median)**	**Mean (median)**	**Mean (median)**
CO (%)	0.90 (0.35)	0.18 (0.03)	0.13 (0.02)	0.06 (0.01)	0.07 (0.02)
HC (ppm)	293 (179)	53 (21)	41 (23)	24 (14)	29 (18)
NO (ppm)	1052 (746)	146 (25)	58 (16)	37 (7)	32 (10)
uvSmoke	0.120 (0.107)	0.013 (0.005)	0.003 (0.003)	0.002 0.002)	0.003 (0.002)

Figure 5.2[4] **Comparison of 2009 NZN petrol fleet emissions for vehicles manufactured after 2003 by emissions standard**



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

Table 5.3 compares the emissions limits that apply to the relevant Euro petrol emissions standards to highlight the emissions improvements that might have been expected to be mirrored in the roadside measurements. (The Euro 1 limits are included for completeness.) As already mentioned, significant reductions in measured emissions were seen with improving standard (see table 5.2) but not necessarily to the extent that would be suggested by the emissions limits, especially beyond Euro 3.

Comparing roadside measurements with emissions limits needs to be treated with caution 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

[4] The y axis scale in figure 5.2 differs from other figures showing emissions measurements.

way the Euro emissions 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 emissions standard change.

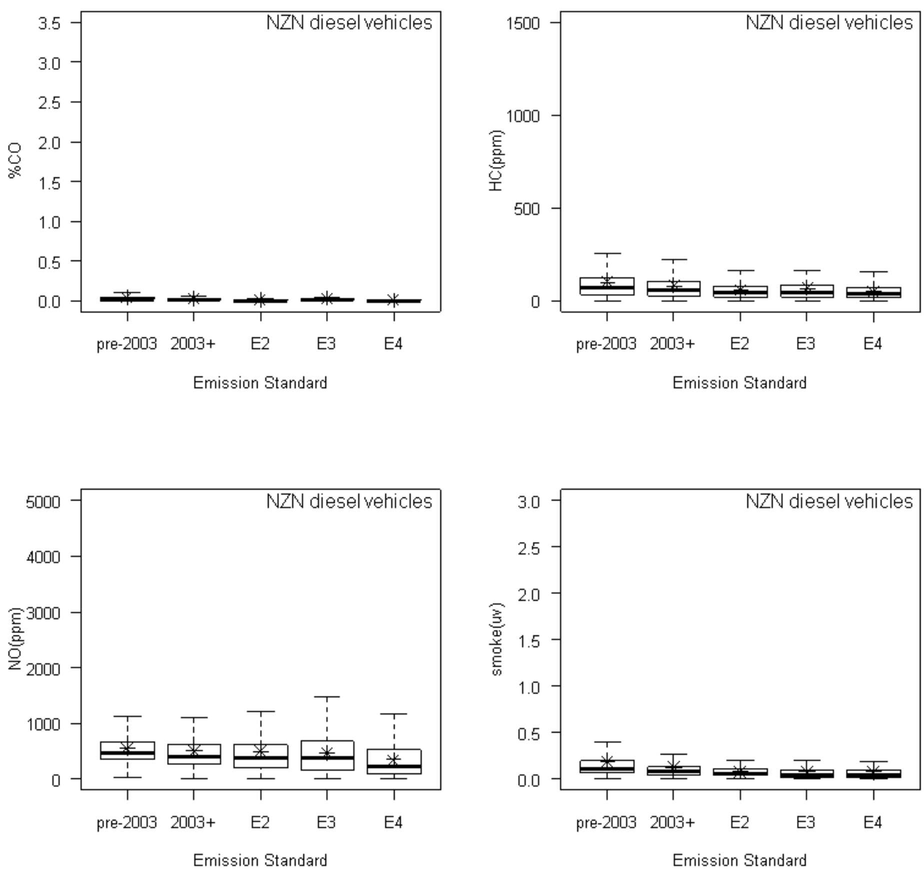
Table 5.3 Emissions limits and date of introduction in Europe (shown in brackets) for Euro 1, Euro 2, Euro 3 and Euro 4 petrol vehicles

Pollutant (g/km)	Euro 1 (1992)	Euro 2 (1996)	Euro 3 (2000)	Euro 4 (2005)
CO	2.72	2.2	2.30	1.0
(NOx + HC)	0.97	0.5	-	-
NOx	-	-	0.15	0.08
HC	-	-	0.20	0.10
PM	-	-	-	-

5.1.2 NZN diesel vehicles

Figure 5.3 and table 5.4 compare the 2009 NZN diesel fleet emissions by emissions standard.

Figure 5.3 Comparison of 2009 NZN diesel fleet emissions by emissions standard



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

Measured emissions of HC, NO and uvSmoke, on average, from diesel vehicles showed only a very slight improvement with improving emissions standard. Euro 4 NO emissions, however, were significantly lower than those for Euro 3 or earlier standards. CO emissions showed no obvious trend with Euro standard but this is probably because diesel vehicles emit very low amounts of CO which are close to the detection limit of the equipment.

Table 5.4 Comparison of median and mean emissions for the 2009 NZN diesel fleet by emissions standard

Pollutant	Pre-2003	2003+	Euro 2	Euro 3	Euro 4
	Mean (median)	Mean (median)	Mean (median)	Mean (median)	Mean (median)
CO (%)	0.031 (0.016)	0.016 (0.005)	0.000 (0.000)	0.022 (0.002)	0.000 (0.000)
HC (ppm)	97 (72)	79 (57)	56 (46)	65 (45)	48 (38)
NO (ppm)	552 (463)	504 (407)	493 (369)	474 (365)	352 (220)
uvSmoke	0.187 (0.110)	0.124 (0.077)	0.080 (0.060)	0.080 (0.047)	0.074 (0.046)

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

Table 5.5 Emissions limits (and introduction dates) for Euro 1, Euro 2, Euro 3 and Euro 4 diesel vehicles

Pollutant (g/km)	Euro 1 (1992)	Euro 2 (1996)	Euro 3 (2000)	Euro 4 (2005)
CO	2.72	1.0	0.64	0.50
(NOx + HC)	0.97	0.7	0.56	0.30
NOx	-	-	0.50	0.25
HC	-	-	-	-
PM	0.14	0.08	0.05	0.025

5.2 JPU vehicles

Mandatory vehicle emissions 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* emissions standard, used vehicles only had to have been built to a *recognised* (any) emissions standard. Minimum emissions 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 emissions standards requirements specify that used 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 Japanese or 'J' standards are more common for used vehicles as the vast majority (~97%) of these are sourced from Japan).

The Japanese motor industry has a complicated system of emissions testing. The light duty petrol and diesel vehicle test regimes contain at least 20 and 18 different emissions standards respectively. To make the emissions standard comparison for JPU vehicles practical, it was necessary to group a number of emissions standards together. This grouping achieved two goals, one to ensure there was a representative number of vehicles within each group and two to reduce the number of groups being compared to a practical number. The grouping of emissions standards was undertaken on advice from MoT staff and was based loosely on the year of manufacture.

Tables 5.6 and 5.7 show the JPU emissions standards and the way they were grouped together for this study for petrol and diesel vehicles respectively.

Table 5.6 Grouping of JPU light duty petrol emissions standards

Emissions standard	Emissions standard grouping	No. of petrol vehicles
E	79-E	6781
GA, GB, GC, GC0, GE, GF, GGH, GJ, GK	79	1071
GH, LA, TA, TC, UA	00/02	1280
ABA, CBA, CBF, DAA, DBA	J05	258

Table 5.7 Grouping of JPU light duty diesel emissions standards

Emissions standard	Emissions standard grouping	No. of diesel vehicles
N, P	N-P	67
Q	Q	234
S, U	S-U	366
X	X	22
Y	Y	113
KA, KB,	KA-KD	616
KC, KD		
KE, KF, KG	KE-KK	204
KH, KJ, KK		

5.2.1 JPU petrol vehicles

Figure 5.4 and table 5.8 compare 2009 JPU petrol fleet emissions by emissions standard grouping.

Figure 5.4 Comparison of 2009 JPU petrol fleet emissions by emissions standard grouping

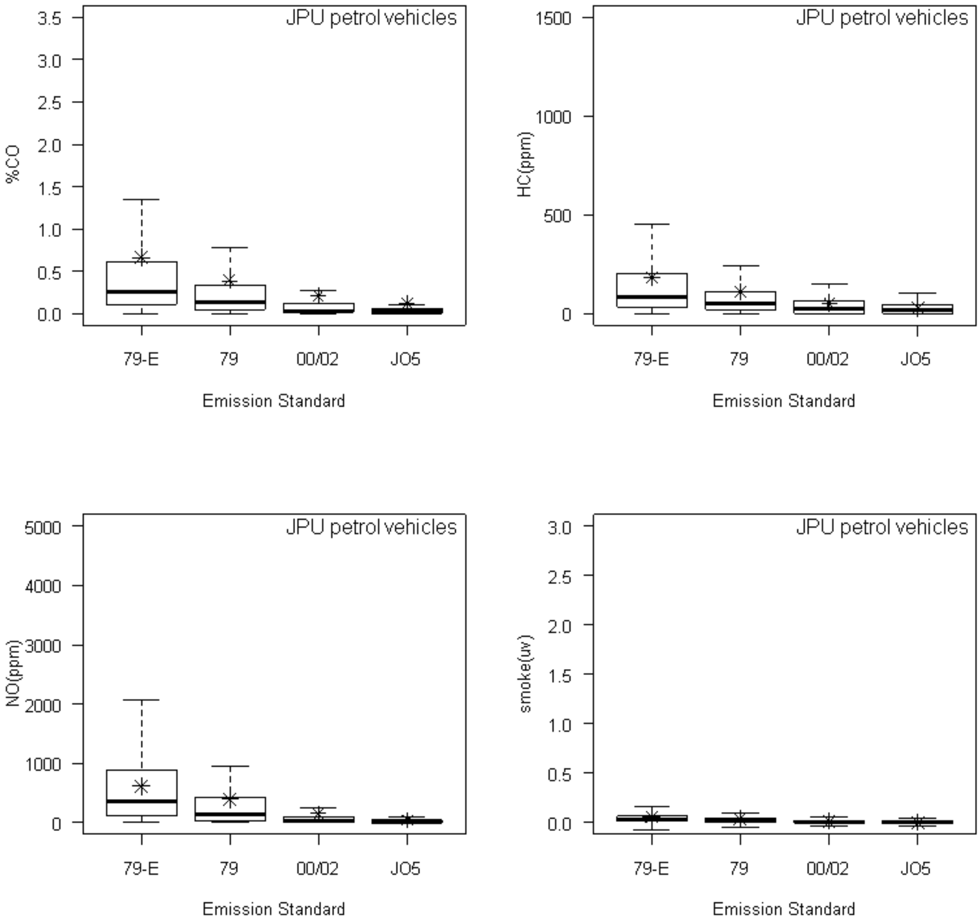


Table 5.8 Comparison of median and mean emissions for the 2009 JPU petrol fleet by emissions standard grouping

Pollutant	79-E	79	00/02	J05
	Mean (median)	Mean (median)	Mean (median)	Mean (median)
CO (%)	0.660 (0.252)	0.384 (0.127)	0.203 (0.030)	0.116 (0.012)
HC (ppm)	179 (84)	107 (51)	49 (21)	25 (18)
NO (ppm)	614 (353)	389 (130)	148 (26)	46 (0)
uvSmoke	0.057 (0.029)	0.035 (0.017)	0.013 (0.005)	0.001 (0.001)

Emissions of CO, HC, NO and uvSmoke from JPU petrol vehicles, on average, all reduced significantly with each change in emissions standard grouping from 79-E to 79 to 00/02 to J05.

5.2.2 JPU diesel vehicles

Figure 5.5 and table 5.9 compare 2009 JPU petrol fleet emissions by emissions standard grouping.

Emissions trends in JPU diesel vehicles were much less conclusive than the strong trends seen for the JPU petrol vehicles. The emissions standard groupings were presented in chronological order and did show a slight improvement in CO, HC and uvSmoke emissions, on average, progressing from N-P to KE-KK diesel vehicles. However, the results for intermediate groupings were very variable.

NO emissions showed no obvious trend across any of the emissions standard groupings. This is a surprising result given that NO emissions would have been expected to decrease with improving emissions standards. The lack of trend in NO emissions is of concern with many urban environments showing steady or even increasing levels of ambient NO_2. If ambient levels do not reduce and/or vehicle emissions improve in the near future, additional vehicle emissions management strategies may be required.

