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Auckland Vehicle Fleet Emission Measurements 2005:

The Big Clean Up "Tune Your Car" Campaign

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Auckland Vehicle Fleet Emission Measurements 2005:

The Big Clean Up "Tune Your Car" Campaign

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Prepared for
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… and the motorists of Auckland.

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Executive Summary

Remote sensing was undertaken in 2005 by the Auckland Regional Council (ARC) to measure exhaust emissions of a large number of vehicles in "real world" situations. Motor vehicles are the largest single cause of Auckland's air pollution, contributing between 50 and 80 per cent of the emissions depending on the pollutant. Understanding how these emissions are changing over time is critical as it highlights whether additional strategies and policies might be required to meet reduction targets. We use emissions models, laboratory testing and fleet profiles to estimate vehicle emissions and we use ambient monitoring to measure the levels of air pollutants in Auckland's air. However, we also need to check whether our emissions estimates are realistic by measuring emissions in the 'real world' vehicle fleet. Laboratory testing can only measure a small number of vehicles and does not tell us about the 'gross emitters' or how the vehicle fleet emissions change over time. Remote sensing of vehicle emissions is a cost effective method for achieving all of these objectives. Therefore, in May and June 2005 the ARC commissioned the National Institute of Water and Atmospheric Research Ltd (NIWA) to undertake remote sensing of vehicle exhausts at a number of sites in the region, in conjunction with an education campaign undertaken by the ARC. This was an update of an earlier study undertaken in 2003. This report describes the results of the 2005 measurement campaign and includes comparisons with the earlier campaign.

The main objectives of the 2005 remote sensing campaign were to:

- identify the factors that most strongly influence vehicle emissions;
- characterise "gross emitting" vehicles;
- evaluate the effect of socio-economic factors on vehicle emissions;
- assess trends in vehicle emission with time; and
- provide drivers with immediate feedback of their emissions through use of a "smart sign".

The road-side monitoring took place over the period 18 May to 30 June 2005 at a total of 23 sites across the Auckland region. Approximately 73,000 vehicles passed through the monitor, yielding valid results for just over 49,000 vehicles.

The main conclusions from this work were that:

- Diesel vehicles had higher emissions of nitric oxide (NO) and smoke than petrol vehicles, whereas petrol vehicles had higher emissions for carbon monoxide (CO). Both had similar emissions of hydrocarbons (HC).
- The main factors influencing vehicle emissions were the year of manufacture, fuel type and the make of the vehicle. The order of importance for each of these factors was different for each pollutant.
- The diesel vehicle fleet had a higher proportion of gross emitters of particulate matter than petrol vehicles, whereas petrol vehicles were more likely to be gross emitters of CO, NO and hydrocarbons.

- Older vehicles were more likely to be gross emitters, but some new vehicles were also gross emitters.

- Petrol vehicles owned by people living in more socially deprived areas were more likely to have higher emissions.

- The results suggest that, with the exception of NO, emissions from the petrol and diesel fleets are improving with fleet changes (i.e. newer less polluting vehicles entering the fleet), technology and fuel improvements. However, it is recommended that further investigation be undertaken to firm up these conclusions.

The comparison between the results of this campaign in 2005 and the earlier one, undertaken in 2003, highlights the advantages of regular remote sensing. The information assists with confirming whether real-world emissions are reducing and, if so, whether it is at a rate fast enough to meet reduction targets. In addition, the data bring to light trends in fleet characteristics, such as increases in the proportion of diesel-fuelled vehicles, which can be used to predict likely future emissions.

The principal recommendation of this work is that remote sensing be conducted on a regular basis using the same equipment at a frequency of at least every two years. Overseas, other agencies have adopted annual surveys but it would still be valuable to repeat monitoring less frequently if funding is limited.

In the 2005 campaign, the monitoring was combined with public education initiatives. From the high level of awareness generated, it would be beneficial to run a combined campaign in future. Involving the public through education is more likely to secure buy-in for any policies that are triggered by the monitoring, as the public will have a greater appreciation of the problem and how they can contribute to its solution.

The results address a critical gap in our understanding of what the "real-world" vehicle fleet emissions are in Auckland and how they are changing with time. This information will be used not only to flag if additional vehicle emission reduction strategies and policies are required to meet national environmental standards and guidelines but also to indicate which sections of the fleet should best be targeted.

In conclusion, the 2005 "Big Clean Up Tune Your Car" remote sensing campaign has achieved its objectives and produced a valuable vehicle emissions database which will assist the ARC in developing and progressing their vehicle emission reduction policies and strategies.

Summary of key findings

Features of the 2005 fleet

- The average vehicle age in the 2005 sampled fleet was 9.2 years old. By comparison, the average vehicle age in the entire Auckland 2005 passenger fleet was 10.9 years.

- 83 per cent were petrol-fuelled vehicles and 17 per cent used diesel.

- Approximately half of the vehicles were New Zealand new with the other half being used vehicles imported from other countries (mainly Japan).
- The total mileage was highest for vehicles made in 1987-1988 but the rate of increase in mileage was higher for newer vehicles indicating they were driven further on average each year. The total mileage was less for older vehicles but this was probably due to these vehicles having been driven less on average in the past.

Factors that influence emissions

Vehicle emissions are determined by a large number of factors.

- Overall, the single most important characteristic was year of manufacture, which correlated strongly with emissions of CO, HC and NO, but less so for uvSmoke.
- Fuel type was important for three of the pollutants, but not for hydrocarbons.

For the individual pollutants, the most influential factors ranked in order of importance were:

- For CO - year of manufacture, fuel type, vehicle make and engine power.
- For HC - year of manufacture, vehicle make, engine size, gross vehicle mass and engine power.
- For NO - year of manufacture, vehicle make, fuel type and gross vehicle mass.
- For uvSmoke - fuel type, year of manufacture, vehicle make and engine power.

Characterisation of "gross emitters"

The total emissions from the on-road fleet tend to be dominated by a small number of vehicles with very high emissions known as "gross emitters". The specific characteristics which were most strongly associated with gross emitters were:

- For CO - older (pre-1998), small to mid-sized (less than 2275cc) petrol-fuelled vehicles.
- For HC - older (pre-1998), smaller (less than 2158cc and less than 95kW) vehicles of both fuel types.
- For NO - either older (pre-1998), small to mid-sized (less than 2400cc) vehicles of both fuel types or newer (manufactured post 1997) petrol-fuelled vehicles.
- For uvSmoke - low powered (less than 60kW) diesel vehicles or heavy (greater than 4,000kg) diesel vehicles.

Effect of social deprivation index

- People from less deprived areas tended to own newer vehicles but this trend was not as strong as might have been anticipated.
- People from more deprived areas were more likely to own diesel vehicles.
- For petrol vehicles, emissions of all four pollutants were significantly higher from vehicles coming from more deprived areas.
- For diesel vehicles, there was no evidence of statistically significant correlations for any of the four pollutants relative to the social deprivation index of vehicle owners.

Trends from 2003 to 2005

- The average vehicle age and proportion of imported used vehicles in both campaigns were more or less unchanged at nine years and 50 per cent respectively.
- The proportion of diesel vehicles in the measured fleet increased from 15 to 17 per cent.
- Petrol vehicle fleet emissions reduced for CO, HC and uvSmoke, but increased for NO.
- Diesel vehicle fleet emissions reduced for CO, uvSmoke and, to a lesser extent, HC but increased for NO.
- Potential factors that contributed to the changes in emissions included:
- Although the average age of both fleets was similar, the average year of manufacture was two years younger for the 2005 fleet (1996 versus 1994 for 2003).
- Fuel specifications were tightened in early 2004 to reduce sulphur in diesel and benzene in petrol. At the same time, minimum emissions standards came into force requiring all new vehicles (diesel or petrol) to be Euro 2 compliant.
- There was also a change in the technique used to measure particulate emissions between 2003 (opacity) and 2005 (uvSmoke). The uvSmoke technique tends to give higher values than the opacity measurement.

The comparison of the 2003 and 2005 emissions data suggests that, with the exception of NO, emissions from the petrol and diesel fleets are improving with “business as usual” fleet trends and technology and fuel improvements. However, further investigation is needed to confirm the trends observed in NO emissions and firm up the conclusions on trends in emissions with time.

Outcomes of the education campaign

The 2005 remote sensing campaign was conducted in tandem with an education campaign highlighting to motorists the importance of tuning their vehicles.

- In a follow up survey, 55 per cent of respondents recalled the campaign without being prompted. A further 14 per cent recalled it after prompting.
- Respondents were most likely to be aware that air pollution causes asthma and other respiratory problems, with 59 per cent citing this effect. This is consistent with the campaign messages that were used in the radio advertising and motorway billboards.
- Just over a quarter of respondents who were aware of the air quality campaign (26 per cent) stated that they had taken some action (e.g. tuned their vehicle) as a result of the campaign.

1 Introduction

1.1 Background

The Auckland region experiences a significant air quality problem, which affects the health of 1.3 million New Zealanders. Air pollution regularly exceeds guidelines and standards set to protect human health, on average more than 20 times per year. Motor vehicle emissions are the largest single cause of Auckland's air pollution, contributing between 50 to 80 per cent of the emissions depending on the contaminant (ARC, 2006), and are significant contributors to poor air quality in other urban centres across the country[1].

Recent research estimates that at least 236 Aucklanders die prematurely every year due to vehicle emissions (ARC, 2010). This is twice the number of deaths resulting from either road accidents or passive smoking. As well as premature deaths, vehicle pollution results in 368,000 days being lost region wide due to illness or poor health, especially in the young, the elderly and people with heart disease, respiratory disease, asthma and bronchitis.

Asthmatics are particularly sensitive to poor air quality and Auckland has one of the highest rates in the world, with a prevalence of one child in four (25 per cent) and one adult in six (17 per cent) (Asthma Foundation, 2009). Groups with the highest levels of exposure include people who live near busy roads or who ventilate their residences with air from road canyons with heavy traffic, road users (such as drivers, commuters and pedestrians) and people whose jobs require them to spend a long time on the roads (WHO, 2005).

The average age of vehicles in New Zealand is higher than that in many other countries, with the national and Auckland 2003 fleets sitting at 12.0 years and 10.6 years respectively (Covec, 2005). Unusually, "new entrants" to the New Zealand fleet are not confined to brand new vehicles but also include a significant number of used imported vehicles (largely from Japan). These used imports arrive at a rate of approximately 150,000 vehicles per year with an average age of 10 years and cause the fleet age profile to show a marked bi-modal distribution.

Coming from well behind the rest of the developed world in terms of fuels and emissions standards in 1995, New Zealand has progressively built up momentum to the point to where the gap between it and the rest of the world has shrunk considerably. Major progress has been made in fuels and technology, with sulphur levels in diesel now at Euro 4 and new vehicles being required to meet a strict schedule of improving emissions standards.

Effective management of vehicle emissions in any urban environment is a challenge. Regardless of whether a person owns a car or not, they have an opinion as to who the

[1] Note, however, that wood burning for domestic home heating is a significant cause of particulate matter in air.

worst polluters are and whether the situation is improving. Overseas experience, especially in the United States, has shown that remote sensing is a very effective method for measuring the effect of gross emitters and assessing the state of the vehicle fleet (Cadle *et al.*, 2003).

1.2 Aims and objectives of the study

Remote sensing has been employed in Auckland in two separate campaigns – one in 2003 and one in 2005 - to measure exhaust emissions of a large number of vehicles in "real world" situations.

In 2003, the ARC commissioned an on-road remote sensing study to investigate emissions from the fleet on the road network. The monitoring was carried out by the National Institute of Water and Atmospheric Research Ltd (NIWA), with assistance from the University of Denver, USA, who developed the original technique in the early 1990s. The aim was to obtain emissions information for up to 40,000 vehicles, sampling across a wide sector of the fleet and therefore acquiring a representative profile of vehicles in the Auckland region. The measured pollutants included:

- carbon monoxide (CO);
- hydrocarbon (HC);
- carbon dioxide (CO_2);
- nitric oxide (NO); and
- opacity (as a qualitative indicator of particulates).

Remote sensing was repeated in 2005 as part of a wider "Big Clean Up - Tune Your Car" education campaign run by the ARC. The objectives of this vehicle emissions monitoring campaign were to:

- extend the coverage of monitoring sites used in 2003;
- provide drivers with immediate feedback of their emissions through use of a "smart sign";
- measure vehicle particulate emissions more accurately (based on an improved measurement of uvSmoke);
- identify the factors that most strongly influence vehicle emissions;
- characterise "gross emitting" vehicles;
- evaluate the effect of socio-economic factors on vehicle emissions; and
- assess trends in vehicle emission with time.

As in 2003, emission results of CO, CO_2, NO, HC and opacity (as uvSmoke) were recorded along with license plate details. For each vehicle in the 2005 dataset, the owner's address was also assigned a social deprivation index score (SDI), based on census data, enabling a match between socio-economic factors and vehicle emissions.

This report is part of a suite of technical reports that have been (or are currently being) prepared by the ARC on vehicle emissions. For additional information, please refer to:

- On-Road Remote Sensing of Vehicle Emissions in the Auckland Region, Technical Publication 198, August 2003
- Vehicle Emissions Prediction Model version 3.0, February 2009
- Remote Sensing of Vehicle Emissions: Light and Heavy Duty Diesel Vehicles, technical report in preparation.

1.3 Structure of the report

This report is structured as follows:

- Chapter 2 outlines the equipment, sites and analysis techniques used in the 2005 campaign.
- Chapter 3 summarises the main features of the 2005 fleet in terms of vehicle characteristics and overall emissions results.
- Chapter 4 explores the factors that have the most influence on vehicle emissions, which vary depending on the contaminant.
- Chapter 5 characterizes the key features of the "gross emitting" vehicles in the 2005 fleet.
- Chapter 6 assesses the effect of social deprivation index on vehicle emissions.
- Chapter 7 compares the results for the 2005 fleet and its emissions versus the 2003 data to establish any trends.
- Chapter 8 presents a summary of results.
- Chapter 9 presents the conclusions and recommendations.

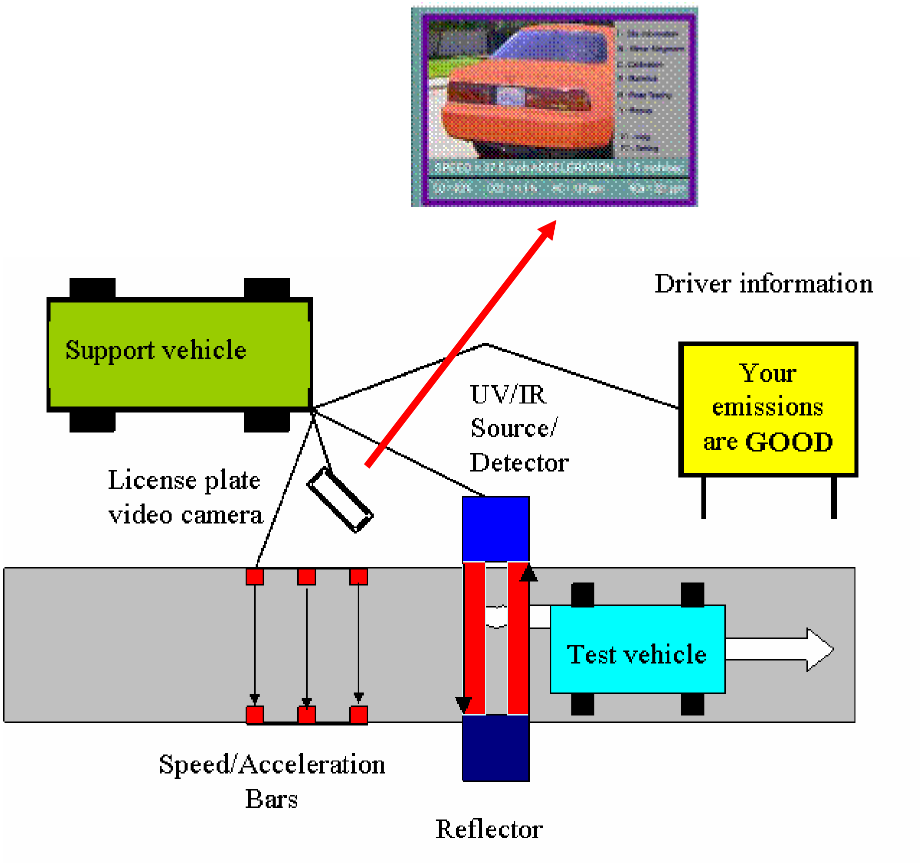
2 Method

2.1 Remote sensing equipment

The remote sensing device (RSD) used in this study was a RSD 4000EN model. The RSD system was developed by Donald Stedman and his team at the Fuel Efficiency Automobile Test Data Centre (FEAT), University of Denver, Colorado, USA.

Technical details on the RSD are provided in Stedman *et al.* (1997)[2]. A schematic diagram of the remote sensor monitoring equipment is shown in Figure 2.1.

Figure 2.1
Schematic diagram showing the remote sensing system in operation



[2] See www.feat.biochem.du.edu/whatsafeat.html

2.1.1 Measurement of gaseous pollutants

The instrument consists of an infrared (IR) component for detecting CO, CO_2 and HC, together with an ultraviolet (UV) spectrometer for measuring NO. The source/detector module (Figure 2.2) is positioned on one side of the road, with a corner cube reflector on the opposite side. Beams of IR and UV light are passed across the roadway into the corner cube reflector and returned to the detection unit. The light beams are then focused onto a beam splitter, which separates 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. The ratios of CO, HC or NO to CO_2 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 reports 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[3].

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 only measuring NO. The purpose of this report is to present the results of the emission-testing programme and will only refer 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. With a scattering configuration and an appropriate wavelength(s), and after making some realistic assumptions about particle properties (e.g. particle composition and size distribution), the smoke measurements are translated into particulate measurement units which approximate to grams of particulate per 100 grams of fuel burned. A fuel-based emission 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.

[3] See www.rsdaccuscan.com

Cautionary note 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 that 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 via 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 main purpose of this report is to assess the relative difference in emissions from vehicles of different ages and types. The RSD uvSmoke data suit this purpose very well. 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.

2.1.3 Calibration and audit

The purpose of the calibration and audit procedure is to ensure that the quality of the data collected meets specified standards. Quality assurance calibrations and audits are performed in the field as required by the standard operating procedures defined by the equipment's manufacturers.

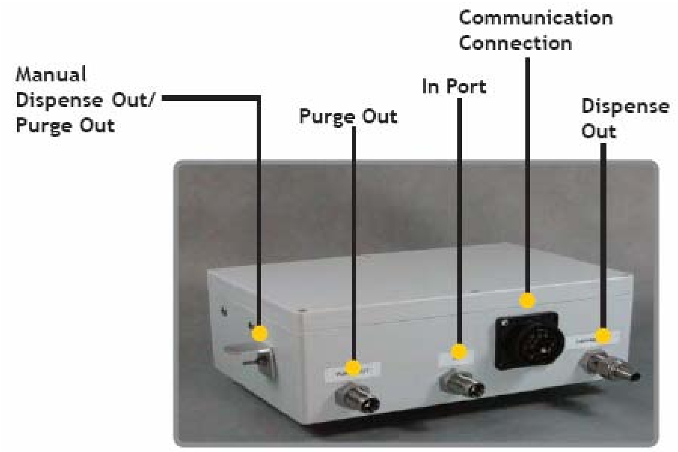
When the source detector module (SDM) has been switched on and is warmed up, the unit is calibrated. Calibration is carried out using a method named cell calibration. A cell which contains a known concentration of calibration gases is placed in the IR beam path and the SDM is then calibrated to the known values of gas within the cell.

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

Audits are carried out by the computer verified audit (CVA) system which employs a gas puff method. This method involves 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 is mounted on the detector window of the SDM. The measured gas ratios from the instrument are then compared to those certified by the cylinder manufacturer. If the gas ratios measured during any of the audits do not fall with specified limits or if the alignment of the unit has been changed, the RSD must be recalibrated and the audit process begun again.

The audits account 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 is used to calibrate the instrument, all hydrocarbon measurements reported by the unit are given as propane equivalents.

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



2.1.4 Vehicle, speed and acceleration data

The RSD 4000EN system includes a module to record the speed and acceleration of each vehicle when its emissions are measured (Figure 2.4). This provides valuable information about the driving conditions of the vehicles at the time of the measurements. The speed and acceleration measurements can also be 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 VSP is provided in Appendix 4: Calculation of Vehicle Specific Power.

The emissions dataset from a vehicle is only considered valid if its VSP falls between zero and 40 kW/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 is useful to have a performance measure (e.g. VSP) to screen out measurements of vehicles operating in enrichment mode.

Figure 2.4
The speed and acceleration bar (see arrows) in the remote sensing system

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

In the 2005 study, the cut off points[4] were set at:

- "Good" - emissions ≤ 0.64 %CO, ≤ 378 ppm HC, and ≤ 1,260 ppm NO. Vehicles with an emission reading for any single contaminant greater than these values were evaluated against the "fair" criteria.
- "Fair" - emissions 0.65-3.39 %CO, 379-959 ppm HC, and 1,261-2,677 ppm NO. Vehicles with an emission reading for any single contaminant greater than these values were evaluated against the "poor" criteria.
- "Poor" – emissions ≥ 3.40 %CO, ≥ 960 ppm HC, and ≥ 2,678 ppm NO. Vehicles receiving a "poor" emissions rating are considered to be "gross emitters".

2.1.6 Vehicle information

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

For the 2005 study, the list of licence plates were submitted to Land Transport New Zealand's vehicle registration database (Motochek) and information obtained for each vehicle.

[4] In 2003, the cut off points were slightly higher as follows:

- "Good" - emissions ≤ 1.05 %CO, ≤ 490 ppm HC, and ≤ 1,463 ppm NO
- "Fair" - emissions 1.06 -3.67 %CO, 491-1,270 ppm HC, and 1,464-3,112 ppm NO.
- "Poor" – emissions ≥ 3.68 %CO, ≥ 1,271 ppm HC, and ≥ 3,113 ppm NO

Table 2.1 lists the relevant information that was obtained on the monitored vehicles from Motochek for this project.

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

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

In this study the remote sensor was operated on single lane motorway 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. Figure 2.8 shows the remote sensing system in operation at a sampling site.

Figure 2.8
The remote sensing system set up at a sampling site

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

Approvals and advice were sought and obtained from all relevant roading and traffic control authorities. In Auckland, these authorities included the relevant city council when monitoring was being undertaken on local road networks and Transit New Zealand 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 that the operational procedures worked well. No incidents or accidents were reported.

2.1.8 Benefits and limitations of RSD monitoring programmes

Typically, vehicle emission data are obtained by putting selected vehicles on a chassis dynamometer, running them through a simulated drive cycle and collecting the exhaust stream for analysis with a bank of gas and particulate analysers. From these measurements, extrapolations are made to the whole fleet, or to particular scenarios. Studies, (e.g. Walsh *et al.*, 1996), however, show that such methods tend to under-estimate real-world emissions. 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. However, the main reason is that the bulk of real-world emissions generally come from a small proportion of vehicles known as the "gross emitters" and it is difficult to capture 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 to a dynamometer testing programme which tests a pre-selected fleet tested in a simulated drive cycle. The RSD monitoring takes less than one second per vehicle and up to 2,000 vehicles can be sampled each hour. This compares to approximately 30 minutes to complete a single IM240 set up 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 emission data collected by the RSD compared to the data collected using a dynamometer and analyser set up. 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 in time (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 monitored will reflect driving conditions that predominate on these types of roadway and will not necessarily be representative of emissions generated on other roadway types, e.g. at busy intersections.
- The measurement of particulate emissions using open path technology is problematic, as discussed in Section Measurement of particulate pollutants, 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.

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 taken large strides forward since the initial stages of development in the early 1990s when the pollutants that were monitored were restricted to CO and HC, and neither the vehicle's speed nor acceleration were measured. 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, US, Australia and New Zealand. The RSD is employed by a number of environmental authorities in the US to enforce and assess the effectiveness of vehicle inspection and maintenance programmes (e.g. Bishop and Stedman, 2005). The California Air Resource Board (CARB) has evaluated remote sensing for improving California's Smog check programme (CARB, 2008). RSD data has been used to assist in evaluation of Denver's vehicle emissions inventory (Pokharel *et al.*, 2002).

Cautionary note on measuring emissions from heavy duty diesel vehicles. Some heavy duty diesel (HDDs) vehicles with a gross vehicle mass (GVM) of greater than 3,500kg have vertical exhausts which discharge pollutants at or above cab height. In the configuration used in this study, the RSD is only capable of measuring emissions discharged at or about road level. Therefore the database of emission measurements collected in this project contains limited data for HDDs with a GVM of greater than 3,500kg.

2.2 Monitoring sites

2.2.1 Overall 2005 RSD campaign sites

The 2005 RSD monitoring campaign was carried out in May and June at 23 sites across the Auckland region. The general locations of these monitoring sites are shown in Figure 2.9, with further details provided in Table 2.2.