It should be noted that the Japanese vehicle classification system defines diesel vehicles with a gross vehicle mass (GVM) less than 2500kg as light duty diesel (LDD) vehicles. In New Zealand, LDDs are classified as diesel vehicles with a GVM of less than 3500kg. JPU diesel vehicles built to meet emissions standards U, KC and KG are tested to a HDD standard in Japan but fit the New Zealand definition of LDD vehicles and were included in this analysis. Within the emissions standard groups S-U, KA-KD and KE-KK approximately 67%, 18% and 83% of the JPU diesel vehicles were built to meet a heavy duty diesel emissions standard. Therefore the conclusions reached in regard to the S-U and KE-KK emissions standard groups, in particular, should be treated with caution.

Figure 5.5 Comparison of 2009 JPU diesel fleet emissions by emissions standard grouping

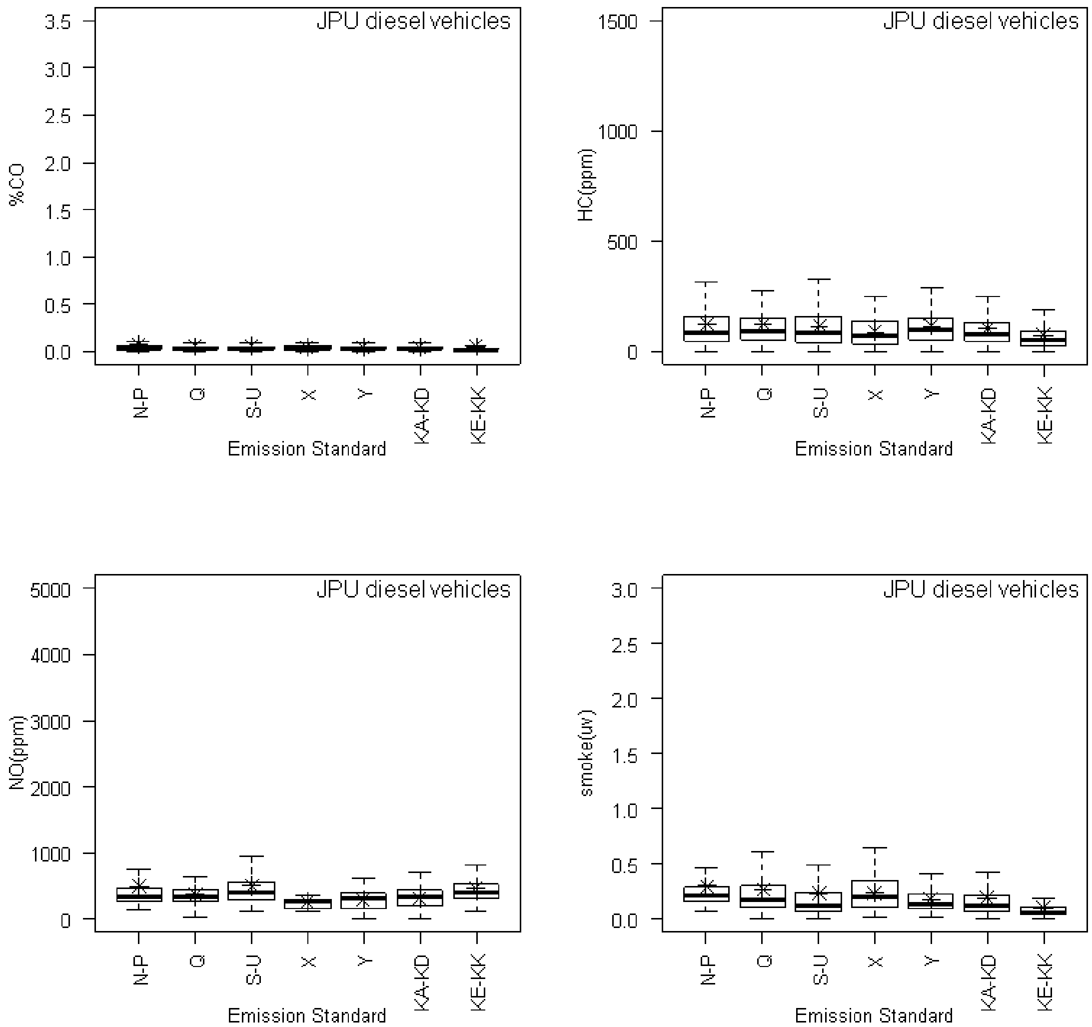


Table 5.9 Comparison of median and mean emissions for the 2009 JPU diesel fleet by vehicle emissions standard

Pollutant	N-P	Q	S-U	X	Y	KA-KD	KE-KJ
	Mean (median)	Mean (median)	Mean (median)	Mean (median)	Mean (median)	Mean (median)	Mean (median)
CO (%)	0.067 (0.029)	0.042 (0.020)	0.045 (0.022)	0.038 (0.034)	0.028 (0.022)	0.033 (0.019)	0.041 (0.012)
HC (ppm)	121 (84)	122 (88)	113 (84)	85 (72)	113 (95)	102 (77)	73 (51)
NO (ppm)	489 (324)	370 (342)	498 (402)	258 (260)	295 (318)	327 (332)	470 (399)
uvSmoke	0.302 (0.208)	0.271 (0.171)	0.227 (0.120)	0.238 (0.204)	0.178 (0.136)	0.189 (0.118)	0.096 (0.059)

6 Effect of vehicle 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 2008b). For example, a properly functioning catalytic converter on a petrol vehicle can reduce the level of emissions by up to 90%, compared to a vehicle without one fitted. However, all technology deteriorates, and with motor vehicles this deteriorating 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 subsectors of the fleet by country of first registration (NZN and JPU) and also split for fuel type (petrol or diesel) and emissions standard.

The distribution in odometer readings was determined for each subsector of the fleet within the 2009 dataset. From this analysis, two categories within each subsector 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 (eg NZN petrol) were selected and their emissions plotted against continuous odometer readings.

6.1 NZN petrol vehicles

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

Table 6.1 NZN petrol vehicle lower (25th) and upper (75th) quartile odometer readings by emissions standard

Odometer reading (km)	Pre-2003	2003+	Euro 2	Euro 3	Euro 4
high mileage	236,000	118,000	87,000	55,000	35,000
low mileage	135,000	52,000	46,000	16,000	200

Figure 6.1 compares emissions for high and low mileage NZN petrol vehicles by emissions standard. Tables 6.2, 6.3, 6.4 and 6.5 summarise the mean and median values for CO, HC, NO and uvSmoke, respectively, and highlight whether any differences between the high and low mileage vehicles were statistically significant.

Figure 6.1 Comparison of emissions for high and low mileage NZN petrol vehicles by emissions standard

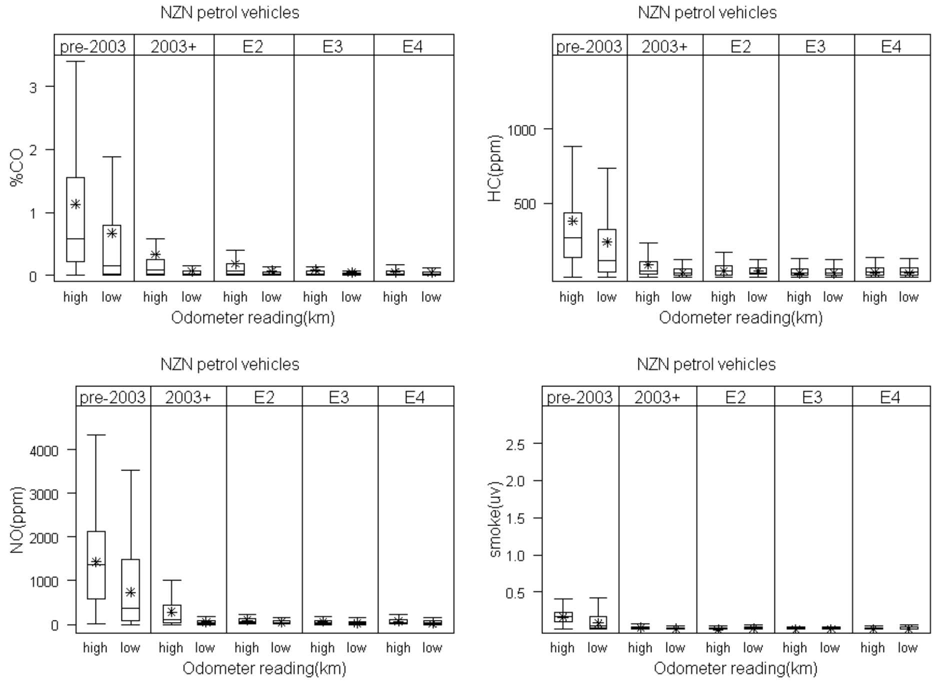


Table 6.2 Comparison of CO emissions for high and low mileage NZN petrol vehicles by emissions standard

CO (%)	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	1.13	0.58	0.34	0.07	0.19	0.06	0.09	0.01	0.05	0.02
low km	0.67	0.12	0.07	0.01	0.07	0.01	0.05	0.01	0.05	0.01
sig. diff.	Y		Y		Y		Y		N	

CO and NO emissions were significantly higher for the high mileage NZN petrol vehicles, on average, than for the low mileage vehicles irrespective of emissions standard (with the exception of Euro 4 CO emissions). However, increasing mileage had a less conclusive impact on HC and uvSmoke emissions. Significant differences were seen in the broad emissions standard categories of pre-2003 and 2003+ (both of which encompassed a range of emissions standards) but not when comparing high and low mileage Euro 2, Euro 3 or Euro 4 NZN petrol vehicles.

Table 6.3 Comparison of HC emissions for high and low mileage NZN petrol vehicles by emissions standard

HC (ppm)	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	381	260	86	34	42	25	26	15	32	20
low km	238	65	33	10	42	19	27	13	31	19
sig. diff.	Y		Y		N		N		N	

Table 6.4 Comparison of NO emissions for high and low mileage NZN petrol vehicles by emissions standard

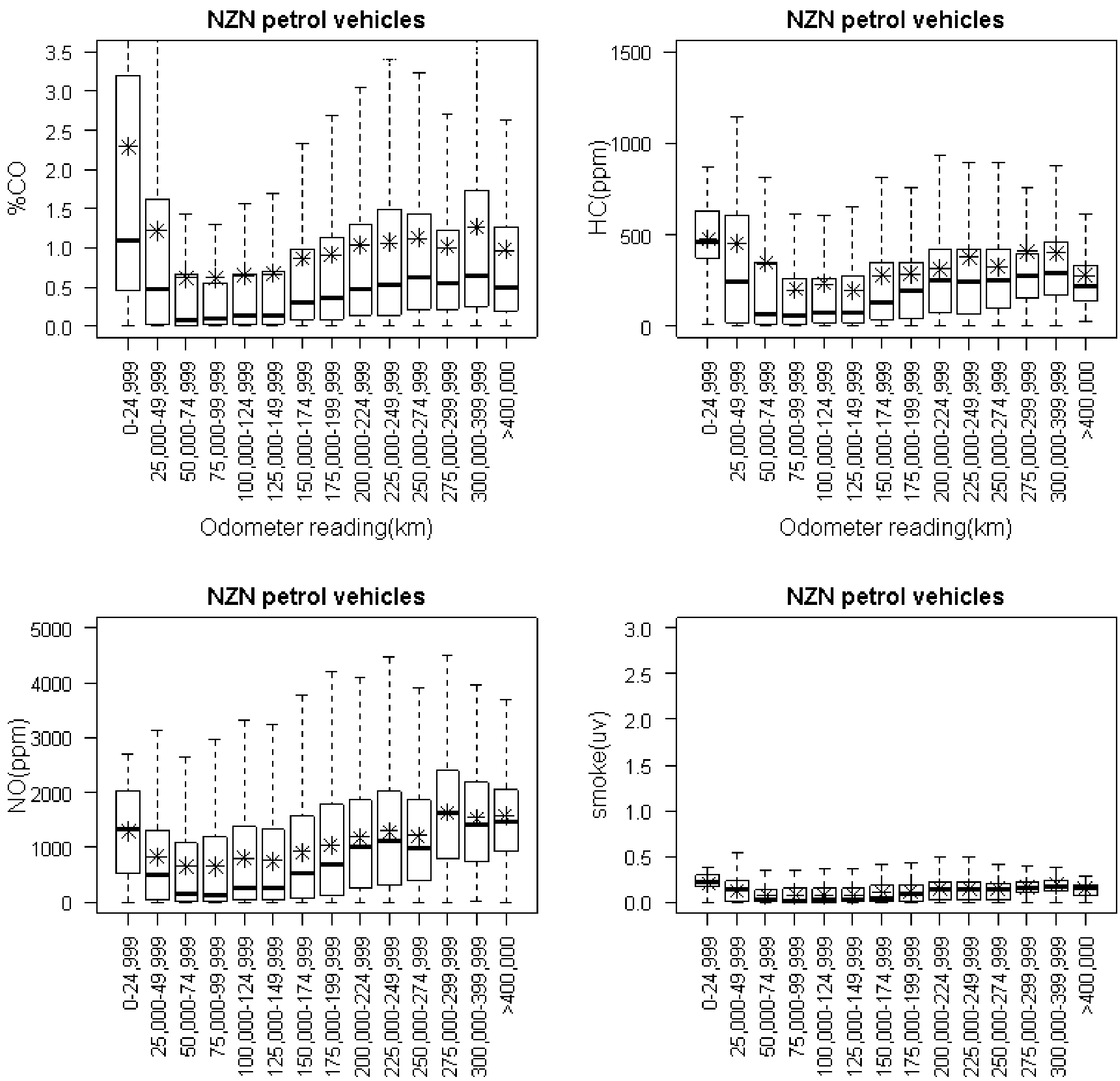
NO (ppm)	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	1431	1349	284	66	95	30	63	13	67	13
low km	734	208	52	9	47	6	23	4	17	2
sig. diff.	Y		Y		Y		Y		Y	

Table 6.5 Comparison of uvSmoke emissions for high and low mileage NZN petrol vehicles by emissions standard

uvSmoke	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	0.164	0.160	0.022	0.008	0.000	0.003	0.001	0.001	0.002	0.003
low km	0.083	0.022	0.009	0.004	0.011	0.011	0.002	0.001	0.004	0.000
sig. diff.	Y		Y		N		N		N	

Figure 6.2 investigates these mileage trends further by comparing the emissions of pre-2003 NZN petrol vehicles by odometer reading. The pre-2003 sector of the fleet was selected for this analysis because it contained the highest number of vehicles, vehicles which had travelled the largest number of kilometres (on average) and vehicles with little or no emissions control equipment.

Figure 6.2 Comparison of pre-2003 NZN petrol vehicle emissions by odometer reading



Emissions of CO, HC and NO steadily increased as the odometer readings went from 50,000km to 400,000km but there appeared to be two exceptions to this general upward trend. Emissions from pre-2003 NZN petrol vehicles with odometer readings of less than 50,000km were unexpectedly high and emissions from vehicles with odometer readings of greater than 400,000km were unexpectedly low. However, these two extremes both contained relatively few readings – 60 vehicles each – and these small sample sizes may well have been the cause of the unexpected observations.

Other potential explanations for the unexpected high emissions from the low odometer reading vehicles is that some of the vehicle odometers had gone 'around the clock' (ie vehicles with five digit odometers had travelled more than 99,999km) or the vehicles may have been 'running in'. Car manufacturers switched odometers from five to six figures in the late 1980s or 1990s. Of the 60 NZN petrol vehicles with odometer readings <50,000km included in this analysis, 23 (40%) of these were manufactured before 1990. These 23 vehicles potentially had five digit odometers and may have been around the clock when the vehicle's emissions were monitored for this study. Anecdotal evidence from vehicle manufacturers in New Zealand suggests new vehicles are tuned to run rich for the first 5000km to 10,000km of vehicle 'running in' while the engine management systems are 'learning' to optimise vehicle emissions.

Emissions of uvSmoke emissions from NZN petrol vehicles also increased as the odometer readings went from 50,000km to 400,000km. However compared with the more gradual increase in the other three pollutants, there appeared to be a step change increase in uvSmoke emissions at around 175,000km.

6.2 NZN diesel vehicles

Table 6.6 shows the high (75th quartile) and low (25th quartile) odometer readings for the NZN diesel vehicle fleet by emissions standard. The differences in odometer reading between the high and low extremes varied widely across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 6.6 NZN diesel vehicle lower (25th) and upper (75th) quartile odometer readings by emissions standard

Odometer reading (km)	Pre-2003	2003+	Euro 2	Euro 3	Euro 4
high mileage	288,000	150,000	55,000	55,000	35,000
low mileage	180,000	62,000	42,000	20,000	200

Figure 6.3 compares emissions for high and low mileage NZN diesel vehicles by emissions standard. Tables 6.7, 6.8, 6.9 and 6.10 summarise the mean and median values for CO, HC, NO and uvSmoke, respectively, and highlight whether any differences between the high and low mileage vehicles were statistically significant.

Figure 6.3 Comparison of NZN diesel vehicle emissions for high and low km odometer readings by emissions standard

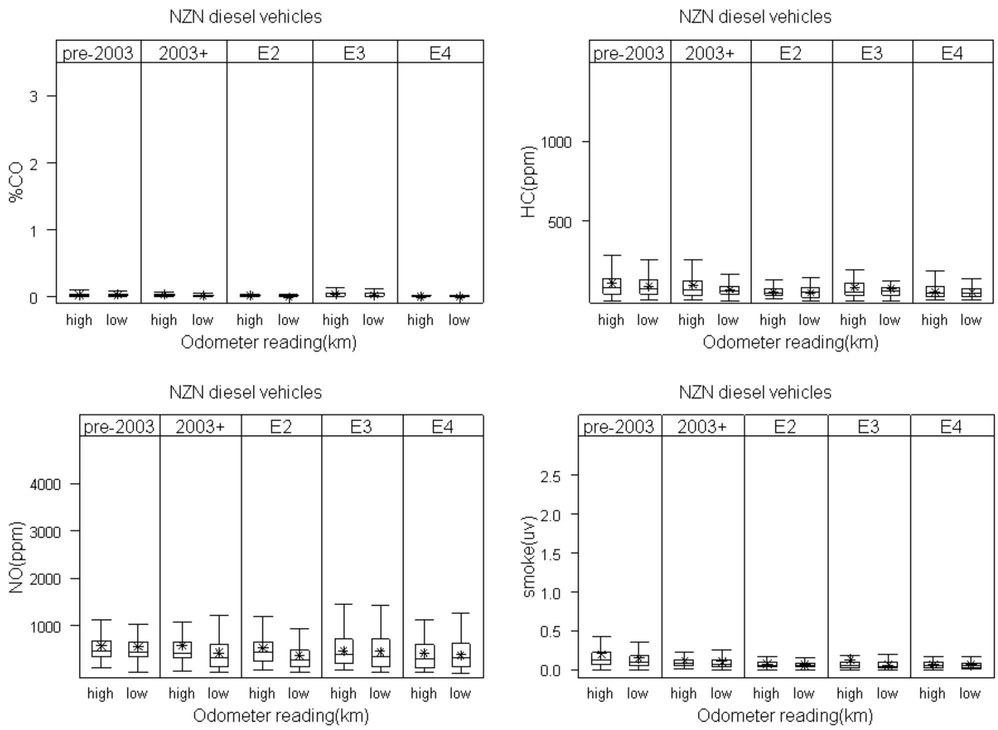


Table 6.7 Comparison of CO emissions for high and low mileage NZN diesel vehicles by emissions standard

CO (%)	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	0.03	0.02	0.02	0.01	0.01	0.00	0.04	0.00	0.00	0.00
low km	0.02	0.02	0.01	0.00	0.00	0.00	0.02	0.00	0.00	0.00
sig. diff.	N		Y		Y		Y		N	

Table 6.8 Comparison of HC emissions for high and low mileage NZN diesel vehicles by emissions standard

HC (ppm)	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	107	77	97	58	51	44	83	49	55	44
low km	88	66	66	52	47	43	74	57	49	41
sig. diff.	Y		Y		N		N		N	

Table 6.9 Comparison of NO emissions for high and low mileage NZN diesel vehicles by emissions standard

NO (ppm)	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	573	470	584	426	535	431	471	393	426	280
low km	554	450	424	311	377	269	456	329	386	287
sig. diff.	N		Y		Y		Y		N	

Table 6.10 Comparison of uvSmoke emissions for high and low mileage NZN diesel vehicles by emissions standard

uvSmoke	Pre-2003		2003+		Euro 2		Euro 3		Euro 4	
	mean	med.	mean	med.	mean	med.	mean	med.	mean	med.
high km	0.208	0.126	0.124	0.088	0.077	0.062	0.134	0.060	0.070	0.048
low km	0.151	0.103	0.109	0.062	0.065	0.057	0.063	0.042	0.069	0.057
sig. diff.	Y		Y		N		N		N	

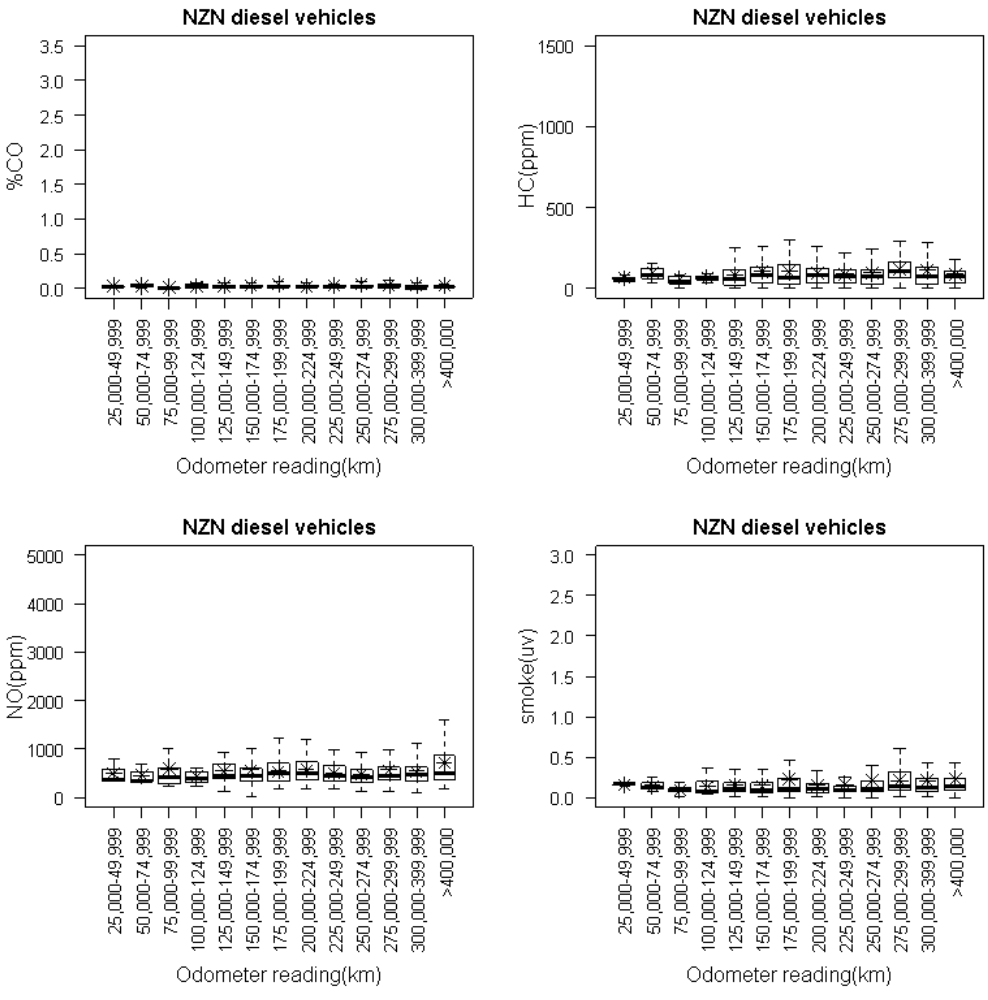
CO and NO emissions were slightly higher for the high mileage NZN diesel vehicles, on average, than for the low mileage vehicles where the specific emissions standard was known (ie Euro 2 and Euro 3) but the differences were marginal compared with NZN petrol vehicles where high mileage emissions were up to double those for low mileage vehicles. For HC and uvSmoke emissions there were clearer differences in the broad categories of pre-2003 and 2003+ but again these differences were nowhere near as conclusive as those seen for the NZN petrol vehicles.

Figure 6.4 investigates these mileage trends further by comparing the emissions of pre-2003 NZN diesel vehicles by odometer readings.

6.3 Comparison of pre-2003 NZN diesel vehicle emissions by odometer readings

There was no apparent trend in CO or NO emissions with increasing mileage and HC emissions increased only very slightly, possibly experiencing a step change at around 125,000km. The trend in uvSmoke emissions from NZN diesel vehicles was also indeterminate. Vehicles with odometer readings of less than 75,000km recorded relatively high uvSmoke emissions but this was a very small sample size of only six vehicles. Discounting these readings, uvSmoke emissions from NZN diesel vehicles did confirm a gradual increase with increasing mileage.