Figure 2.9

Map indicating locations of all monitoring sites used in the 2005 RSD campaign

Table 2.2

Details of all monitoring sites used in the 2005 Big Clean Up campaign

Site No	Site Name	Suburb	Date 2005	Site Code	Vehicles Tested	Valid Tests	Capture Rate
1	Auckland Girls Grammar	Freemans Bay	3 June	AGG1	80	43	54%
2	St Heliers Bay Rd	St Heliers	24 May	AUC1	3,591	1,403	39%
3	Lagoon Dr	Panmure	23 May	AUC2	5,024	3,001	60%
4	Hayr Rd On Ramp	Hillsborough	10 June	AUC4	4,021	2,729	68%
5	West End Rd	Coxes Bay	25 May	AUC8	3,158	2,743	87%
6	Lynfield College	Lynfield	1 June	LYN1	217	105	48%
7	Lambie Dr (N)	Manukau	15 June	MAN1	3,252	1,726	53%
8	Lambie Dr (S)	Manukau	17 June	MAN2	2,742	1,982	72%
9	Takanini On Ramp	Takanini	20 June	MAN3	3,134	2,230	71%
10	Highland Park Dr	Pakuranga	29 June	MAN4	1,249	1,093	88%
11	Constellation Dr Off Ramp	Sunnynook	22 June	NOR3	5,854	3,850	66%
12	Greville Rd	Rosedale	28 June	NOR4	2,081	799	38%
13	Upper Harbour Highway	Meadowood	30 June	NOR5	4,487	3,302	73%
14	Elliot St	Papakura	2 June	PAP1	1,963	1,496	76%
15	Grand Dr (N)	Orewa	16 June	ROD1	2,673	1,893	71%
16	Grand Dr (S)	Orewa	18 May	ROD2	2,607	2,040	78%
17	Whangaparaoa Rd	Whangaparaoa	19 May	ROD3*	1,234	903	73%
	Whangaparaoa Rd	Whangaparaoa	26 May	ROD3*	6,022	3,241	54%
18	Rangitoto College	Mairangi Bay	23 June	RTC1	181	136	75%
19	Te Atatu North On Ramp	Te Atatu	13 June	WAI1	3,387	2,176	64%
20	Lincoln Rd On Ramp	Lincoln	8 June	WAI2	2,706	1,984	73%
21	Hobsonville Rd	Hobsonville	9 June	WAI3	3,944	2,898	73%
22	Parrs Cross Rd	McLaren Park	14 June	WAI4	4,669	3,849	82%
23	Universal Dr	Lincoln	7 June	WAI5	4,909	2,711	55%
Total					73,185	48,333	69%

* Note that the ROD3 site was repeated because monitoring was cut short on the first day resulting in fewer vehicles being sampled than expected.

2.2.2 Baseline sites

A subset of the 23 monitoring sites used in the 2005 campaign were classified as "baseline" sites. These were defined as sites that were used in both the 2003 and 2005 campaigns. The purpose of identifying baseline sites was to assess any changes in fleet emissions between 2003 and 2005. The 2003 and 2005 emission monitoring programmes involved 14 and 23 sites respectively. A total of 12 sites were monitored in both 2003 and 2005. The baseline site names and numbers of vehicles monitored are provided in Table 2.3.

Table 2.3

Baseline monitoring sites for the 2003 and 2005 RSD campaigns

Site Name (Code)	Total number of vehicles monitored at baseline sites in 2003	Total number of vehicles monitored at baseline sites in 2005
St Heliers Bay Rd (AUC1)	Approximately 31,000 (74% of vehicles monitored at all 2003 sites)	Approximately 22,000 (45% of vehicles monitored at all 2005 sites)
Lagoon Dr (AUC2)		
Lambie Dr (N) (MAN1)		
Lambie Dr (S) (MAN2)		
Takanini On Ramp (MAN3)		
Highland Park Dr (MAN4)		
Upper Harbour Highway (NOR5)		
Elliot St (PAP1)		
Grand Dr (N) (ROD1)		
Grand Dr (S) (ROD2)		
Te Atatu North On Ramp (WAI1)		
Lincoln Rd On Ramp (WAI2)		

2.2.3 Driver education sites

Three schools took part in a driver education component of the Big Clean Up campaign (see Appendix 1: The "Big Clean Up" air education campaign for more details).

The RSD system was set up at Lynfield College, Auckland Girls Grammar and Rangitoto College for a day each. This was advertised to the pupils, their parents, teachers and the local community who were encouraged to take their cars through. The opportunity was also taken to explain the science behind the equipment to pupils, e.g. all Lynfield College students came down to see the monitor during the day. Two of the ARC's Air Quality team and a NIWA technician provided an overview of the instrument and discussed air pollution in Auckland.

2.3 Statistical tools and techniques for data analysis

2.3.1 Limitations of previous "standard error" analysis undertaken in 2003

Emissions data from vehicles do not conform to a normal distribution. They are highly skewed with many low values and relatively few high values. The skewed nature of the vehicle emission data set collected is further explained in Appendix 2: Skewed (non-normal) nature of vehicle emission data.

In 2003, data were compared using the average value and the standard error. The calculation of the 'average' and 'standard error' are sensitive to outlying data points so can be misleading when applied to a skewed dataset. The standard error method does give an indication of the comparative ranges of the data but does not give a defensible conclusion as to whether or not any difference is statistically significant. For this reason, analysis of the data using parametric statistical methods was not repeated.

For the 2005 campaign, 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 test of significant differences was used because it handles the skewed nature of the data and provides statistically defensible conclusions.

2.3.2 Treatment of negative RSD data

As with all scientific instruments, the RSD is not perfectly precise and there is some uncertainty or error associated with the data that it records, e.g. 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 that 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" that is contained within the data that the RSD instrument produces.

Ordinarily the negative data are left in the data set as is, however, in this study negative data were converted to zero. This conversion was undertaken to assist with the ease of data display within the report and to simplify reader interpretation of results. The conversion of negative data to zero does create a slight positive bias (<2%) in the mean values. However, the statistical methods used in this study are based on median values, which are not affected by the conversion of negative data to zero. Therefore, the conversion of negative data to zero has no significant affect on the results displayed or conclusions drawn in this report.

2.3.3 Kruskal-Wallis test for significant differences

Skewed datasets like emissions data (see Appendix 3) can be analysed using the Kruskal-Wallis (K-W) test which is a non-parametric one-way analysis of variance[5]. This test does not assume that the data come from a *normal* distribution but it does assume that all data come 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.

The results from the K-W test can be displayed as boxes for visual comparison (e.g. Figure 3.7). If the boxes of two groups that are being compared do not overlap, then the two groups are statistically significantly different. The significance level used for all K-W tests in this report was 95 per cent (i.e. $p = 0.05$).

2.3.4 Tree models (multivariate regression trees)

Tree models were used in this project to identify the vehicle parameters that are most important in affecting emissions (see Section 4: What are the most important influences on vehicle emissions? and Section 5: Who are the "gross emitters"?).

Tree models are used to look for relationships in complex data with very few assumptions about data distribution and interactions between data categories. A tree model identifies which *predictor* variables explain the most variation in the response data.

In this project, the predictor variables were vehicle details such as fuel type, year of manufacture, mileage etc. The response variables were the vehicle emissions of CO, HC, NO and uvSmoke.

The tree model clusters the vehicles into groups with similar emission values using rules based on the predictor variables. A more detailed description about tree models is contained in Appendix 3: Description of multivariate regression trees. A full technical description of the method has been documented by De'ath and Fabricius (2000).

[5] A non-parametric one-way analysis of variance is a test which does not rely on having to know the distribution of data in advance.

2.4 The Big Clean Up air education campaign

The 2005 remote sensing campaign was conducted in tandem with an education campaign highlighting to motorists the importance of tuning their vehicles. The key objectives of the Big Clean Up air education campaign were to:

- put air quality front of mind for the Auckland public once again;
- show how individuals and businesses could take action; and
- help people understand what they could do to reduce air pollution.

The primary messages came from radio advertising, motorway billboards and a "smart sign" connected to the remote sensor which gave motorists an immediate indication of the state of their emissions.

Vehicles driving through the monitor were rated "good", "fair" or "poor", according to their exhaust emissions. Those motorists who received a "poor" rating were followed up with a letter from the ARC informing them that their car was causing pollution and might need tuning. They were encouraged to join The Big Clean Up whereby they would receive a 10 per cent discount on tune-ups from selected MTA members. Out of the total of 48,333 vehicles which drove past the monitor over seven weeks, 4,090 (8.5 per cent) received a "poor" rating. The proportion of "poor" readings was consistent with the previous monitoring that had been undertaken in 2003.

The 2005 campaign received a high level of awareness with the regional public:

- In a follow up survey, 55 per cent of respondents recalled the campaign without being prompted. A further 14 per cent recalled it after prompting.
- Respondents were most likely to be aware that air pollution causes asthma and other respiratory problems, with 59 per cent citing this effect. This is consistent with the campaign messages that were used in the radio advertising and motorway billboards.
- Just over a quarter of respondents who were aware of the air quality campaign (26 per cent) stated that they had taken some action (e.g. tuned their vehicle) as a result of the campaign.

Further details on the education campaign are in Appendix 1: The "Big Clean Up" air education campaign.

3 Features of the 2005 fleet

This section profiles the 2005 monitored fleet by presenting details on vehicle characteristics and pollutant emission parameters for petrol and diesel vehicles.

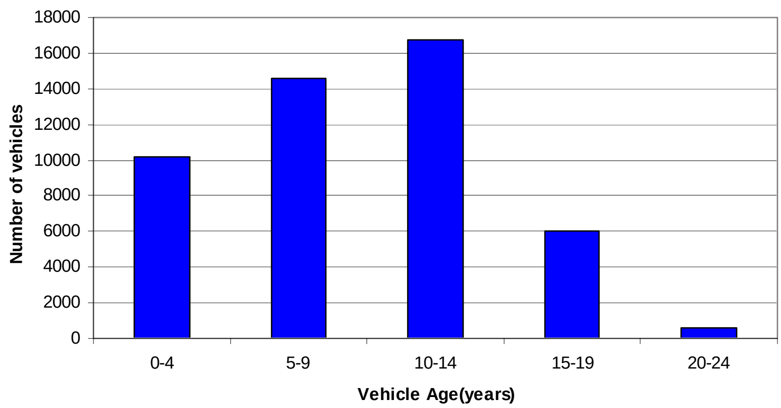
Dataset used for the analysis in this section: In total, records were available for 48,333 individual vehicles in the 2005 dataset. Of these, 48,242 were petrol- or diesel-fuelled with the remainder (91 vehicles) powered by other energy sources, e.g. LPG. The dataset included records for approximately 1,000 heavy duty vehicles.

3.1 Vehicle characteristics

3.1.1 Age and year of manufacture

The age of a vehicle is one of the primary factors that determine the quantity of pollutants discharged. For example, how worn the engine is and the type of emissions control technology that is installed tends to be well correlated with the age of a vehicle. Therefore, it is important to know the age of the individual vehicles that were monitored and to be able to profile the age of the monitored fleet. Year of manufacture is also important as it aligns with improvements in vehicle emissions control technology. Figure 3.1 and Figure 3.2 show the age and year of manufacture of the monitored vehicle fleet respectively.

Figure 3.1
Age of vehicles monitored in 2005*



*48,333 vehicles average age = 9.2 years

The two figures show that the average vehicle was manufactured in late 1998 and was 9.2 years old when monitored. By comparison, the average ages of vehicles in New Zealand's passenger vehicle fleet and the Auckland passenger fleet in mid 2005 were

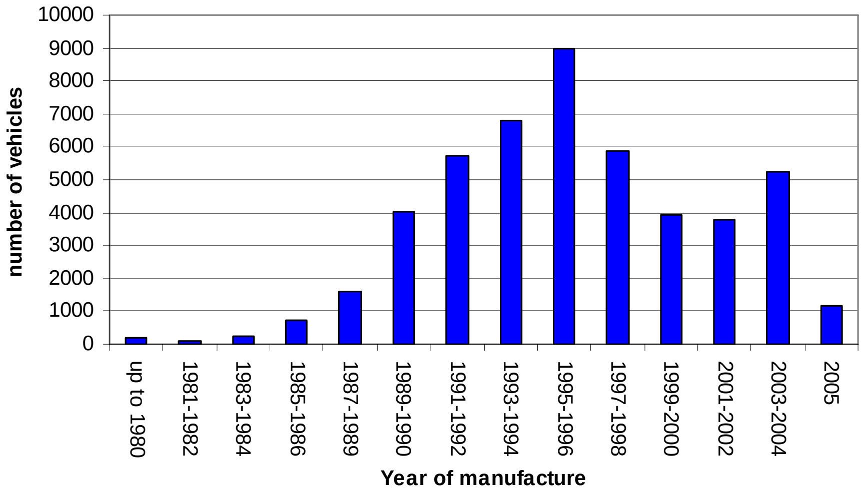
12.1 years and 10.9 years respectively (NZTA, 2009). The difference between the ages of the sampled and total fleet (more than 18 months) in Auckland was unexpected, but is an interesting observation that warrants exploration.