Figure 6.4 Comparison of pre-2003 NZN diesel vehicle emissions by odometer readings



6.4 JPU petrol vehicles

Table 6.11 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 widely across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 6.11 JPU petrol vehicle lower (25th) and upper (75th) quartile odometer readings by emissions standard

Odometer reading (km)	79-E	79	00/02	J05
high mileage	198,000	145,000	109,000	59,000
low mileage	131,000	88,000	63,000	27,000

Figure 6.5 compares emissions for high and low mileage JPU petrol vehicles by emissions standard. Tables 6.12, 6.13, 6.14 and 6.15 summarise the mean and median values for CO, HC, NO and uvSmoke, respectively, and highlight whether any differences between the high and low mileage vehicles were statistically significant.

CO, HC, NO, and uvSmoke emissions were significantly higher (in some cases, double) for high mileage JPU petrol vehicles than for low mileage vehicles for all except the most recent emissions standard category (J05). The J05 vehicles were relatively new vehicles and consequently had relatively low odometer readings at the 75th percentile.

Figure 6.5 Comparison of JPU petrol vehicle emissions for high and low km odometer readings by emissions standard

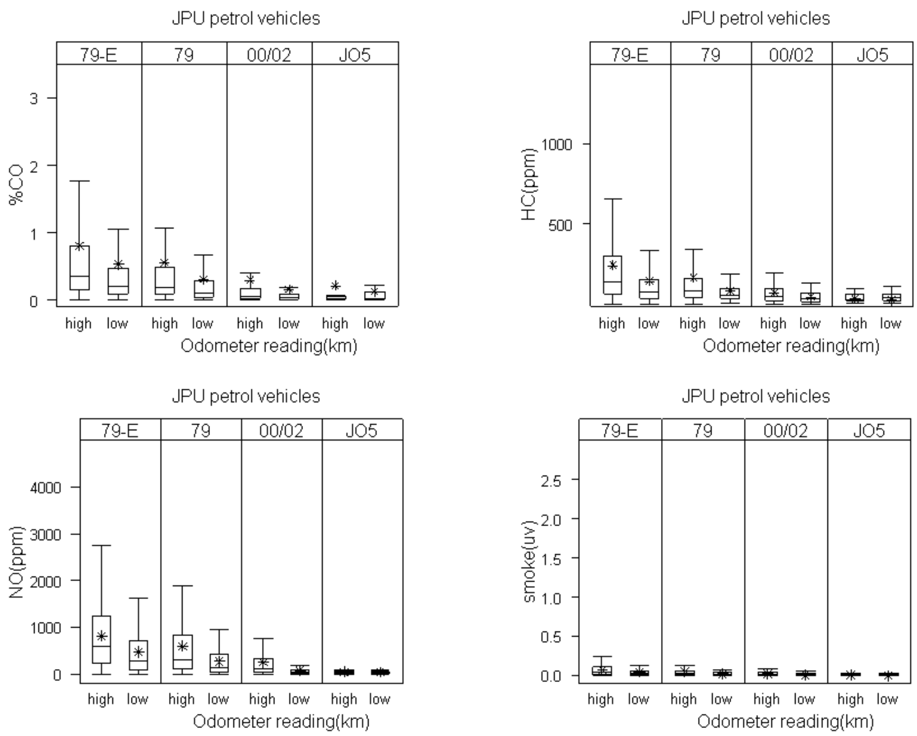


Table 6.12 Comparison of CO emissions for high and low mileage JPU petrol vehicles by emissions standard

CO (%)	79-E		79		00/02		J05	
	mean	med.	mean	med.	mean	med.	mean	med.
high km	0.81	0.36	0.56	0.19	0.29	0.05	0.21	0.02
low km	0.54	0.20	0.30	0.09	0.15	0.02	0.12	0.02
sig. diff.	Y		Y		Y		N	

Table 6.13 Comparison of HC emissions for high and low mileage JPU petrol vehicles by emissions standard

HC (ppm)	79-E		79		00/02		J05	
	mean	med.	mean	med.	mean	med.	mean	med.
high km	239	127	161	68	68	36	29	13
low km	140	64	79	42	42	18	25	19
sig. diff.	Y		Y		Y		N	

Table 6.14 Comparison of NO emissions for high and low mileage JPU petrol vehicles by emissions standard

NO (ppm)	79-E		79		00/02		J05	
	mean	med.	mean	med.	mean	med.	mean	med.
high km	808	555	593	256	248	45	44	0
low km	471	218	271	79	70	18	51	0
sig. diff.	Y		Y		Y		N	

Table 6.15 Comparison of uvSmoke emissions for high and low mileage JPU petrol vehicles by emissions standard

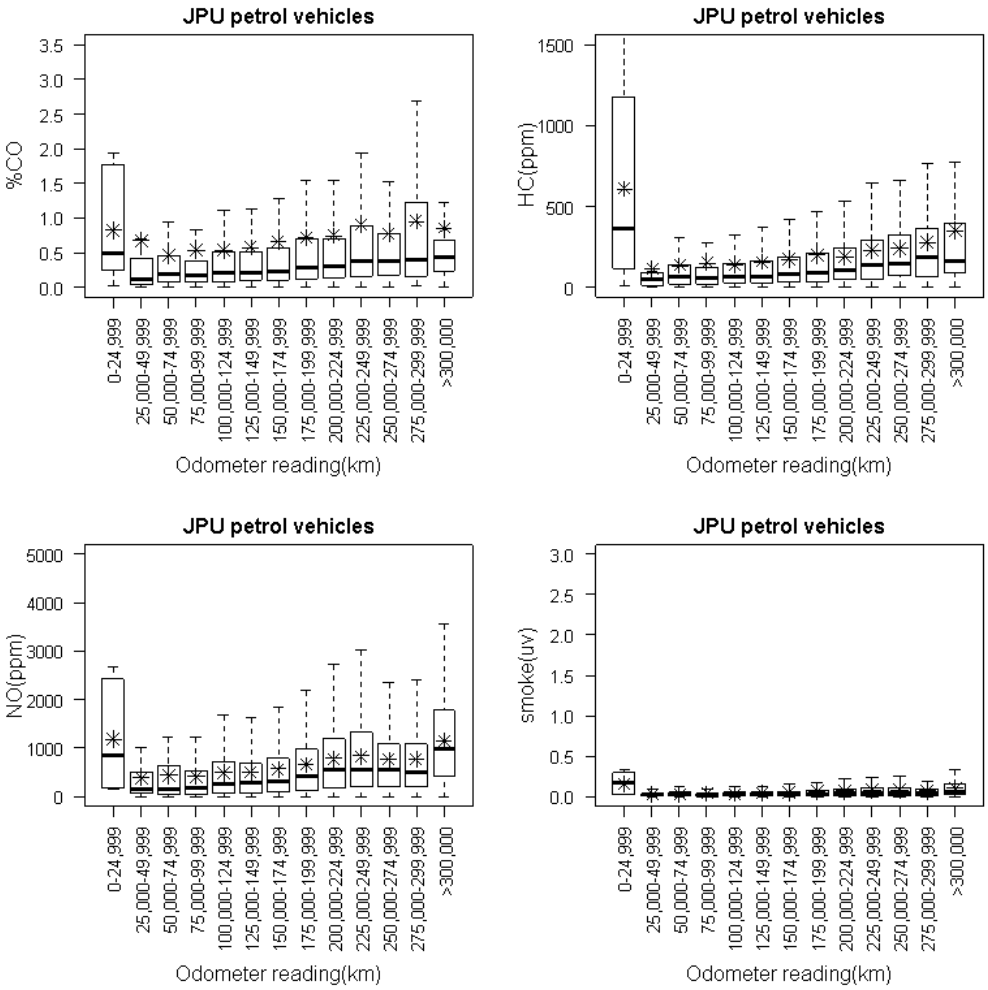
uvSmoke	79-E		79		00/02		J05	
	mean	med.	mean	med.	mean	med.	mean	med.
high km	0.077	0.041	0.056	0.024	0.022	0.008	0.006	0.002
low km	0.043	0.022	0.023	0.014	0.008	0.004	0.000	0.000
sig. diff.	Y		Y		Y		N	

Figure 6.6 investigates these mileage trends further by comparing the emissions of JPU petrol vehicles classified as the 79-E emissions standard.

Emissions of CO, HC, NO and uvSmoke all steadily increased from 79-E JPU petrol vehicles as odometer readings increased from 25,000km to 400,000km. The one clear exception to these trends was in the emissions from vehicles with odometer readings of less than 25,000km, which were unexpectedly high for all pollutants. This particular odometer grouping contained very few readings – only six vehicles – and the small sample size may well have been the cause of the unexpected observation.

Another potential explanation for the unexpected high emissions from the low odometer reading vehicles was that some of the vehicle's odometers had gone 'around the clock', ie vehicles with five digit odometers had travelled more than 99,999km. Car manufacturers switched odometers from five to six figures in the late 1980s or 1990s. However none of the six JPU petrol vehicles with odometer readings of less than 25,000km included in this analysis were manufactured before 1990. It is therefore unlikely that around the clock vehicles had an influence on the relatively high emissions observed from the low odometer JPN petrol vehicles.

Figure 6.6 Comparison of 79-E JPU petrol vehicle emissions by odometer reading



6.5 JPU diesel vehicles

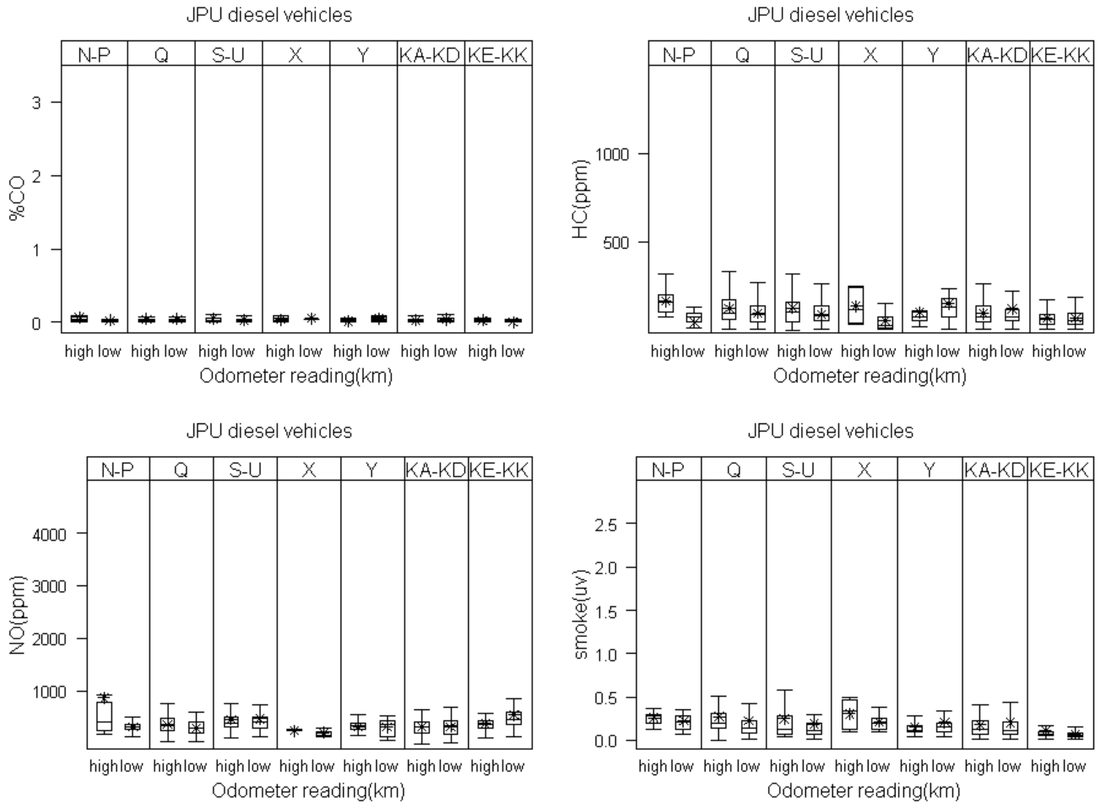
Table 6.16 shows the high (75th quartile) and low (25th quartile) odometer readings for the JPU diesel vehicle fleet by emissions standard arranged in approximate order from oldest to newest. The differences in odometer reading between the high and low extremes varied widely across the categories as the newer vehicles had not been in the fleet long enough to travel very far.

Table 6.16 JPU diesel vehicle lower (25th) and upper (75th) quartile odometer readings by emissions standard

Odometer reading (km)	N-P	Q	S-U	X	Y	KA-KD	KE-KK
high mileage	279,000	264,000	271,000	314,000	221,000	212,000	203,000
low mileage	172,000	186,000	183,000	207,000	158,000	139,000	130,000

Figure 6.7 compares emissions for high and low mileage JPU diesel vehicles by emissions standard. Tables 6.17, 6.18, 6.19 and 6.20 summarise the mean and median values for CO, HC, NO and uvSmoke, respectively, and highlight whether any differences between the high and low mileage vehicles were statistically significant.

Figure 6.7 Comparison of JPU diesel vehicle emissions for high and low km odometer readings by emissions standard



Statistically significant emissions differences between high and low mileage JPU diesel vehicles were seen primarily for the earlier emissions standards (ie N-P and Q) but there was considerable variability across the standards.

Table 6.17 Comparison of CO emissions for high and low mileage JPU diesel vehicles by emissions standard

CO (%)	N-P	Q	S-U	X	Y	KA-KD	KE-KK
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
high km	0.07 (0.03)	0.04 (0.02)	0.05 (0.02)	0.04 (0.03)	0.02 (0.02)	0.04 (0.02)	0.03 (0.02)
low km	0.03 (0.02)	0.05 (0.02)	0.03 (0.02)	0.05 (0.04)	0.05 (0.21)	0.03 (0.02)	0.00 (0.01)
sig. diff.	Y	N	N	N	N	N	Y

Table 6.18 Comparison of HC emissions for high and low mileage JPU diesel vehicles by emissions standard

HC (ppm)	N-P	Q	S-U	X	Y	KA-KD	KE-KK
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
high km	163 (155)	123 (96)	125 (101)	135 (116)	101 (75)	119 (71)	67 (49)
low km	43 (51)	96 (73)	88 (72)	52 (24)	150 (128)	0 (0)	0 (0)
sig. diff.	Y	N	N	Y	Y	N	N

Table 6.19 Comparison of NO emissions for high and low mileage JPU diesel vehicles by emissions standard

NO (ppm)	N-P	Q	S-U	X	Y	KA-KD	KE-KK
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
high km	869 (411)	365 (338)	460 (390)	24 (265)	314 (333)	324 (348)	548 (466)
low km	316 (313)	298 (296)	472 (404)	203 (214)	312 (368)	313 (314)	380 (372)
sig. diff.	Y	Y	N	N	N	N	Y

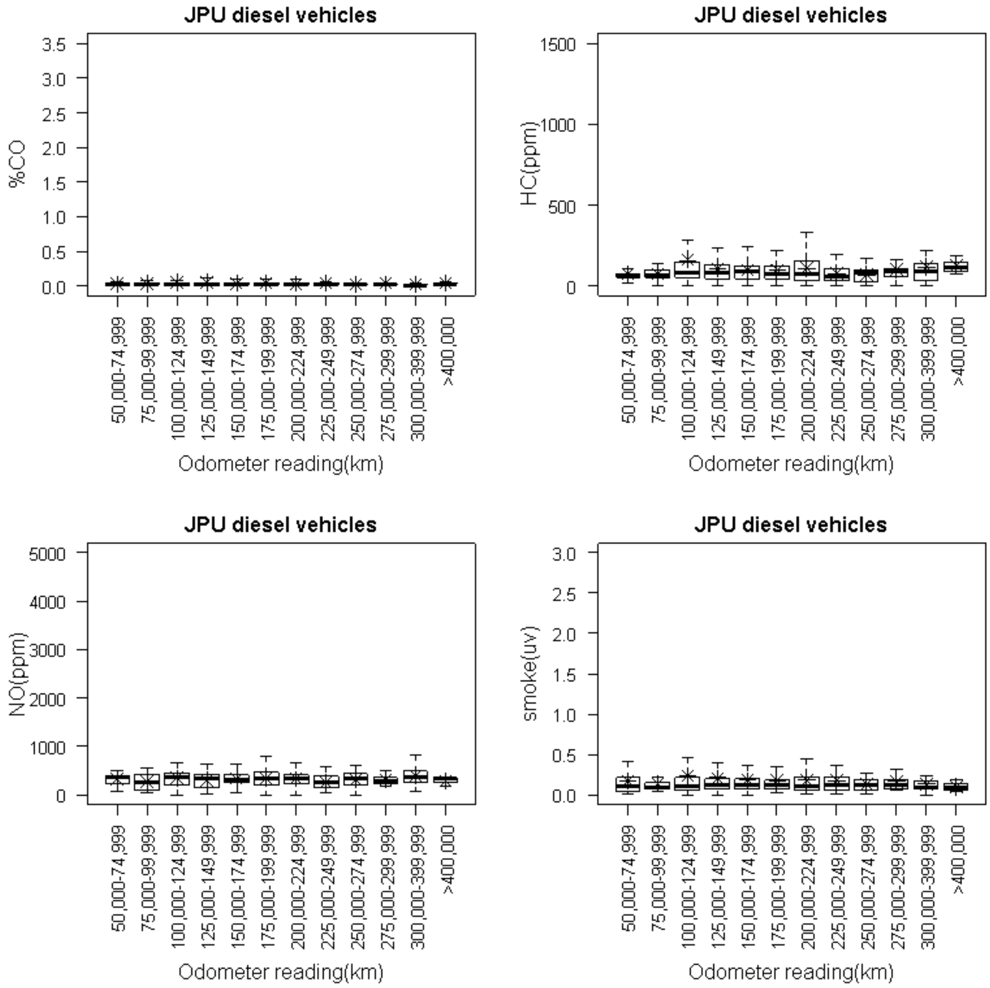
Table 6.20 Comparison of uvSmoke emissions for high and low mileage JPU diesel vehicles by emissions standard

uvSmoke	N-P	Q	S-U	X	Y	KA-KD	KE-KK
	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)	mean (median)
high km	0.258 (0.277)	0.274 (0.194)	0.247 (0.129)	0.304 (0.344)	0.149 (0.114)	0.21 (0.11)	0.07 (0.00)
low km	0.224 (0.208)	0.223 (0.137)	0.188 (0.113)	0.214 (0.191)	0.208 (0.151)	0.00 (0.00)	0.00 (0.00)
sig. diff.	N	Y	N	N	N	N	N

The results show that for JPU diesel vehicles there was some relationship between high odometer readings and increased emissions. However, the tendency for emissions of pollutants to increase with odometer readings was observed in a limited number of emissions standards and appears much weaker than that observed for JPU petrol vehicles or even NZN diesel vehicles.

Figure 6.8 investigates these mileage trends further by comparing the emissions of JPU diesel vehicles classified as the KA-KD emissions standard. This emissions standard grouping was selected for this analysis because it contained a relatively high number of vehicles compared with the others. Regardless, these results showed no significant trend in emissions of CO, HC, NO or uvSmoke from JPU diesel vehicles with increasing mileage and were considered representative of the trends for the other JPU diesel emissions standard groupings.

Figure 6.8 Comparison of KA-KD JPU diesel vehicle emissions by odometer reading



The lack of a trend in uvSmoke emissions with increasing mileage was particularly noteworthy as mileage is generally considered to be a proxy for maintenance. However, previous vehicle emissions testing undertaken in New Zealand also failed to demonstrate definitive trends in emissions with mileage when vehicles were idle tested. Studies such as the pilot emissions testing (Campbell et al 2006) and the vehicle scrappage trial (MoT 2008b) concluded that technology (such as the presence or absence of an exhaust catalytic converter or of a carburettor) was the best predictor of a vehicle's likely emissions.

7 Summary of key findings

7.1 Fleet trends from 2003 to 2009

In total, records were available for approximately 11,000 individual light duty vehicles in the 2003 dataset, 21,000 in the 2005 dataset and 22,000 in the 2009 dataset. Heavy duty vehicles were not considered in this study.

The average age of the light vehicles within the Auckland monitored fleet increased from 8.8 to 9.3 and 9.9 years during the period 2003, 2005 and 2009. This aging trend mirrored the increases recorded in the actual national and Auckland fleet average ages. However, the average age of the monitored Auckland fleet was consistently younger (by approximately 1.5 years) than the actual Auckland fleet. In addition, the Auckland fleet was typically one year younger than the national fleet.

Between 2003 and 2009, the proportion of the monitored fleet using diesel increased from 12.2% to 15.5%.

The mean age of the petrol vehicles monitored in 2009 was approximately eight months older than those monitored in 2005 and more than one year older than those monitored in 2003. There was a consistent increasing trend in the mean age of the monitored petrol vehicles from 2003 to 2009.

The mean age of the diesel vehicles monitored in 2009 was approximately 12 months younger than those monitored in 2005 but seven months older than those monitored in 2003. From 2003 to 2009, the mean age of monitored diesel vehicles increased slightly but oscillated between an initial increase (2003 to 2005) to a decrease (2005 to 2009).

Approximately half of the vehicles monitored were NZN and the other half entered the New Zealand fleet as used vehicles imported from other countries (mainly Japan). There was a growth in imported used vehicles within the monitored fleets from 48% in 2003 to 51% in 2009, resulting in a decline in the proportion of NZN vehicles within the monitored fleet.

The trends observed within the monitored fleet of increasing vehicle age, increasing proportion of diesel vehicles and increasing proportion of imported used vehicles were all generally consistent with trends seen in the national light duty vehicle fleet.

7.2 Emissions trends from 2003 to 2009

Emissions of CO, HC and NO, on a per vehicle average, decreased significantly from the light duty fleet between 2003 and 2009. uvSmoke emissions, on a per vehicle average, also showed an improvement but only from 2005 onwards. The overall average emission concentrations reduced by 43% for CO, 58% for HC, 39% for NO and 27% for uvSmoke over the three monitoring campaigns. However, these were reductions per vehicle, on average, and did not necessarily reflect reductions in the total light fleet emissions (as these would be offset by any increases in vehicle numbers, kilometres travelled and congestion over the period).

Petrol vehicle average emissions of CO, HC and NO decreased significantly between 2003 and 2009, while uvSmoke decreased appreciably between 2005 and 2009. The petrol vehicle average concentrations reduced by 40% for CO, 59% for HC, 42% for NO and 22% for uvSmoke over the three monitoring campaigns. The results from the NZN and JPU petrol vehicle fleets mirrored those observed in the total petrol fleet except there was no significant decrease in emissions of uvSmoke from JPU petrol vehicles measured between 2005 and 2009. It should be noted that uvSmoke is a relatively minor pollutant for petrol vehicles.

Considering the petrol results by country of first registration, the NZN fleet had higher median and mean emissions of CO, HC and NO in 2003 than the JPU fleet. However, the rate of emissions improvement for CO, HC and NO from NZN petrol vehicles was appreciably faster than the JPU petrol fleet. By 2009, the NZN fleet had lower median and mean emissions of CO, HC and NO than its JPU counterpart. This observation reflects that many NZN vehicles monitored in 2009 were manufactured relatively recently and therefore they were built to stringent emissions standards.

The mean age of the JPU petrol vehicles was considerably higher than the NZN petrol vehicles in all three campaigns. Since 2003, the mean age of the NZN petrol vehicles has been stable at around 7.5 years but the age of the JPU petrol vehicles increased from 10.5 years (only three years difference) to 12.4 years (nearly five years difference) in 2009.

Despite popular perceptions that JPU vehicles were 'cast offs from Japan' and more polluting than their NZN counterparts, the 2003 campaign found JPU petrol vehicles were emitting significantly less CO than NZN vehicles of the same age. This reflects that the Japanese vehicles were originally built to a standard that required the fitting of emissions controls, unlike the NZN vehicles which at that point were still generally not fitted with this equipment. It is recognised that some of this emissions control technology on the imported vehicles may have been damaged, or even removed once in New Zealand. However, in general, the vehicles were still lower emitting, especially under the conditions where they were monitored by the remote sensing device (warm engine and free running traffic). However, as improved emissions control technology found its way into the NZN fleet during 2003 to 2009, the difference between younger (<10 years) NZN and JPU vehicles reduced significantly. Nonetheless, older NZN petrol vehicles (>10 years) continue to emit significantly more CO than JPU petrol vehicles of the same age.

Comparisons of HC and NO emissions from NZN and JPU petrol vehicles by age for 2003, 2005 and 2009 showed very similar results to those described for CO. The comparison of uvSmoke emissions from NZN and JPU petrol vehicles by age showed similar results to those described for the 2005 and 2009 CO comparison.

Diesel vehicle average emissions of CO and uvSmoke decreased significantly between 2003 and 2009, although it should be noted that CO is a minor pollutant for diesel vehicles. HC emissions were also significantly lower in 2009 relative to 2003 but much of this improvement seemed to have occurred by 2005. There was no obvious improvement or trend in NO emissions from diesel vehicles. This was an unexpected finding with potentially significant policy implications and is highlighted as a priority issue in section 8.3. The diesel vehicle average concentrations reduced by 80% for CO, 31% for HC and 73% for uvSmoke over the three monitoring campaigns. While a large proportion of the decrease in diesel emissions was likely to be the result of improving vehicle technology, the quality of diesel fuel also improved significantly over that period and would have contributed to the reductions. The lack of trend in NO emissions is of concern for at least two reasons. Many urban environments are showing steady or even increasing levels of ambient NO_2. Research suggests that direct NO_2 emissions from modern vehicles is 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. The results of the NZN and JPU diesel vehicle fleets mirrored those observed in the total diesel fleet.