There are two main reasons that may explain why the monitored fleet was newer than the average age of vehicles registered in Auckland. Newer vehicles tend to be driven a greater number of kilometres each year than do older vehicles (MOT, 2010). Hence they have a greater chance of driving through a monitoring site than older vehicles that do fewer kilometres. Another possible explanation is that all monitoring sites were located in urban areas where the average age of vehicles may be lower than the region wide average that includes smaller towns and rural areas, where older vehicles may be more commonly used.

Figure 3.2 shows that year of manufacture of vehicles has a bi-modal distribution with peaks occurring in 1995-1996 and 2003-2004. The bi-modal pattern is due to the two points where vehicles enter the fleet. The first peak (1995-1996) is generated by Japanese imported used vehicles entering the New Zealand fleet at around seven years of age. The second peak (2003-2004) indicates the effect of new vehicles entering the fleet. Note that the monitoring campaign was undertaken in mid 2005 and hence the full influence of vehicles manufactured in that year is not evident in Figure 3.2.

Figure 3.2

Year of manufacture of vehicles monitored in 2005*



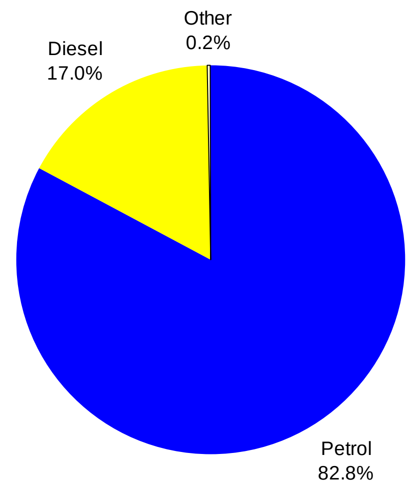
*48,333 vehicles. Average year =1995.8

3.1.2 Fuel type

The type of fuel used in a vehicle is another primary factor that determines the type and quantity of pollutants discharged. Figure 3.3 presents the breakdown of fuel types used by vehicles in the sampled fleet, showing 83 per cent of the vehicles used petrol and 17 per cent used diesel.

Figure 3.3

Distribution of fuel type used by vehicles monitored in 2005



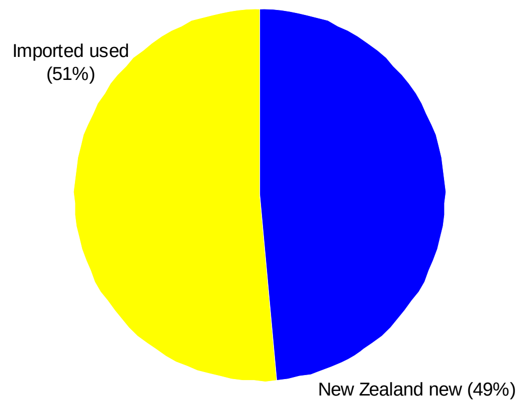
3.1.3 Country of first registration

Vehicles manufactured in different countries tend to be built to different emission control specifications. Therefore it is relevant to have an understanding of where the vehicles, which make up New Zealand's fleet, come from.

Figure 3.4 shows a breakdown of the fleet by the county of first registration. Approximately half of the vehicles monitored were New Zealand new and the other half of the vehicles entered the New Zealand fleet as used vehicles imported from other countries (mainly Japan).

Figure 3.4

Country of first registration of vehicles monitored in 2005

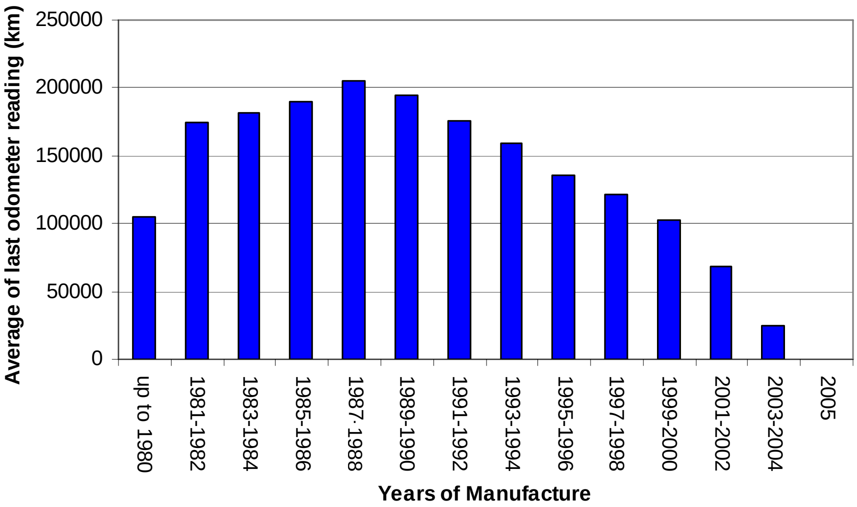


3.1.4 Mileage

As vehicles travel a greater number of kilometres, engines and emission control systems begin to wear and pollutant emissions tend to increase. It is therefore helpful to have an understanding of the number of kilometres that the monitored vehicles have travelled. Figure 3.5 shows the average total odometer reading (mileage) of the vehicles monitored by year of manufacture.

Figure 3.5

Odometer reading by year of manufacture for vehicles monitored in 2005*



*48,333 vehicles. Average odometer reading =127093 km

The average total mileage increased as vehicles got older, peaking at just over 200,000km for vehicles manufactured in 1987-1988. The rate of mileage increase was greater for newer vehicles (manufactured between 1999 and 2004) than for older vehicles (manufactured between 1989 and 1998). This indicates that newer vehicles tend to be driven further each year than older vehicles.

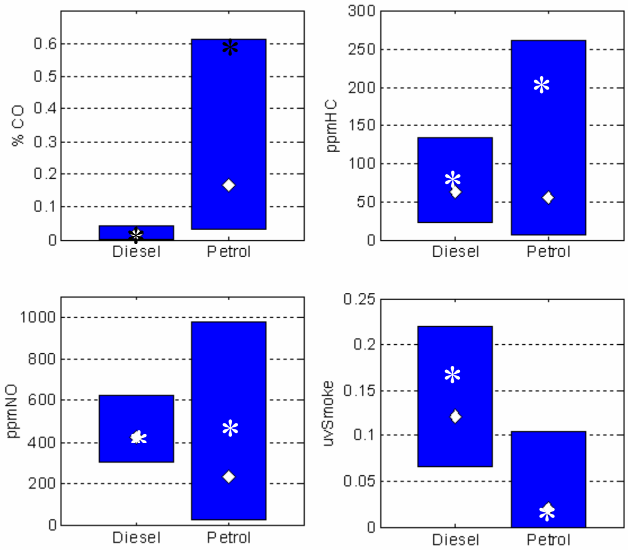
The opposite trend (lower odometer readings for older vehicles) was observed for vehicles manufactured before 1987. While this result may appear to be counter-intuitive, it can be explained. Vehicles are designed and built to drive a maximum number of kilometres. Once they have covered that number of kilometres they are worn out and retired from the fleet. A vehicle's useful life can be extended by good maintenance, but not indefinitely. Therefore the older vehicles that are still operational tend to be those that have travelled a relatively low number of kilometres and have not yet reached the end of their useful working life.

3.2 Emissions measurements

Figure 3.6 compares the emissions of CO, HC, NO and uvSmoke from the monitored petrol and diesel vehicle fleets. The median values are indicated by diamonds and the inter-quartile (25th to 75th percentile) range is noted by the box. The mean values are indicated by stars.

Figure 3.6

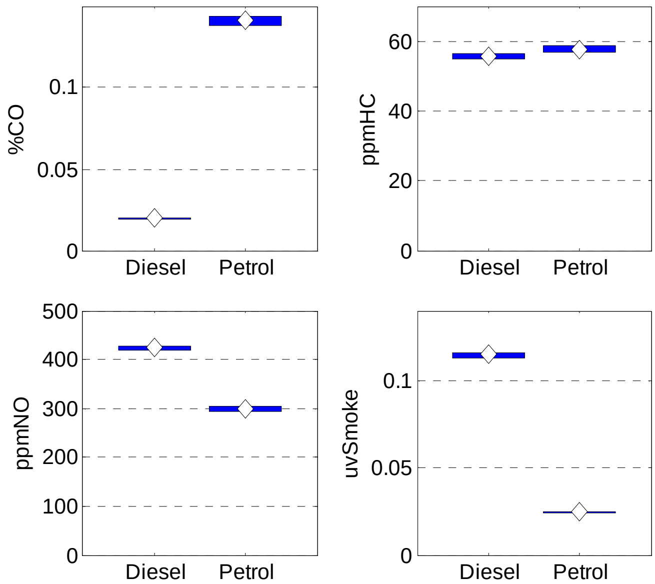
Medians, mean and quartiles for CO, HC, NO and uvSmoke emissions from the monitored fleet in 2005*



*For diesel and petrol-fuelled vehicles only, 48,242 data.

Figure 3.7 presents the results of the Kruskal-Wallis (K-W) test for significant differences at the 95th percentile confidence interval between emissions of CO, HC, NO and uvSmoke from the monitored petrol and diesel vehicle fleets. If the blue boxes within the K-W plots overlap the difference between the two data sets is not statistically significant. Conversely if the boxes do not overlap the difference between the two data sets is statistically significant. For further detail on K-W test refer to Section 2.3.2.

Figure 3.7
Kruskal-Wallis test results for CO, HC, NO and uvSmoke emissions from the monitored fleet in 2005



Note: For diesel and petrol-fuelled vehicles only, 48,242 data.

Figures 3.6 and 3.7 show that the:

- CO median values and concentrations across the petrol-fuelled fleet were significantly higher than diesel-fuelled fleet.
- HC median values and concentrations across the petrol- and diesel-fuelled fleets were similar.
- NO median values and concentrations across the diesel-fuelled fleet were significantly higher than petrol-fuelled fleet.
- uvSmoke median values and concentrations across the diesel-fuelled fleet were significantly higher than petrol-fuelled fleet.

The comparison of mean values (Figure 3.6) for CO and uvSmoke produce conclusions consistent with those reached using the median values and the K-W test, i.e. petrol vehicles tend to emit higher CO concentrations and diesel vehicles tend to have higher uvSmoke measurements. However, the mean values of HC and NO concentrations from the monitored petrol fleet are higher than the diesel fleet mean, i.e. petrol vehicles emit higher HC and NO concentrations than diesel vehicles. These outcomes appear to be inconsistent with the conclusions reached using the median values and the K-W test but for good reasons.

Unlike the median, the mean value is highly sensitive to extreme values. A small number of very high measurements will increase the mean value significantly. The HC and NO data sets for the petrol fleet data contain a small number of very high values that disproportionately influence (increase) the mean value. This explains why the outcomes of the comparison of petrol and diesel HC and NO concentrations using the mean and median values do not appear to be consistent. Due to the disproportionate influence of the small number of very high HC and NO petrol vehicle values, it is more appropriate to assess the statistical difference between the overall petrol and diesel fleet concentration profiles using the median values and K-W test rather than the difference in the mean values. Therefore, while the mean value is a useful indicator, the conclusions drawn in this section are based on the analysis undertaken using the median values and the K-W test.

3.3 Summary - features of the 2005 fleet

The road-side monitoring took place over the period 18 May to 30 June 2005 at a total of 23 sites across the Auckland region. Approximately 73,000 vehicles passed through the monitor during the monitoring campaign and a capture rate of 69 per cent was achieved. The monitoring campaign provided valid data for approximately 48,000 vehicles.

The average vehicle in fleet was manufactured in late 1998 and was 9.2 years old when monitored in 2005. In comparison the average age of the whole of the Auckland passenger vehicle fleet in mid 2005 was 10.9 years (NZTA, 2009). Across the sampled fleet, 83 per cent of the vehicles were petrol-fuelled and 17 per cent used diesel. Approximately half of the vehicles monitored were New Zealand new and the other half entered the fleet as used vehicles imported from other countries (mainly Japan).

The average total mileage increased as vehicles got older, peaking at just over 200,000km for vehicles manufactured in 1987-1988. The rate of mileage increase was greatest for new vehicles indicating that newer vehicles on average travel further each year than older vehicles. Paradoxically, the total mileage declined as vehicles got older than 1987 but this was most likely due to these vehicles having been driven less frequently on average in the past and therefore they were yet to reach the end of their operational life.

The CO median values and concentrations across the petrol-fuelled fleet were significantly higher than diesel-fuelled fleet. The median values for CO concentrations from monitored petrol and diesel vehicle fleets were approximately 0.16% and 0.03% respectively.