Considering the diesel results by country of first registration, the 2003 campaign found very little difference between emissions of CO or HC between the NZN and JPU fleets. In the two later campaigns (2005 and 2009), CO and HC emissions from NZN diesel vehicles tended to be lower than those from the JPU diesel fleet. NO emissions, on average, were significantly higher from NZN vehicles than those from

JPU vehicles for all three monitoring campaigns. The lower NO emissions from JPU diesels may reflect the relative stringency of Japanese diesel emissions standards, especially compared with the European standards that most NZN diesel vehicles are manufactured to. The reverse was found for uvSmoke emissions, where JPU diesel vehicles tended to be higher than NZN diesel vehicles in all years.

The mean age of the JPU diesel vehicles was considerably higher than the NZN diesel vehicles in all three campaigns. Both fleets aged between 2003 and 2009 but the JPU diesel fleet aged faster. The mean age of the NZN diesel vehicles increased from 4.3 years in 2003 to 5.2 years in 2009, while the mean age of the JPU diesel fleet increased from 10.9 years (a 6.7 year difference) in 2003 to 13.8 years (an 8.6 year difference) in 2009.

In the 2003 monitoring campaign, before New Zealand introduced emissions standards for new vehicles entering the fleet, JPU diesel vehicles were significantly cleaner than NZN vehicles of the same age. However, as improved emissions control technology found its way into the NZN fleet, the difference in emissions performance between younger (<8 years) NZN and JPU vehicles reduced significantly. Nonetheless, older NZN diesel vehicles (>8 years) continued to emit significantly more NO than JPU diesel vehicles of the same age.

Comparisons of CO, HC, and uvSmoke emissions from NZN and JPU diesel vehicles by age showed very little difference between emissions from NZN and JPU vehicles of the same age.

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 built post-2003, irrespective of the emissions standard. Significant reductions in measured emissions of CO, HC and NO from petrol vehicles, on average, were seen with the improving emissions standard but only as far as Euro 3. Euro 4 emissions showed no discernible improvement over Euro 3. The numbers of Euro 3 and 4 petrol vehicles monitored were relatively low and this may explain why no significant difference was observed between these two emissions standards. uvSmoke emissions showed no obvious trend with the Euro standard.

NZN diesel 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 built post-2003, irrespective of the emissions standard. Measured emissions of HC, NO and uvSmoke, on average, from diesel vehicles showed only a very slight improvement with the improving emissions standard. The numbers of Euro 2, 3 and 4 diesel vehicles monitored were relatively low and this may explain why no significant difference was observed between these three emissions standards. Euro 4 NO emissions, however, were significantly lower than those for Euro 3 or earlier standards. CO emissions showed no obvious trend with the Euro standard. It is important to note that CO emissions from diesel vehicles were very low and the lack of any trend might reflect that the measurements were often close to zero.

Emissions of CO, HC, NO and uvSmoke from JPU petrol vehicles, on average, all reduced significantly with each change in emissions standard grouping from 79-E to 79 to 00/02 to J05.

Emissions trends in JPU diesel vehicles were much less conclusive than the strong trends seen for the JPU petrol vehicles. The emissions standard groupings were presented in chronological order and did show a slight improvement in CO, HC and uvSmoke emissions, on average, between the oldest and newest diesel vehicles. However, the results for intermediate groupings were very variable. NO emissions showed no obvious trend across any of the emissions standard groupings.

7.4 Effect of vehicle mileage

To analyse trends in emissions as a result of increased distance travelled, comparisons were made between vehicles with the same fuel type and technology (emissions standards).

CO and NO emissions were significantly higher for the high mileage NZN petrol vehicles, on average, than for the low mileage vehicles irrespective of the emissions standard (with the exception of Euro 4 CO emissions). However, increasing mileage had a less conclusive impact on HC and uvSmoke emissions. Significant differences were seen in the broad emissions standard categories of pre-2003 and 2003+ (both of which encompassed a range of emissions standards) but not when comparing high and low mileage Euro 2, Euro 3 or Euro 4 NZN petrol vehicles.

For NZN petrol vehicles manufactured pre-2003, a steady increase of emissions of CO, HC and NO was observed from vehicles with odometer readings from 50,000 km through to vehicles with odometer readings of 400,000 km. Emissions of uvSmoke from NZN petrol vehicles also increased going from odometer readings of 50,000 km to 400,000km. However compared with the more gradual increase in the other three pollutants, there appeared to be a step change increase in uvSmoke emissions at around 175,000 km. This step change could be a result of some engine components reaching their durability limits after travelling this distance.

In NZN diesel vehicles, a relationship between high odometer readings and increased emissions was observed for CO and NO. However, the tendency for emissions of pollutants to increase with odometer readings was restricted to a limited number of emissions standards and appeared to be much weaker than observed for NZN petrol vehicles. For HC and uvSmoke emissions, there were clearer differences in the broad categories of pre-2003 and 2003+ but these observed differences were nowhere near as conclusive as those seen for the NZN petrol vehicles. Older diesel or diesel vehicles with high odometer readings are popularly perceived to be the smokiest vehicles so the result that there was no or little increase of uvSmoke with higher odometer reading was unexpected. However this observation may be explained to some degree by the fact that the RSD uvSmoke measurements catch very small particles (~100 nm) and visibly smoky vehicle exhausts contain high concentrations of much larger particles, ie the RSD was not measuring the visible smokiness of the plume.

The detailed odometer analysis on NZN diesels manufactured before 2003 showed no apparent trend in CO or NO emissions with increasing mileage and HC emissions increased only very slightly, possibly experiencing a step change at around 125,000 km. uvSmoke emissions from NZN diesel vehicles did confirm a general but gradual increase with increasing mileage.

CO, HC, NO, and uvSmoke emissions were significantly higher (in some cases, double) for high mileage JPU petrol vehicles than for low mileage vehicles for all except the most recent emissions standard category (J05). The J05 vehicles were relatively new vehicles and consequently had relatively low odometer readings at the 75th percentile.

For JPU petrol vehicles that fell within the 79-E emissions standard group there was a steady increase of emissions of CO, HC, NO and uvSmoke from vehicles with odometer readings from 25,000 km through to 400,000 km.

The results showed that for JPU diesel vehicles there was some relationship between high odometer readings and increased emissions. However, the tendency for emissions of pollutants to increase with odometer readings was observed in a limited number of emissions standards and appeared much weaker than that observed for JPU petrol vehicles or even NZN diesel vehicles.

For JPU diesel vehicles that fell into the KA-KD emissions standard group no significant trend in emissions of CO, HC, NO or uvSmoke was observed with odometer reading. The KA-KD emissions standard group was the largest subset of the monitored diesel vehicle fleet. The KA-KD vehicles were manufactured from the early to mid-1990s and are fairly typical of the JPU diesel vehicles in the New Zealand fleet. Older diesel or diesel vehicles with high odometer readings are popularly perceived to be the smokiest vehicles so the result that there was no increase of uvSmoke with higher odometer reading was unexpected. As for the NZN diesel vehicles it is important to remember that the RSD was not measuring the smokiness of the plume.

8 Conclusions and recommendations

The section reviews the objective and aims of the project and reflects upon the achievement of these. An overview of the key findings is presented. The potential science and policy implications of the findings are discussed and recommendations are made for future emissions monitoring projects.

8.1 Project objective and aims

The primary objective of this project was to address the question:

> *Are the harmful emissions from New Zealand's light duty fleet improving (reducing) under the current 'business as usual' scenario?*

The aims of the project were to:

- undertake roadside vehicle emissions measurements in 2009 to obtain a representative profile of light duty vehicles
- collate the 2009 vehicle emissions measurements with similar databases developed in 2003 and 2005
- characterise and compare the features of the monitored light duty vehicle fleet in 2003, 2005 and 2009
- assess any trends in fleet emissions over the period 2003 to 2009
- evaluate the effect of emissions standards on vehicle emissions
- review the effect of odometer readings on vehicle emissions.

The results generated by this project and the results presented in this report confirm that the aims and objective were met.

8.2 Key findings

The mean age of the vehicles within the monitored vehicle fleet increased from 8.8, 9.3 and 9.9 years during the period 2003 to 2009. Between 2003 and 2009 the proportion of the monitored fleet using diesel increased from 12.2% to 15.5%. There was a growth in imported used vehicles within the monitored fleets from 48% in 2003 to 51% in 2009, resulting in a decline in the proportion of New Zealand new vehicles within the monitored fleet.

Emissions of all pollutants, on average, decreased significantly from the light duty vehicle fleet between 2003 and 2009. Changes in mean emissions from the petrol fleet emissions mirrored that observed in the total monitored fleet (petrol plus diesel vehicles). Emissions of CO and uvSmoke from diesel vehicles, on average, decreased significantly between 2003 and 2009, although CO is a relatively minor pollutant for diesel vehicles. HC emissions were also significantly lower in 2009 relative to 2003 but much of this improvement seemed to have occurred by 2005. While a large proportion of the decrease in diesel emissions is likely to be the result of improving vehicle technology, the quality of diesel fuel also improved significantly over that period and would have contributed to the reductions. There was no obvious improvement or trend in NO emissions from diesel vehicles. This was an unexpected finding with potentially significant policy implications and is highlighted as a priority issue in section 8.3.

The introduction of vehicle emissions standards for New Zealand new vehicles significantly reduced the mean emissions of CO, HC, NO and uvSmoke for vehicles manufactured from 2003 onwards compared with vehicles manufactured pre-2003. However, the step change reductions expected as a result of the differences between emissions test limits were not clearly seen in the roadside data. JPU petrol vehicles demonstrated a clear and significant reduction of emissions with each change in emissions standard group. Emissions trends in JPU diesel vehicles were much less conclusive than the strong trends seen for the JPU petrol vehicles but did show a slight improvement in CO, HC and uvSmoke emissions, on average as emissions standards progressed. NO emissions showed no obvious trend across any of the emissions standard groupings.

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.

8.3 Potential scientific and policy implications

The overall conclusion from the project is that harmful emissions from New Zealand's light duty fleet are generally improving (reducing) on a per vehicle basis under the current 'business as usual' scenario. While this is an encouraging result, there are three issues which will need to be considered and monitored.

First, NO emissions improvements may have plateaued (especially from diesel vehicles) which is of concern with many urban environments showing steady or even increasing levels of ambient NO_2 and the increasing direct emissions from modern vehicles (Gense et al 2006).

Second, the aging vehicle fleet is also a concern because much of the improvement observed in the fleet emissions is due to new lower emitting vehicles entering the fleet.

Third, while per vehicle average emissions are reducing, the total fleet emissions are also influenced by the number of vehicles on the road, the distance they travel and the driving conditions they are operated in. The number of vehicles in New Zealand and the distance they are being driven is increasing and driving conditions are becoming more congested, especially in the urban areas. Therefore it is likely that at least some of the individual vehicle emissions improvements are being eroded by the other factors that influence the total amount of emissions being discharged by New Zealand's light duty vehicle fleet.

These three issues will need to be watched closely and will require additional data collection and analysis to improve understanding and perhaps the implementation of future in-service interventions/policies.

It is also important to note that the study was based only on vehicles measured in Auckland and did not consider emissions from heavy duty vehicles, which are the largest source of particulate pollution from the road transport sector.

The results from this project will be invaluable for the NZTA, MoT and other stakeholders 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.

The results from this project have raised additional research questions. Potentially high-priority issues include to:

- investigate why no improvement was observed in NO emissions from diesel vehicles over the period 2003 to 2009
- examine why anticipated step change reductions in emissions with improving emissions standards were not observed
- define the trend in total emissions from New Zealand's light duty fleet by integrating the findings of this study with the combined effects of increased vehicle numbers, increased kilometres driven and change in driving conditions (eg 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 New Zealand's vehicle fleet generate the largest quantities of air pollution
- quantify regional (national and international) differences in vehicle fleet emissions profiles.

8.4 Future vehicle emissions monitoring

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 three. The data has already proved invaluable for the identification and assessment of the key trends that influence the emissions performance of the fleet.

Consequently, 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 database by expanding the monitoring to other regions beyond Auckland and/or perhaps targeting specific sectors of the fleet (eg heavy duty diesel vehicles).

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.

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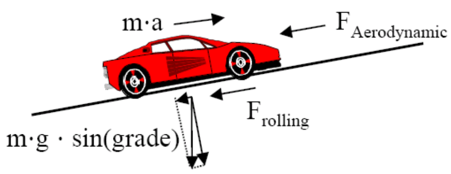
Appendix A: Calculation of vehicle specific power

A1 Definition of VSP

In remote sensing studies, vehicle specific power (VSP) is a useful performance measure for determining whether a vehicle is operating within an acceptable power range. VSP is a measure of the load on a vehicle as it drives along and is defined as the power per unit mass to overcome road grade, rolling resistance, aerodynamic resistance, and internal friction as shown in the figure A1.

Figure A1 Schematic diagram and equation showing how VSP is calculated



$$VSP = \frac{Power}{Mass} = \frac{\frac{d}{dt}(E_{Kinetic} + E_{Potential}) + F_{Rolling} \cdot v + F_{Aerodynamic} \cdot v + F_{internal\ friction} \cdot v}{m} =$$

$$\approx v \cdot a \cdot (1 + \varepsilon_i) + g \cdot grade \cdot v + g \cdot C_R \cdot v + \frac{1}{2}\rho_a C_D \frac{A}{m}(v + v_w)^2 \cdot v + C_{if} \cdot v =$$

$$\approx 1.1 \cdot v \cdot a + 9.81 \cdot grade + 0.213 \cdot v + 0.000305 \cdot (v + v_w)^2 \cdot v$$

Where:

v is the vehicle speed assuming no headwind (m/s)

a is the vehicle acceleration (m/s^2)

grade is the road grade at the monitoring location (%)

v_w is the windspeed at the monitoring location (m/s)

VSP is the vehicle specific power (kW/tonne)

VSP is a convenient measure that can be used directly to predict emissions and is a common metric for remote sensing, inspection and maintenance test, drive cycles and emissions models. It allows comparison of the results of different methods and conditions, such as IM240 drive cycle tests and remote sensing.

A2 Using VSP for quality assurance

In this study, VSP was used to check that differences in vehicle power output were not responsible for the differences observed in fleet average emissions measured in 2005 and 2009. For example, if the vehicles measured in 2005 had been driven more aggressively (faster and/or higher acceleration) than in 2009, then vehicle power output (as measured by VSP) could have been one of the major factors causing the higher emissions observed in the 2005 fleet.

Figure A2 shows a comparison of emissions from petrol vehicles measured in the 2005 and 2009 campaigns by VSP bands. Table A1 compares the median and mean values of petrol vehicle emissions by VSP bands.

Figure A2 and table A1 show that the comparison of 2005 and 2009 petrol vehicle emissions for each pollutant by VSP bin is consistent with the fleet average comparison shown in figure 4.2, ie 2005 petrol fleet emissions are higher than 2009 for all pollutants. The conclusion from the VSP comparison shown in figure A2 and table A1 is that the differences observed in the petrol fleet average emissions measured in 2005 and 2009 were not a result of changes in vehicle power output.

Figure A3 shows a comparison of emissions from diesel vehicles measured in the 2005 and 2009 campaigns by VSP bands. Table A2 compares the median and mean values of diesel vehicle emissions by VSP bands.

Figure A3 and table A1 show that the comparison of 2005 and 2009 diesel vehicle emissions for each pollutant by VSP bin is consistent with the fleet average comparison shown in figure 4.8. In other words, 2005 diesel fleet emissions tend to be higher than 2009 for CO and uvSmoke and there is little or no difference in emission of HC or NO. The conclusion from the VSP comparison shown in figure A2 and table A1 is that the differences observed in the diesel fleet average emissions measured in 2005 and 2009 are not the result of changes in vehicle power output.

Figure A2 Effect of VSP on the comparison of the 2005 and 2009 petrol vehicle emissions

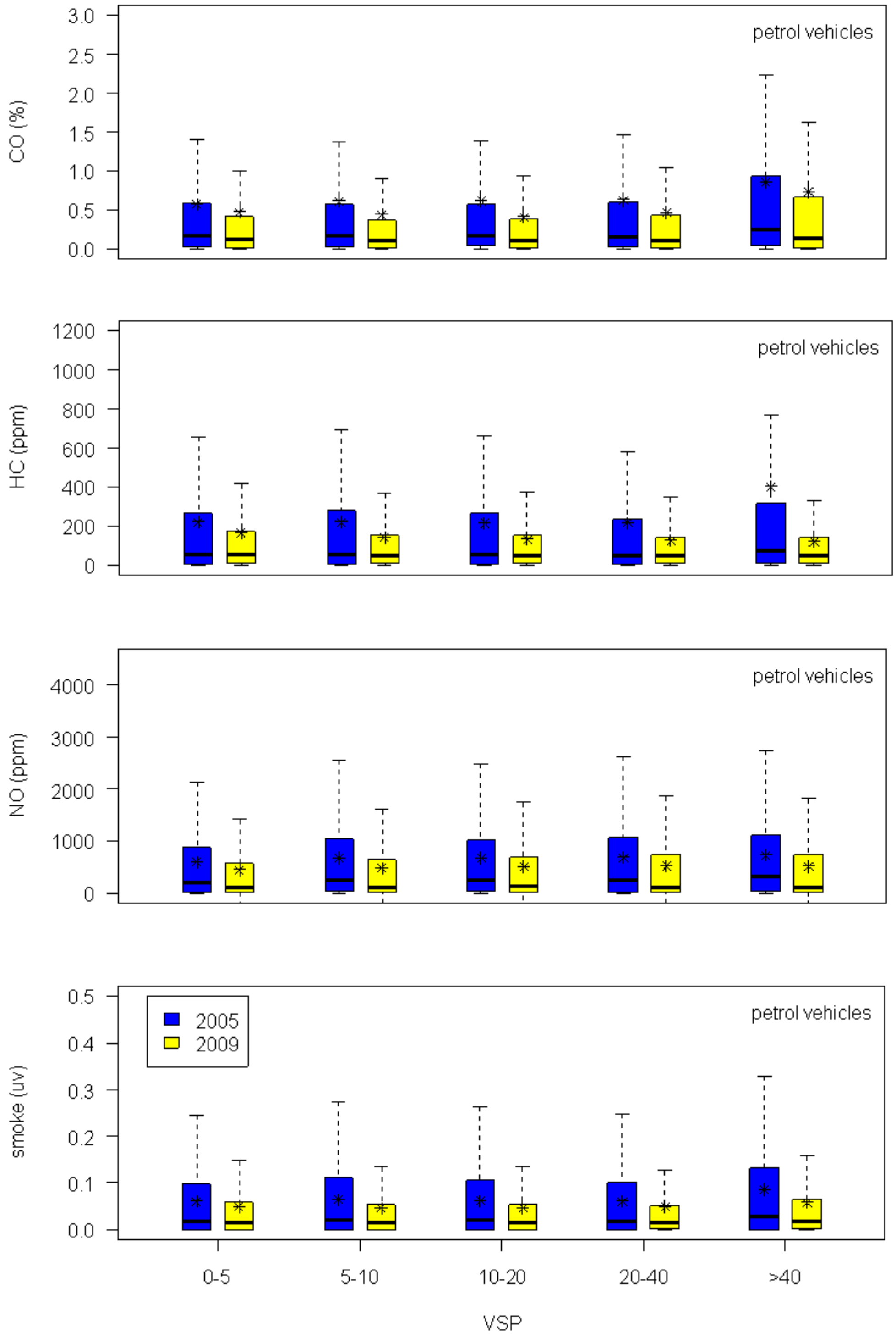


Figure A3 Effect of VSP on the comparison of the 2005 and 2009 diesel vehicle emissions

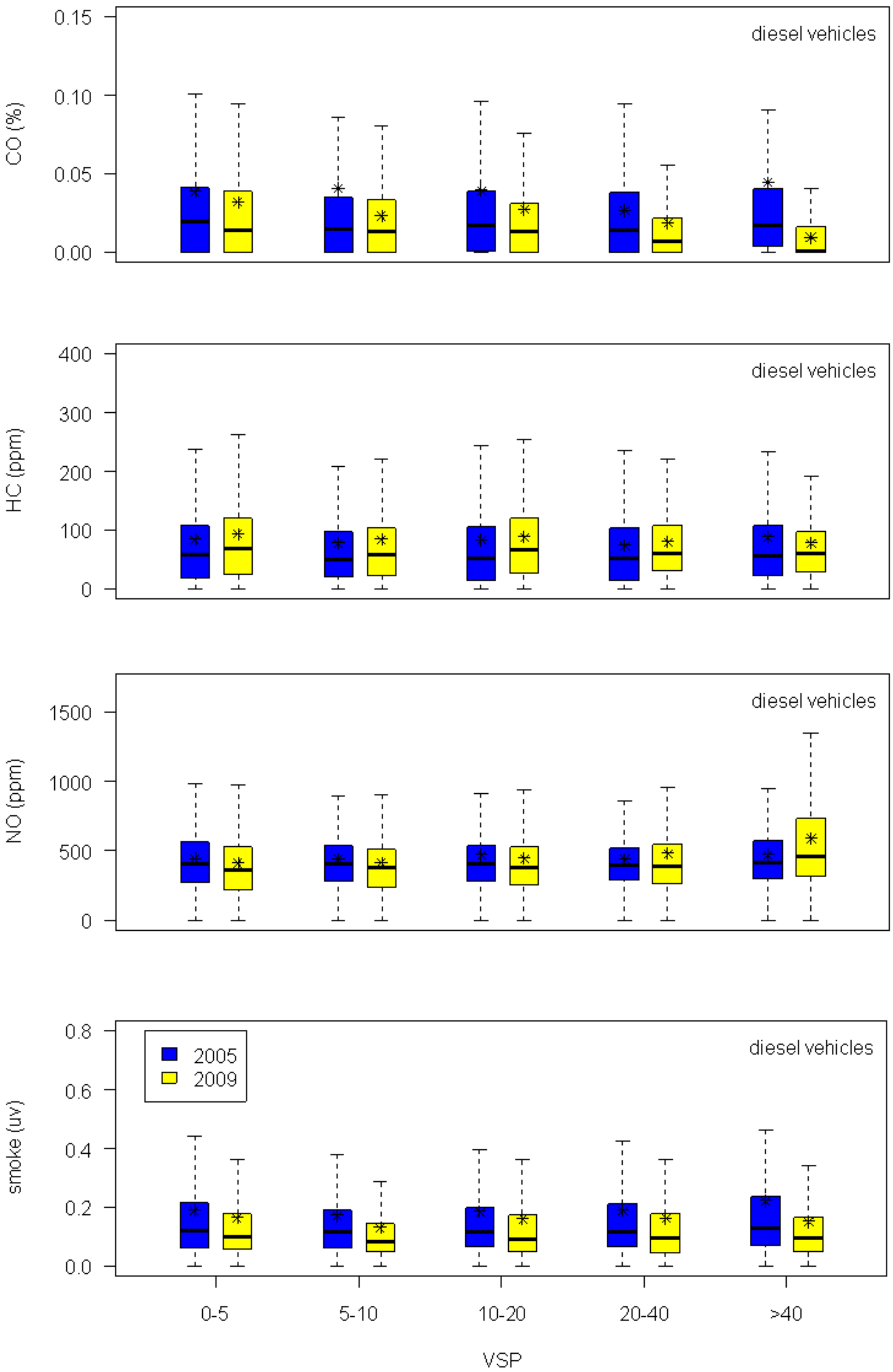


Table A1 Comparison of median and mean emissions by VSP bin for petrol vehicles in 2005 and 2009

Year	VSP range (kW/tonne)	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Median	Mean	Median	Mean	Median	Mean	Median	Mean
2005	0-5	0.166	0.578	52	221	206	599	0.018	0.061
2009		0.116	0.474	56	167	120	452	0.016	0.049
2005	5-10	0.165	0.616	55	222	243	675	0.021	0.065
2009		0.103	0.444	50	144	122	490	0.014	0.047
2005	10-20	0.172	0.618	55	217	248	675	0.02	0.062
2009		0.111	0.416	51	134	138	521	0.015	0.048
2005	20-40	0.157	0.629	49	218	254	683	0.019	0.061
2009		0.106	0.471	47	128	124	533	0.015	0.050
2005	>40	0.2505	0.860	76	403	324	726	0.029	0.086
2009		0.1305	0.735	47	124	123	522	0.017	0.059

Table A2 Comparison of median and mean emissions by VSP bin for diesel vehicles in 2005 and 2009

Year	VSP range (kW/tonne)	CO (%)		HC (ppm)		NO (ppm)		uvSmoke	
		Median	Mean	Median	Mean	Median	Mean	Median	Mean
2005	0-5	0.019	0.039	58	84	401	443	0.120	0.189
2009		0.014	0.032	68	93	359	413	0.098	0.165
2005	5-10	0.015	0.041	49	78	402	441	0.116	0.172
2009		0.013	0.023	58	84	380	416	0.081	0.131
2005	10-20	0.017	0.039	51	84	404	471	0.116	0.1851
2009		0.013	0.027	67	88	376	447	0.089	0.161
2005	20-40	0.014	0.027	51	74	397	439	0.117	0.190
2009		0.007	0.019	60	80	385	482	0.093	0.163
2005	>40	0.017	0.044	55	88	415	474	0.128	0.221
2009		0.001	0.009	60	78	454	588	0.094	0.151

Appendix B: Skewed (non-normal) nature of vehicle emissions data

This appendix illustrates the skewed nature of the of the RSD vehicle emissions data (ie it does not conform to a normal distribution) and why non-parametric statistical methods are used to analyse the data.