HC median values and concentrations across the petrol- and diesel-fuelled fleets were similar. The median values for HC concentrations from the monitored petrol and diesel vehicle fleets were approximately 50ppm and 60ppm respectively.

NO median values and concentrations across the diesel-fuelled fleet were significantly higher than petrol-fuelled fleet. The median values for NO concentrations from monitored petrol and diesel vehicle fleets were 200ppm and 400ppm respectively.

uvSmoke median values and concentrations across the diesel-fuelled fleet were significantly higher than petrol-fuelled fleet. The median values for uvSmoke measurements from monitored petrol and diesel vehicle fleets were 0.025 and 0.125 respectively.

4 What are the most important influences on vehicle emissions?

"What are the most important influences on vehicle emissions?" is an important question because the answer aids the understanding and modelling of the vehicle fleet emissions profile.

The amount of pollutants discharged by vehicles is determined by a large number of factors such as vehicle age, fuel type and distance travelled. Given the large number of factors and the even larger number of combinations and permutations of these factors it is a difficult problem to identify which factors have the largest influence on vehicle emissions.

The on-road vehicle emissions database contains emissions data on four different pollutants for approximately 48,000 vehicles, each of which is described by more than 20 different vehicle characteristics. Therefore this database provides a unique and very useful resource to help answer the question of "What are the most important influences on vehicle emissions?"

This section of the report presents the results of four interrogations of the vehicle emissions database and aims to identify which vehicle factors have the largest influence on emissions of CO, HC, NO and uvSmoke.

To achieve this aim regression tree models were fitted to each pollutant. Because of its skewed nature, the emission data were square root transformed for use in the models. A list of the 20 most relevant vehicle characteristics can be found in Table 2.1. A preliminary investigation identified the ten most influential predictor variables and these were used in the regression tree model. The ten predictor variables used in the analysis were: year of manufacture; fuel type; vehicle make; engine power; gross vehicle mass; odometer reading; engine capacity; monitoring location; purpose of vehicle use; and country of first registration (if not New Zealand new).

Dataset used for the analysis in this section: The regression tree models were fitted using all vehicles in the dataset that had valid information for all of the ten predictor variables (about 15,000 vehicles or 33 per cent of the monitored fleet).

4.1 Influences on CO emissions

A regression tree model was fitted to find which vehicle characteristics most strongly influenced CO emissions. The analysis (summarised in Figure 4.1) indicates that the vehicle characteristics that most strongly influenced CO emissions were:

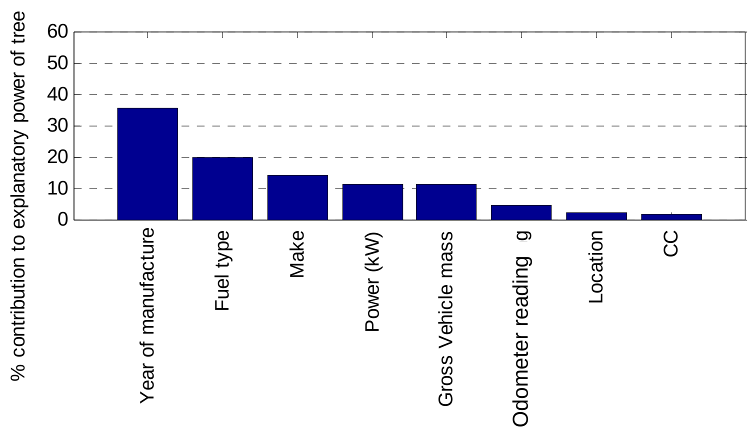
- year of manufacture;
- fuel type;
- vehicle make; and
- engine power.

Other characteristics that had weaker but still quantifiable influences included gross vehicle mass, odometer reading, engine capacity and monitoring location.

Country of first registration and purpose of vehicle use were not identified as having a measurable influence on emissions of CO.

Figure 4.1

Vehicle characteristics that most strongly influenced CO emissions



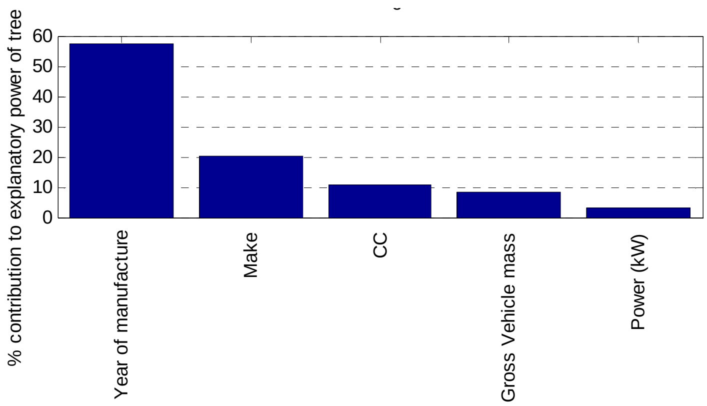
4.2 Influences on HC emissions

A regression tree model was fitted to find which vehicle characteristics most strongly influenced HC emissions. The analysis (summarised in Figure 4.2) indicates that the vehicle characteristics that most strongly influenced HC emissions were:

- year of manufacture;
- vehicle make;
- engine size;
- gross vehicle mass; and
- engine power.

Figure 4.2

Vehicle characteristics that most strongly influenced HC emissions



Fuel type, country of first registration, monitoring location, purpose of vehicle use and latest odometer reading were not identified as having a measurable influence on emissions of HC.

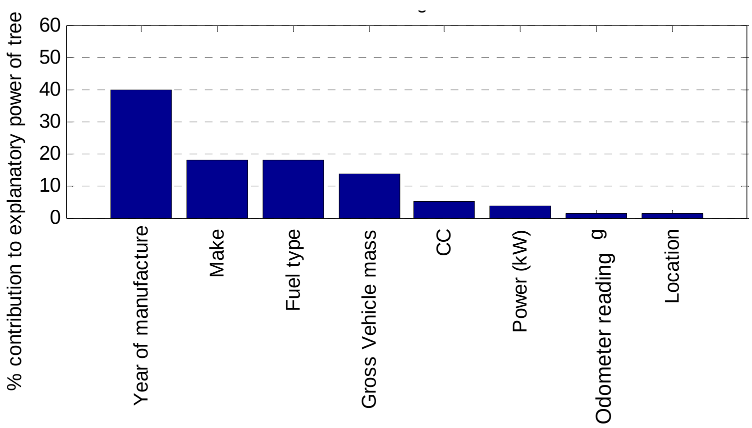
4.3 Influences on NO emissions

A regression tree model was fitted to find which vehicle characteristics most strongly influenced NO emissions. The analysis (summarised in Figure 4.3) indicates that the vehicle characteristics that most strongly influenced NO emissions were:

- year of manufacture;
- vehicle make;
- fuel type; and
- gross vehicle mass.

Figure 4.3

Vehicle characteristics that most strongly influenced NO emissions



Other characteristics that had weaker but still quantifiable influences included engine size, engine power, odometer reading and monitoring location.

Purpose of vehicle use and country of first registration were not identified as having a measurable influence on emissions of NO.

4.4 Influences on uvSmoke emissions

A regression tree model was fitted to find which vehicle characteristics most strongly influenced uvSmoke emissions. The analysis (summarised in Figure 4.4) indicates that the vehicle characteristics that most strongly influenced uvSmoke emissions were:

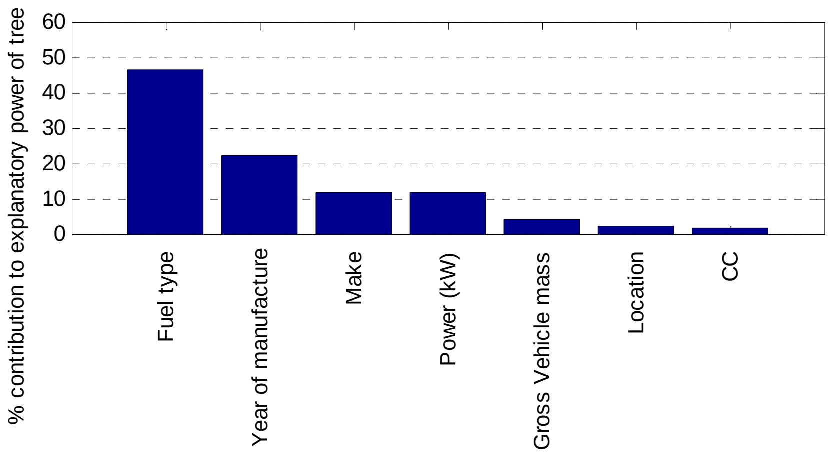
- fuel type;
- year of manufacture; and
- vehicle make.

Other characteristics that had weaker but still quantifiable influences were vehicle mass, testing location and engine size.

Purpose of vehicle use, country of first registration and odometer reading were not identified as having a measurable influence on emissions of uvSmoke.

Figure 4.4

Vehicle characteristics that most strongly influenced uvSmoke emissions



4.5 Summary of influences on vehicle emissions

The vehicle emissions database was interrogated and regression tree models fitted for each of the four pollutants – CO, HC, NO and uvSmoke – to identify which vehicle characteristics had the greatest influence on emissions.

The single most influential vehicle factor was year of manufacture, which contributed strongly to all four tree models. Fuel type contributed strongly to three of the trees but was not significant for the HC tree.

Other significant factors included engine size, engine power and gross vehicle mass. The purpose of vehicle use and country of first registration did not appear to have a significant influence on emissions of any of the monitored contaminants.

Looking at the individual pollutants, the most influential factors on emissions ranked in order of importance were:

- For CO, -year of manufacture, fuel type, vehicle make and engine power.
- For HC - year of manufacture, vehicle make, engine size, gross vehicle mass and engine power.
- For NO - year of manufacture, vehicle make, fuel type and gross vehicle mass.
- For uvSmoke - fuel type, year of manufacture, vehicle make and engine power.

This information highlights the key vehicle factors that need to be considered in the development of emissions reduction policies and vehicle emissions models.

5 Who are the "gross emitters"?

The total amount of emissions from the on-road vehicle fleet tends to be dominated by a relatively small number of vehicles with very high emissions. These high emitting vehicles are termed "*gross emitters*". The data from the 2003 Auckland on-road vehicle emissions study demonstrated that the highest emitting 10 per cent of vehicles were responsible for discharging 53 per cent, 51 per cent and 39 per cent of the total CO, HC and NO respectively (ARC, 2003). In contrast the cleanest 50 per cent of the fleet collectively contributed only 5 per cent, 3 per cent and 8 per cent of the total CO, HC and NO respectively (ARC, 2003).

"Who are the "Gross Emitters"?" is an important question to be answered because this information can be used to identify specific sectors of the fleet that are disproportionately causing detrimental environmental effects. Establishing the profile of high emitting vehicles gives environmental planners and policy makers an opportunity to develop targeted and effective emission reduction strategies.

This section presents the results of four interrogations of the vehicle emissions database, once for each pollutant, with the aim of identifying and profile gross emitting vehicles of CO, HC, NO and uvSmoke.

Dataset used for the analysis in this section: The "gross emitters" were defined as the highest 10 per cent of emitting vehicles for each pollutant and therefore the number of vehicles in each "gross emitter" dataset was approximately 4,830. Results for these vehicles were then compared to the total dataset of 48,333 vehicles.

5.1 Definition of a "gross emitter"

"Gross emitters" were defined as the highest 10 per cent of emitting vehicles for each pollutant. Using the 2005 RSD data, this definition established emission cut-offs for gross emitting vehicles as shown in Table 5.1. The remainder of the fleet (90 per cent) whose emissions fell below the gross emitter criteria were classified as "typical" emitters.