Figure B1 shows a box plot of CO emissions from petrol and diesel vehicles measured in the 2005 road-side vehicle emissions monitoring campaign. This box plot is a basic way of graphically showing the data are skewed towards high values. The horizontal red line shows the median (50th percentile), the horizontal blue lines of the box are the quartiles (25th and 75th percentiles). The whiskers extend to 1.5 times the inter-quartile range. Red + signs mark statistical outliers. The long stream of outliers above each box confirms the data is skewed to the right (ie the mean is biased towards high values).

Figure B1 Box and whisker plot of CO emissions from petrol and diesel vehicles

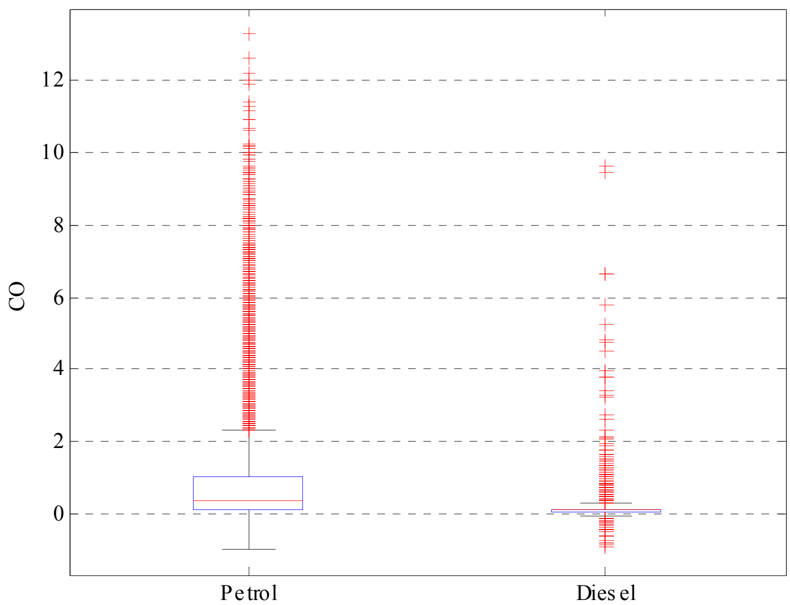
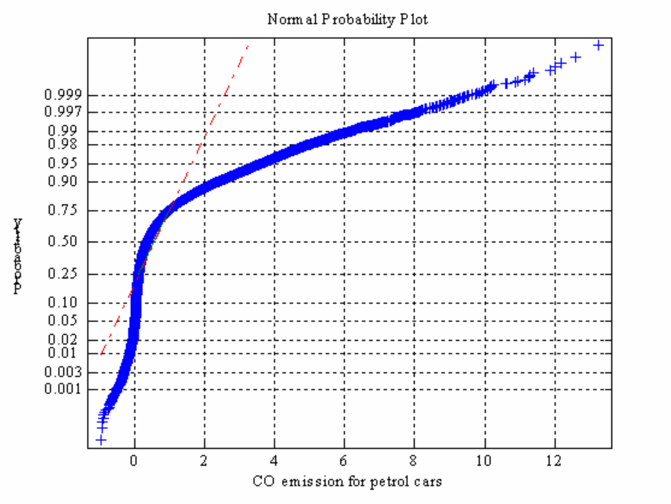


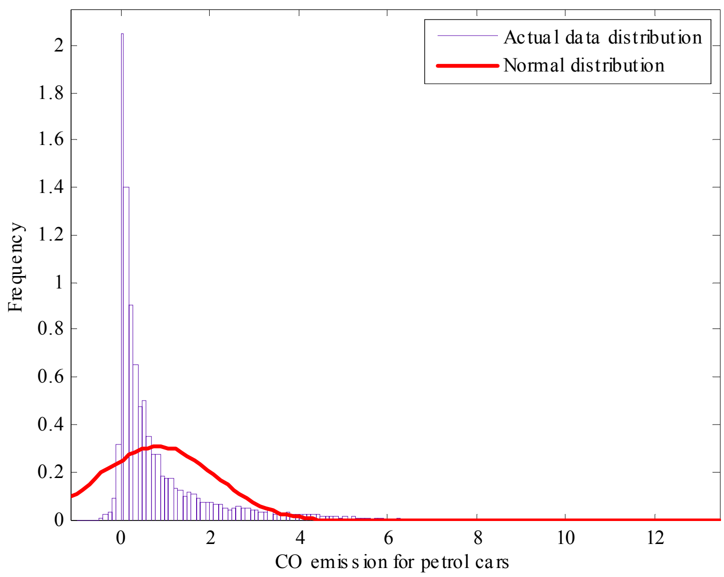
Figure B2 shows a normal probability plot for the CO emissions from petrol vehicles. A normal probability plot is a statistical way of comparing the actual distribution of the data to a normal distribution. If the data is normally distributed then the blue crosses should line up along the red line. For this dataset, the blue crosses deviate far from the red line so the data is not normally distributed.

Figure B2 Normal probability plot of CO emissions from petrol vehicles



A histogram is another way to show graphically the distribution of the data. Figure B3 shows a histogram for the CO emissions from petrol vehicles. The red line shows where the tops of the blue bars should come to if the data was normally distributed. The dataset peaks well to the left of centre of the normal distribution and has a long tail to the right. The distribution of the data is very different from a normal distribution.

Figure B3 Histogram of CO emissions from petrol vehicles



The Lilliefors test is another statistical test of whether the data is normally distributed or not. It evaluates the hypothesis that X has a normal distribution with unspecified mean and variance, against the alternative that X does not have a normal distribution. The Lilliefors test confirms that the vehicle emissions data is definitely not normally distributed.

Skewed datasets can be analysed using the Kruskal-Wallis (K-W) test (a non-parametric[5] one-way analysis of variance). This test does not assume that the data comes from a *normal* distribution (though 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 that the observed differences could occur purely by chance.

With large data sets the K-W test can sometimes detect differences that could be considered practically insignificant. To address this issue the positive K-W test results were cross checked using the Mann-Whitney (M-W) test.

A set of example results for the K-W and M-W tests for significant differences is provided in appendix C. The significance level used in this report for all K-W and M-W tests was 95%.

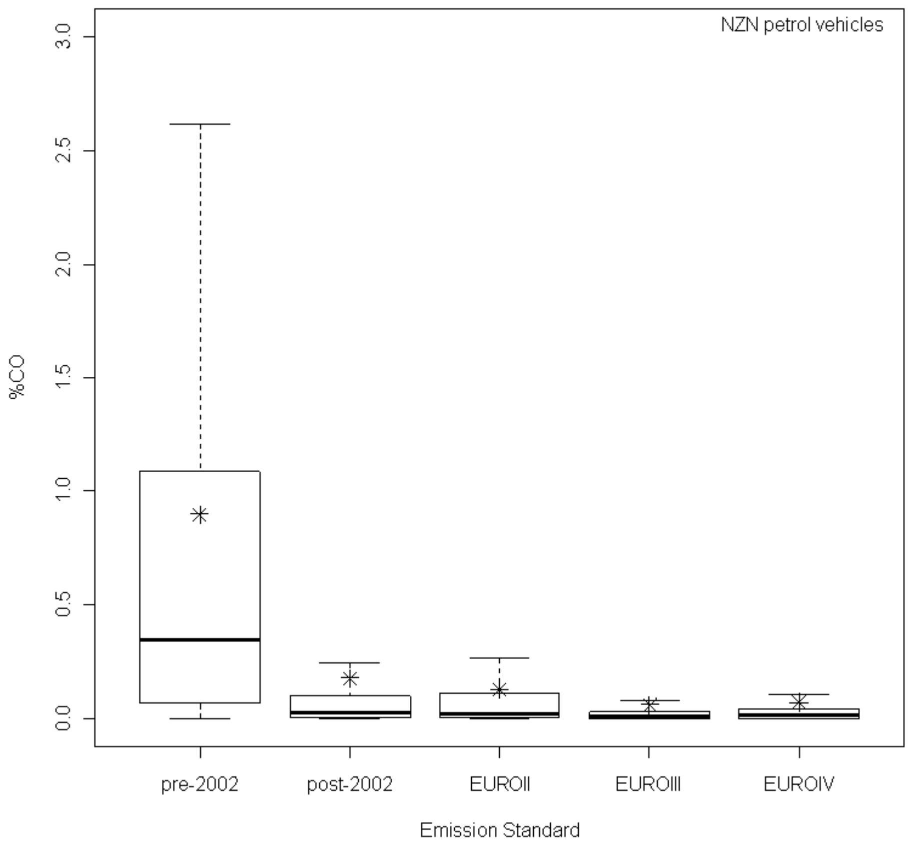
[5] A parametric test is a statistical test that depends on an assumption about the distribution of the data, eg that the data is normally distributed. Therefore a *non*-parametric test does not rely on having to know the distribution of the data in advance.

Appendix C: Example results for the Kruskal-Wallis and Mann-Whitney tests for significant differences

In the body of this report, the Kruskall-Wallis (K-W) test was applied to each analysis to establish whether the results presented were indeed significantly different or not. The K-W results were then cross checked using the Mann-Whitney (M-W) test. However, for the sake of brevity, the actual K-W and M-W analyses for each were not presented in the report. This appendix takes one example and shows what the corresponding K-W and M-W analyses look like to indicate how the conclusions in the text were reached.

Figure C1 repeats figure 5.1 and compares various emissions by emissions standard build.

Figure C1 Comparison of 2009 NZN petrol fleet emissions by emissions standard



The results presented in figure C1 suggest that CO emissions from pre-2002 NZN petrol vehicles are significantly higher than vehicles manufactured post-2002 and Euro 2 vehicles, which in turn are significantly higher than Euro 3 and Euro 4 vehicles.

In order to test whether these apparent differences are statistically significant, the data is subjected to the Kruskal-Wallis test, as shown in the matrix plots summarised in table C1.

Table C1 Multiple comparison Kruskal-Wallis test: for p = 0.05

	Pre-2002 obs. diff. (critical diff.)	Post-2002 obs. diff. (critical diff.)	Euro 2 obs. diff. (critical diff.)	Euro 3 obs. diff. (critical diff.)	Euro 4 obs. diff. (critical diff.)
Pre-2002		2819 (197)	2959 (366)	3901 (231)	3607 (374)
Post-2002			140 (372)	1082 (241)	788 (380)
Euro 2				942 (391)	648 (489)
Euro 3					294 (399)
Euro 4					

When the observed difference (obs. diff.) is greater than the critical difference (critical diff) the two sets of data are significantly different at the 95% confidence interval (red squares). Conversely when the observed difference is less than the critical difference the difference between the two sets of data is not significant at the 95% confidence interval (green squares).

Table A3.2 Mann-Whitney cross check of positive K-W test results for p = 0.05

	Pre-2002	Post-2002	Euro 2	Euro 3	Euro 4
Pre-2002		TRUE	TRUE	TRUE	TRUE
Post-2002			FALSE	TRUE	TRUE
Euro 2				TRUE	TRUE
Euro 3					FALSE
Euro 4					

Figure C1 and tables C1 and C2 all confirm that the emissions of CO from:

- pre-2002 vehicles are significantly higher than all other emissions standard builds
- post-2002 and Euro 2 vehicles are significantly lower than pre-2002 vehicles
- Euro 3 and Euro 4 vehicles are significantly lower than all other emissions standard builds.

Glossary

AQNES	National Environmental Standards for Air Quality
ARC	Auckland Regional Council
CO	Carbon monoxide, a type of air pollutant
CO_2	Carbon dioxide, a type of greenhouse gas
Gross emitter	Vehicle whose emissions fall in the top 10% of the readings for the fleet it is part of
GVM	Gross vehicle mass, kg
HC	Hydrocarbons, a type of air pollutant
HDV	Heavy duty vehicle, usually with a GVM over 3500kg
IM240	The IM240 test is a chassis dynamometer schedule used for emissions testing of in-use light duty vehicles in inspection & 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
LDV	Light duty vehicle, usually with a GVM under 3500kg
MED	NZ Ministry of Economic Development
MfE	NZ Ministry for the Environment
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
M-W test	Mann-Whitney test of significant difference
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 eg mg/kg or by volume eg 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