Table 5.1

Cut-off values used to define "gross emitting" vehicles in the 2005 study

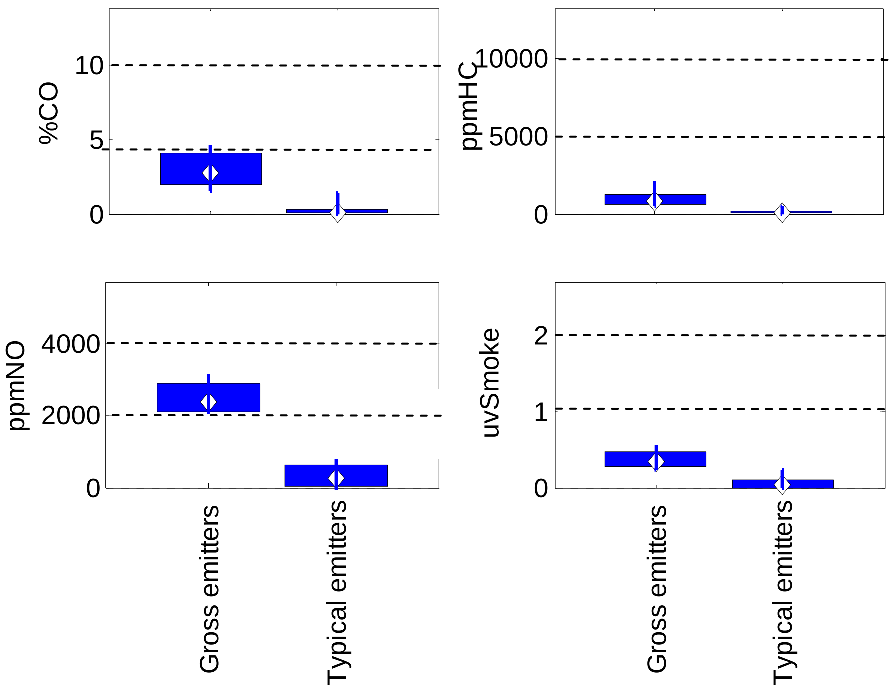
Pollutant	Cut-off value for gross emitters (90th percentile)
CO (%)	1.5
HC (ppm)	510
NO (ppm)	1,850
uvSmoke	0.24

5.2 Emissions from typical and gross emitters

Figure 5.1 compares the emissions from typical and gross emitting vehicles for the four pollutants measured. The upper and lower limit of the boxes indicates the inter-quartile range, with the median value highlighted by the diamond.

There is a statistically significant difference between the emission profiles of typical and gross emitting vehicles. The emissions from gross emitters are significantly higher than those from typical vehicles.

Figure 5.1
Comparison of emissions from gross and typical emitting vehicles



5.3 Age and fuel profiles of gross emitters

Figure 5.2 compares the age profile of all vehicles within the monitored fleet with those of vehicles that have emissions that fall within the gross emitter category (shown for each of the four pollutants). The y axis represents the percentage of the respective fleet that was manufactured in that year. The blue bars within each subplot add to 100 per cent.

The age profile of the entire monitored vehicle fleet differed from those of the gross emitting vehicle fleets. The gross emitting fleets contained a much greater proportion of older vehicles (mainly manufactured pre-1996) and a lower proportion of newer vehicles (mainly manufactured post 1999) than the entire fleet. However Figure 5.2 also shows that while the proportions were relatively low, some new vehicles were classified as gross emitters.

Figure 5.2

Comparison of the age profile of all monitored vehicles versus the gross emitters

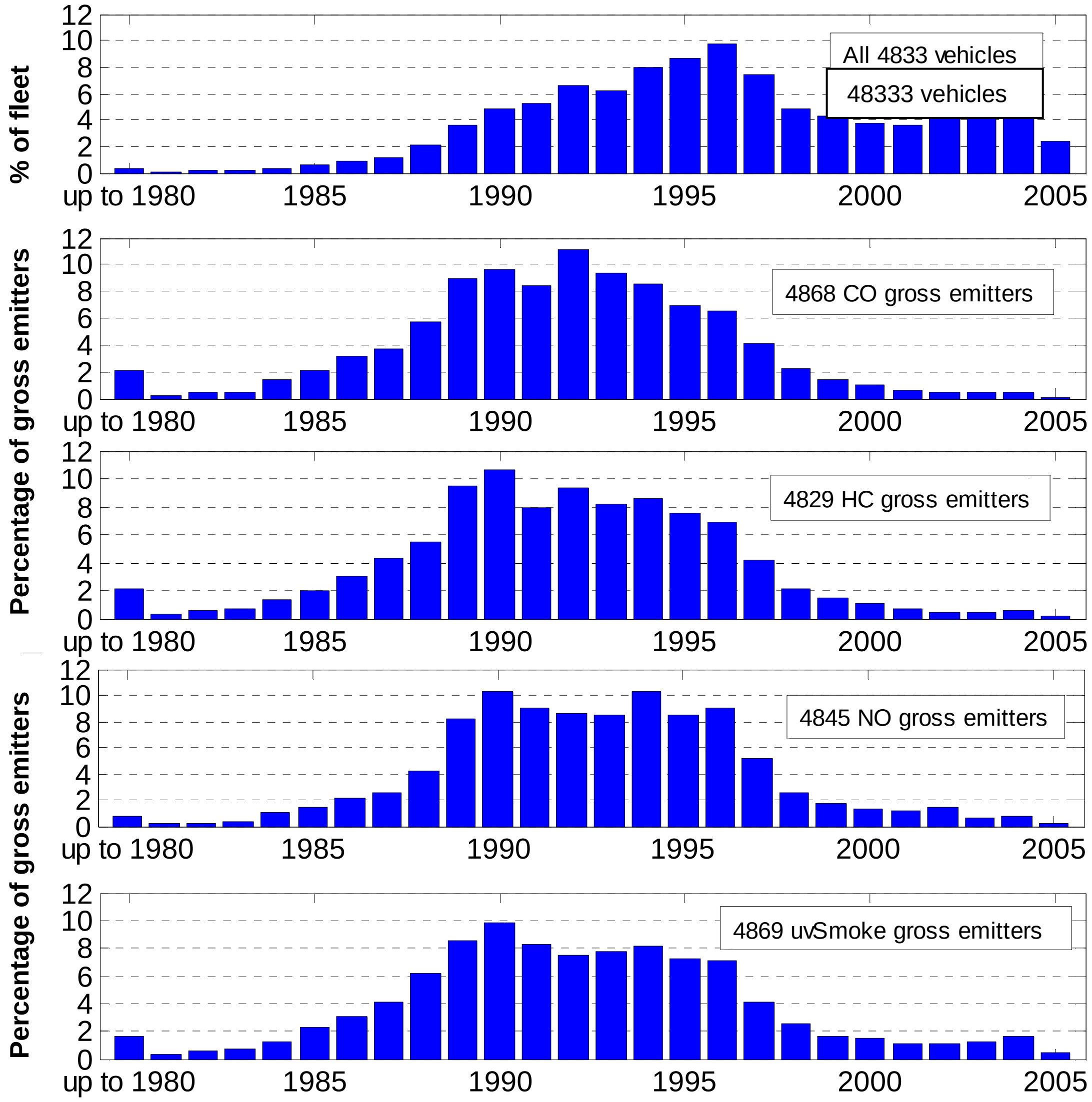
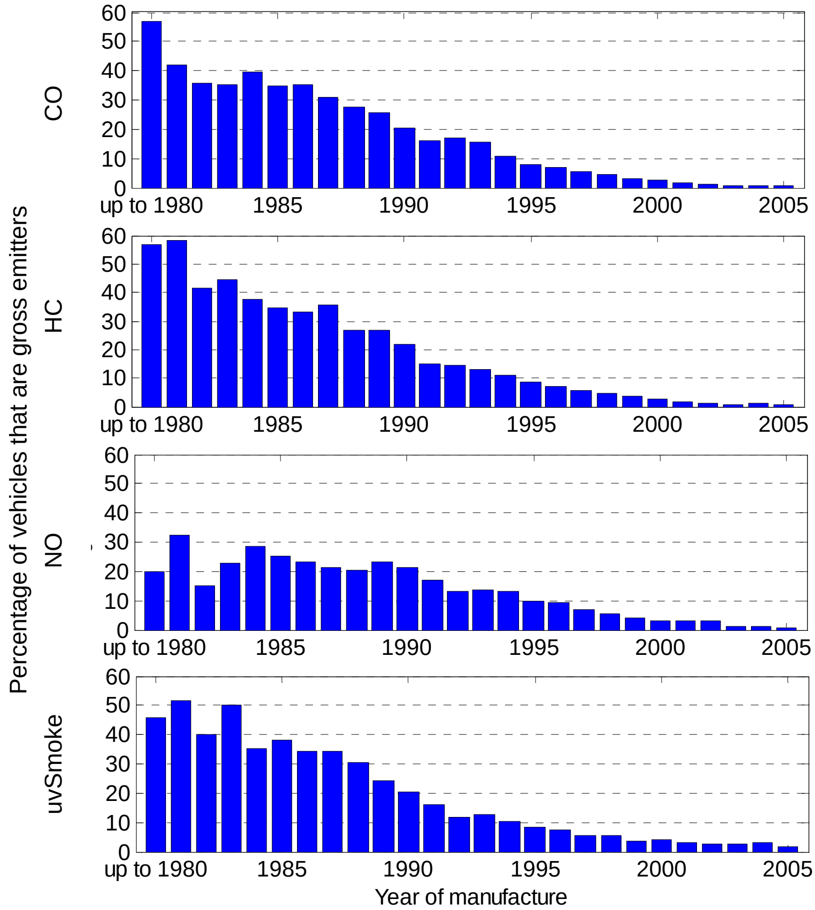


Figure 5.3 shows the percentage of vehicles manufactured each year which are classified as gross emitters for each of the four pollutants monitored.

For each of the four pollutants, older vehicles were much more likely to be gross emitters than newer vehicles. Approximately 40 per cent of the vehicles monitored that were manufactured before 1985 were classified as gross emitters of CO, HC and uvSmoke. Contrasting this result, Figure 5.3 shows that less than five per cent of vehicles manufactured after 2000 were classified as gross emitters.

Figure 5.3

Proportion of the 2005 monitored fleet by year of manufacture classified as gross emitters*



*48,333 vehicles

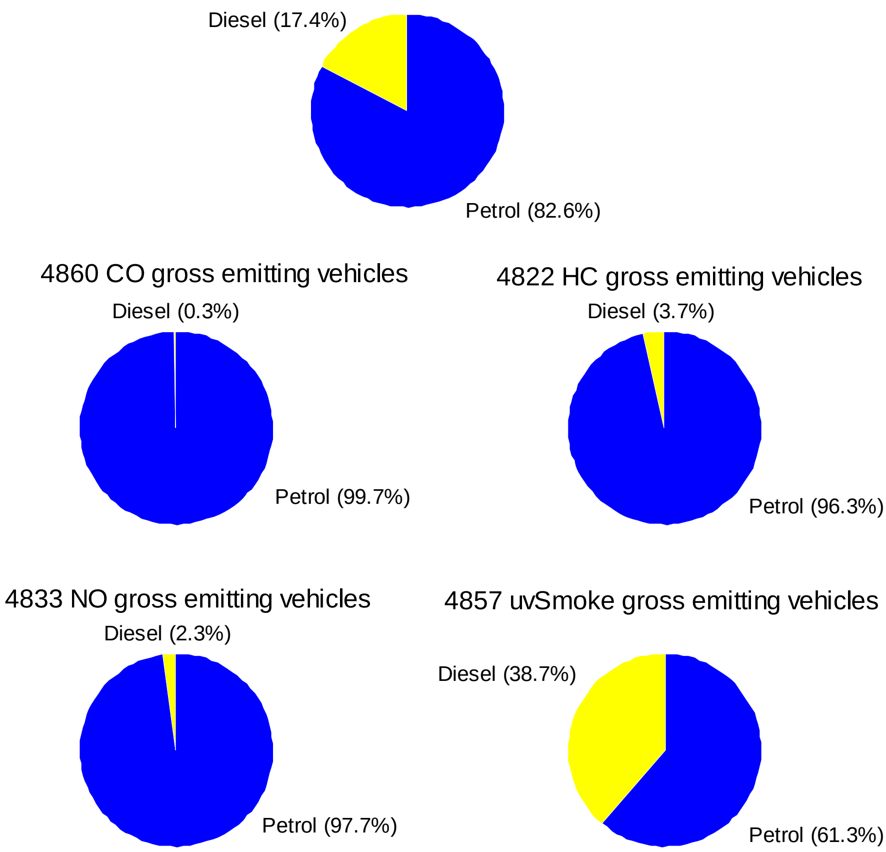
Figure 5.4 shows a breakdown of the entire monitored and gross emitting vehicle fleets by fuel type.

Overall, petrol and diesel vehicles made up 83 per cent and 17 per cent respectively of the monitored fleet. However, more than 96 per cent of gross emitters of CO, HC and NO were petrol vehicles. This result indicates that petrol vehicles were over represented within the gross emitting fleets of CO, HC and NO and were therefore much more likely to be gross emitters of these three pollutants than diesel vehicles.

For uvSmoke, approximately 40 per cent of the gross emitting vehicles were fuelled by diesel, which indicates that diesel vehicles were over represented within the gross emitters of uvSmoke. Therefore diesel vehicles were much more likely to be gross emitters of uvSmoke than petrol vehicles.

Figure 5.4

Comparison of the fuel breakdown of the gross emitters versus all monitored vehicles



5.4 Characterisation of gross emitters

Section 4 of this report summarises the results of regression tree models that were applied to the vehicle emission database to identify which predictor variables (vehicle characteristics) have the largest explanatory power on the response variable (the emissions) for all monitored vehicles.

This section uses the same regression tree models to identify the specific characteristics of gross emitting vehicles. For CO, HC, NO and uvSmoke emissions, regression trees were applied to:

- isolate the groups of highest emitting vehicles - found in the terminal nodes of each tree; and then
- identify which predictor variables (vehicle characteristics) were associated with these groups.

See Appendix 3.2 for figures showing the regression tree models and distributions of the emissions in relation to the classes used in the models.

5.4.1 CO gross emitters

A total of 684 vehicles were captured within the two highest CO gross emitting groups identified by the multivariate regression tree (MRT). The vehicles captured by the high pollution groups in the regression trees include 40 per cent of the CO gross emitting vehicles and only three per cent of the CO typical emitting vehicles. The vehicles within these two high pollution nodes were characterized by the following predictor variables:

- manufactured pre-1998
- petrol-fuelled
- engine power less than 94.5kW
- engine capacity less than 2275cc
- vehicle makes other than Alfa-Romeo, Audi, BMW, Daewoo, Daihatsu, Holden, Kia, Mitsubishi , Peugeot, Renault , Rover, Subaru , Suzuki and Volkswagen.

5.4.2 HC gross emitters

A total of 1,200 vehicles were captured within the two highest HC gross emitting groups identified by the MRT. The high emitting groups in the regression trees captures 41 per cent of the HC gross emitting vehicles and only seven per cent of the HC typical emitting vehicles. The vehicles contained within the predominant gross emitting groups (node 14) were characterised by the following predictor variables:

- manufactured pre-1998
- engine capacity less than 2158cc
- engine power less than 95kW
- makes other than Alfa Romeo, Audi, BMW, Daewoo, Fiat, Holden, Kia, Mercedes-Benz, Nissan, Peugeot, Renault, Rover, Subaru, Suzuki, Volkswagen and Volvo.

The vehicles contained within the other predominant gross emitting groups (node 7) were characterized by the following predictor variables:

- manufactured post-1997
- makes other than Alfa Romeo, Audi, BMW, Chrysler, Citroen, Daewoo, Daihatsu, Fiat, Ford, Holden, Honda, Jaguar, Jeep, Kia, Land Rover, Lexus, Maserati, Mazda, Mercedes-Benz, MB, Mini, Mitsubishi, Musso, Nissan, Peugeot, Porsche, Renault, Rover, Saab, Smart, Ssangyong, Subaru, Suzuki, Toyota, Volkswagen and Volvo.

5.4.3 NO gross emitters

A total of 1,551 vehicles were captured within the 11 highest gross emitting groups identified by the MRT. The high emitting groups captured 54 per cent of the NO gross emitting vehicles and only seven per cent of the NO typical emitting vehicles. The vehicles contained within the predominant groups (nodes 24, 25 and 34-37) were characterised by the following predictor variables:

- manufactured pre-1998
- engine capacity less than 2442cc
- makes other than Alfa Romeo, Audi, BMW, Chrysler, Chrysler Jeep, Daewoo, Daihatsu, Fiat, Holden, Jaguar, Jeep, Kia, Lexus, Mercedes-Benz, Musso, Nissan, Peugeot, Porsche, Rover, Subaru, Suzuki, Volkswagen and Volvo.

The vehicles contained within the other predominant gross emitting groups (nodes 20 and 46-49) were characterised by the following predictor variables:

- manufactured post-1997
- petrol-fuelled
- makes other than Alfa Romeo, Audi, BMW, Chrysler, Citroen, Daewoo, Daihatsu, Fiat, Ford, Holden, Honda, Isuzu, Jaguar, Jeep, Kia, Landrover, Lexus, Maserati, Mazda, Mercedes-Benz, MG, Mini, Mitsubishi, Nissan, Peugeot, Porsche, Renault, Rover, Saab, Smart, Ssangyong, Subaru, Suzuki, Toyota, Volkswagen and Volvo.

5.4.4 uvSmoke gross emitters

A total of 3,446 vehicles were captured in the six highest gross emitting groups identified by the MRT. The high emitting groups captured 81 per cent of the uvSmoke gross emitting vehicles. The vehicles contained within the predominant gross emitting groups (nodes 6, 13, 24 and 25) were all diesel-fuelled vehicles except those with engine power greater than 57.5kW and engine capacity greater than 2901cc and gross vehicle mass less than 4,445kg.

The vehicles contained within the gross emitting groups identified within the next most common group (node 20) were characterised by the following predictor variables:

- petrol-fuelled
- manufactured pre-1998
- engine power between 94.5kW and 122.5kW
- makes other than Alfa Romeo, Audi, BMW, Chrysler, Daewoo, Daihatsu, Fiat, Holden, Kia, Mercedes-Benz, Rover, Saab, Subaru, Suzuki, Volkswagen and Volvo.

The vehicles contained within the gross emitting groups identified within the remaining predominant group (node 27) were characterised by the following predictor variables:

- petrol-fuelled
- manufactured pre-1998
- engine power less than 122.5kW
- makes other than Alfa Romeo, Audi, BMW, Chrysler, Daewoo, Daihatsu, Fiat, Holden, Kia, Mercedes-Benz, Rover, Saab, Subaru, Suzuki, Volkswagen, Ford, Mazda, Toyota and Volvo.

5.5 Using uvSmoke measurements to identify smoky vehicles

Despite the fact that most of the most harmful contaminants are unable to be detected by the naked eye, visible discharges from vehicles are widely considered to indicate the quality of vehicle exhaust emissions.

Public concern in Auckland about visible emissions first rose in prominence in 2000, when the ARC ran the “0800 SMOKEY” campaign. The public were encouraged to ring a hotline to report smoky vehicles and over 43,000 calls were received from Aucklanders during this 15 week campaign. Many vehicles were dobbed in on multiple occasions and the hotline was extended informally for more than a year after the campaign’s official end date due to continuing smoky vehicle complaints.

Based on the ground swell of popular support, the Ministry of Transport (MoT) introduced a regulation known as the "10-second rule" in 2001, which states under clause 7.5 that:

> *A driver must not operate a motor vehicle other than a traction engine that, for 10 or more seconds, emits a continuous stream of smoke or vapour that is visible to a person with normal vision.*

This regulation allows the police to issue infringement notices to drivers of vehicles that smoke excessively for more than 10 seconds (MoT, 2004).

In 2006, the MoT reinforced the 10-second excessive smoke on-road rule by implementing a five-second visible smoke test into the warrant of fitness and certificate of fitness test programme (MoT, 2006). Section 4.2 of this states that:

> *A vehicle to which this section applies must not emit clearly visible smoke when the vehicle’s engine is running at its normal operating temperature, under either of the following conditions:*
>
> *a) for a continuous period of five seconds when the engine is idling;*
>
> *b) as the engine is being accelerated rapidly to approximately 2,500 revolutions per minute or approximately half the maximum engine speed (whichever is lower).*

Because visible smoke tests are used as part of MoT's strategies to help reduce vehicle emissions, the decision was made to use the remote sensing database to investigate:

- how the uvSmoke measurements made in this programme might compare to visible plume indicators;
- whether it would be possible to develop a Ringelmann-type[6] scale for vehicle emissions based on the photographs captured by the RSD system.

For the visible plume comparison, four subsets were taken from the uvSmoke data as follows:

- maximum measurements (uvSmoke = 2.60 to 16.0);
- 99.9th percentile measurements (uvSmoke = 2.41 to 2.59);
- 99th percentile measurements (uvSmoke = 0.81 to 2.40); and
- 90th percentile measurements (uvSmoke = 0.25 to 0.80).

Photos of vehicles within these four subsets were chosen at random until 12 photos were obtained for each subset that clearly showed the rear of the vehicle and the exhaust pipe as being visible. Table 5.2 shows the number of photographs that had to be inspected before 12 viable images were found. It was harder to find viable photos for the higher emission categories. This was because many of these vehicles were large and it proved difficult to get clear photos of the exhaust outlet and plumes. Table 5.2 shows that about one half of the photos taken were viable for this exercise.

Table 5.2

Occurrence of viable smoky vehicle photographs

uvSmoke subset	Number of photos needed to find 12 viable images
Maximum emitters (2.60 to 16.0)	39
99.9th percentile (2.41 to 2.59)	26
99th percentile (0.81 to 2.40)	20
90th percentile (0.25 to 0.80).	19

Figure 5.5, Figure 5.6 and Figure 5.7 show three of the viable photographs taken from either the maximum or the 99.9th percentile uvSmoke measurement categories. The smoky vehicles shown in Figure 5.5, Figure 5.6 and Figure 5.7 had uvSmoke measurements of 4.02, 2.56 and 2.86 respectively.

[6] The Ringelmann scale has been used in air pollution evaluation for assigning the degree of blackness of smoke emanating from a source. The observer compares the shades of grey (white to black) with a series of shade diagrams formed by horizontal and vertical black grid lines on a white background. A corresponding number, the Ringelmann number, is then assigned to describe the best match; numbers range from 0 (white) to 5 (black). The Ringelmann scale has been largely superseded by quantitative methods.

Figure 5.5

Photo of smoky vehicle 1: uvSmoke = 4.02

Figure 5.6

Photo of smoky vehicle 2: uvSmoke = 2.56

Figure 5.7

Photo of smoky vehicle 3: uvSmoke = 2.86

Figure 5.5 and Figure 5.7 clearly show a visible smoky plume being discharged from the vehicles. Figure 5.6 shows that while the uvSmoke measurement was 2.56 (above the 99.9th percentile value) there was no visible plume.

Table 5.3 shows the percentage of viable images analysed that yielded identifiable visible plumes.

Table 5.3

Occurrence of visible plumes in the viable smoky vehicle photographs

uvSmoke subset	Number of plumes visible in the 12 viable images (%)
Worst emitters (2.60 to 16.0)	5 images - (42%)
99.9^{th} percentile (2.41 to 2.59)	7 images- (58%)
99^{th} percentile (0.81 to 2.40)	1 image - (8%)
90^{th} percentile (0.25 to 0.80)	0 images - (0%)

The percentage of vehicles with visible smoke plumes was about 50 per cent for the top two categories down to zero for the 90th percentile of uvSmoke measurements. It was anticipated that the photographs of gross emitting uvSmoke vehicles would reveal more frequent and more clearly visible plumes.

There are two theories as to why plumes were not visible more often in the photographs. Firstly, the RSD measures uvSmoke in the 232nm wavelength, which is outside the light spectrum visible by the human eye. Therefore it is possible to get a high uvSmoke reading without a visible plume. Secondly, even when visible smoke is emitted, the degree to which it can be detected in the photograph depends on the angle of the camera, the lighting (front or back lit) and the contrast between the plume colour and the background including the road surface. Unfortunately it is not possible to modify the surroundings in such a way as to guarantee sufficient contrast for a plume to be visible.

In conclusion, this investigation shows that the uvSmoke measurements made in this programme did not compare well to visible plume indicators and therefore there is limited potential for developing a Ringelmann-type scale for vehicle emissions using the photographs captured by the RSD system. This finding may have potential implications for MoT's strategies to help reduce vehicle emissions, which largely depend on visible smoke tests.

5.6 Summary of "who are the gross emitters?"

The total amount of emissions from the on-road vehicle fleet tends to be dominated by a relatively small number of vehicles with very high emissions called "gross emitters". The vehicle emissions database was interrogated to identify and profile these gross emitters for Auckland in 2005.

The gross emitting fleets contained a much greater proportion of older vehicles (mainly manufactured pre-1996) and a lower proportion of newer vehicles (mainly manufactured post 1999) than the entire monitored fleet. Approximately 40 per cent of the monitored vehicles that were manufactured before 1985 were classified as gross emitters of CO, HC and uvSmoke, whereas less than five per cent of vehicles manufactured after 2000 were classified as gross emitters.

Gross emitters of CO, HC, NO and uvSmoke were more likely to be petrol vehicles rather than diesel vehicles. However relative to their fleet proportions, petrol vehicles were over-represented in the gross emitters for CO, HC and NO (96 per cent versus 83 per cent in the fleet) and diesel vehicles were over-represented in the gross emitters of uvSmoke (40 per cent versus 17 per cent in the fleet).

The characteristics which were most strongly associated with gross emitters of CO were older (pre-1998), smaller (less than 2275cc) petrol-fuelled vehicles.

The characteristics which were most strongly associated with gross emitters of HC are older (pre-1998), smaller (less than 2158cc and less than 95 kW) vehicles of both fuel types.

The characteristics which were most strongly associated with gross emitters of NO were either:

- older (pre-1998), smaller (less than 2400cc) vehicles of both fuel types; or
- newer (manufactured post 1997) petrol-fuelled vehicles.

The characteristics which were most strongly associated with gross emitters of uvSmoke were either:

- low powered (less than 60kW) diesel-fuelled vehicles; or
- heavier (greater than 4.000kg) diesel-fuelled vehicles.

An analysis of the photographs of gross emitting vehicles showed that the uvSmoke measurements made in this programme did not compare well to visible plume indicators and that the potential of using these photographs to develop a Ringelmann-type scale for vehicle emissions is limited.

6 Vehicle emissions and social deprivation index

To reduce the impact of vehicle emissions on the environment, planners and policy makers may consider implementing rules and regulations that target high emitting vehicles. Such rules and regulations are potentially effective because they require high emitting vehicles be fixed or scrapped. However, while policies that target high emitting vehicles may have positive environmental outcomes, the policies may also have unintended negative socio-economic impacts. It is possible that low income households own a disproportionate number of high emitting (older and/or poorly maintained) vehicles than other sectors of the community. Therefore the economic impact of policies of this type could fall on the sector of society that can least afford to bear the additional costs of fixing or upgrading high emitting vehicles.

This section uses the on-road vehicle emission database to investigate whether there is any relationship between the socio-economic status of vehicle owners and their vehicle's emissions.

The Social Deprivation Index (SDI) is a measure of socio-economic status calculated for small geographic areas (as defined by Statistics New Zealand's census area units). The SDI was developed by the Department of Health at the Wellington School of Medicine and Health Sciences (Ministry of Health, 2001). The SDI uses a range of variables from the 2001 Census of Population and Dwellings which represent nine dimensions of social deprivation. The nine variables in used to calculate the index for an area are:

- Income — People aged 18-59 receiving a means tests benefit
- Employment — People aged 18-59 years who are unemployed
- Income — People living in equivalised[7] households with income below an income threshold
- Communication — People with no access to a telephone
- Transport — People with no access to a car
- Support — People aged less than 60 years living in a single parent family
- Qualifications — People aged 18-59 years without any qualifications
- Living Space — People living in equivalised[7] households below a bedroom occupancy threshold
- Owned Home — People not living in own home

[7] Equivalisation is a method used to control for household compensation.

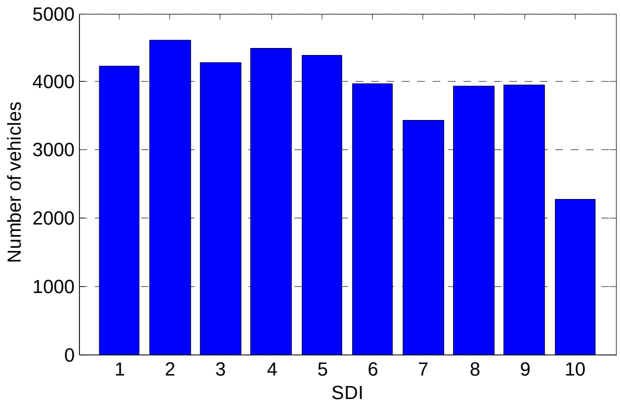
Important note about SDIs: The SDI is provided as an *ordinal*[8] scale which ranges from 1 to 10, where 1 represents the areas with the least deprived scores and 10 the areas with the most deprived scores. It is important to note that the SDI applies to areas rather than to individuals who live in those areas.

Dataset used for the analysis in this section: For each vehicle in the 2005 dataset, the owner's address was assigned the relevant SDI, enabling a match between the socio-economic status of the area (census area units) the vehicle came from and its emissions. SDIs were extracted for just over 80 per cent (39,554) of the addresses of the owners of the vehicles sampled in 2005.

6.1 Fleet profiles by social deprivation index

Figure 6.1 shows that the owners of the cars monitored in 2005 came from the full range of SDIs but that fewer vehicles were sampled from the higher deprivation indices. The number of vehicles sampled that were owned by people living in areas with SDI of 10 (most deprived) were approximately half the number of vehicles sampled that were owned by people living in areas with SDI of 1 (least deprived).

Figure 6.1
Distribution of SDI values for owners of vehicles monitored in 2005*



* 39,554 vehicles

Figure 6.2 shows that the percentage of diesel vehicles varied across SDI classes, with a general trend for the proportion of diesel ownership to rise slightly with increasing SDI. The significance of this trend was tested using a two-sample z-test for proportions. Vehicles from owners with SDI from 1-3 were pooled (low SDI) and compared with vehicles from owners with SDI 8-10 (high SDI). Results showed that

[8] Measurements with ordinal scales are ordered in the sense that higher numbers represent higher values. However, the intervals between the numbers are not necessarily equal. For example, on a five-point rating scale, the difference between a rating of 2 and a rating of 3 may not represent the same difference as the difference between a rating of 4 and a rating of 5.

there was a significant difference (at the 95% level) between the proportion of diesel vehicles in the low SDI fleet (15 per cent of vehicles) compared to the proportion of diesel vehicles in the high SDI fleet (18 per cent of vehicles).

Figure 6.2

Proportion of diesel vehicles in each SDI category for the monitored fleet in 2005

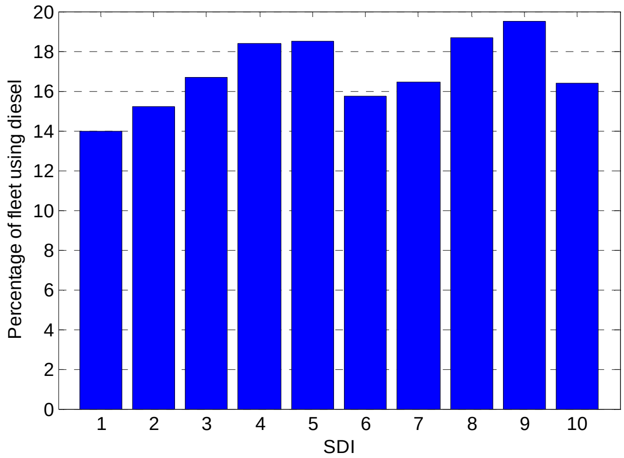
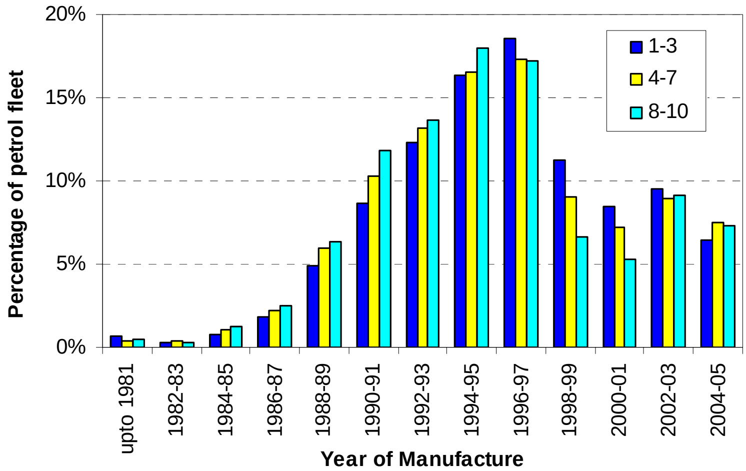


Figure 6.3 and Figure 6.4 respectively show the age profile of petrol and diesel vehicles by SDI of owner. To simplify the figures, the ten SDIs have been grouped into three bins: low (SDI = 1-3); medium (SDI = 4-7) and high (SDI = 8-10).

Figure 6.3

Age profile of the monitored petrol vehicles by SDI of owner in 2005*



*32,762 vehicles

Figure 6.3 shows that the age profiles of the petrol vehicles owned by the groups with low (11,078 vehicles), medium (13,427 vehicles) and high (8,257 vehicles) SDI were generally similar. However, there was a tendency for the high SDI group (green bars) to own proportionally more older (pre-1996) petrol vehicles. Vehicles of this age made up about 54 per cent of the petrol fleet owned by people with SDIs of 8-10 compared with about 46 per cent of the petrol fleet owned by people with SDIs of 1-3.

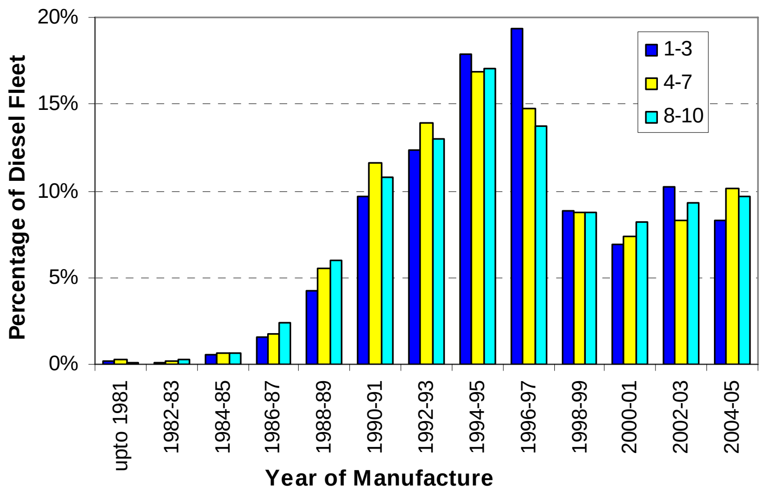
At the other end of the scale, there was a tendency for the low SDI group (blue bars) to own proportionally more newer (1996-2005) petrol vehicles. Vehicles of this age range made up about 54 per cent of the petrol fleet owned by people with SDIs of 1-3 compared with only about 46 per cent of the petrol fleet owned by people with high SDIs of 8-10.

Interestingly, Figure 6.3 shows the proportion of petrol vehicles in the two newest year of manufacture bins was similar across all three groups of SDIs at about seven to nine per cent.

Figure 6.4 shows that the age profiles of the diesel vehicles owned by the groups with low, medium and high SDI were generally similar. The age profiles of diesel vehicles for the different SDI groups showed less variation than those observed for petrol vehicles. However some differences are still apparent.

Figure 6.4

Age profile of the monitored diesel vehicles by SDI of owner in 2005*



*6,711 vehicles

There was a tendency for the high SDI group to own a higher proportional of older diesel vehicles. Vehicles manufactured prior to 1994 made up about 33 per cent of the diesel fleet owned by people with SDIs of 8-10 compared with about 28 per cent of the diesel fleet owned by people with SDIs of 1-3.

Another feature was the tendency for the low SDI group to own proportionally more mid-aged (1994-1999) diesel vehicles. Vehicles of this age made up approximately 46 per cent of the diesel fleet owned by people with SDIs of 1-3 compared with about 39 per cent of the diesel fleet owned by people with SDIs of 8-10.

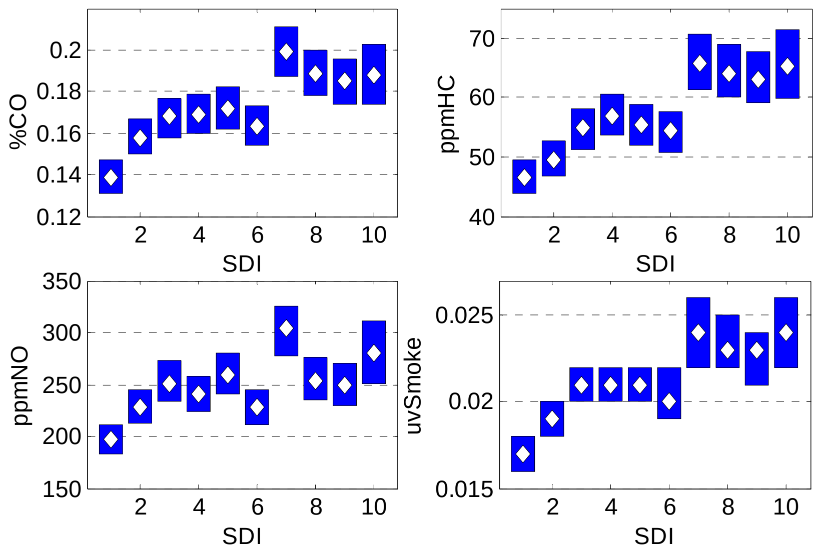
Figure 6.4 shows the high SDI group was more likely to own newer diesel vehicles (2000-2005) than the group with the low SDI. Newer vehicles made up about 27 per cent of the diesel fleet owned by people with SDIs of 8-10 compared with only about 25 per cent of the diesel fleet owned by people with SDIs of 1-3.

6.2 Petrol emission profiles by SDI

Figure 6.5 compares the emissions of CO, HC, NO and uvSmoke from petrol vehicles owned by people within the ten different SDI categories.

Figure 6.5

Emissions by SDI of owner for petrol vehicles monitored in 2005*



*32,762 vehicles, Kruskal-Wallis 95% significant difference ranges

All four pollutants presented in Figure 6.5 showed a strong trend towards higher emissions from petrol vehicles whose owners lived in more socially deprived areas. In each case, the difference between the emissions from the highest and lowest SDI categories was statistically significant.

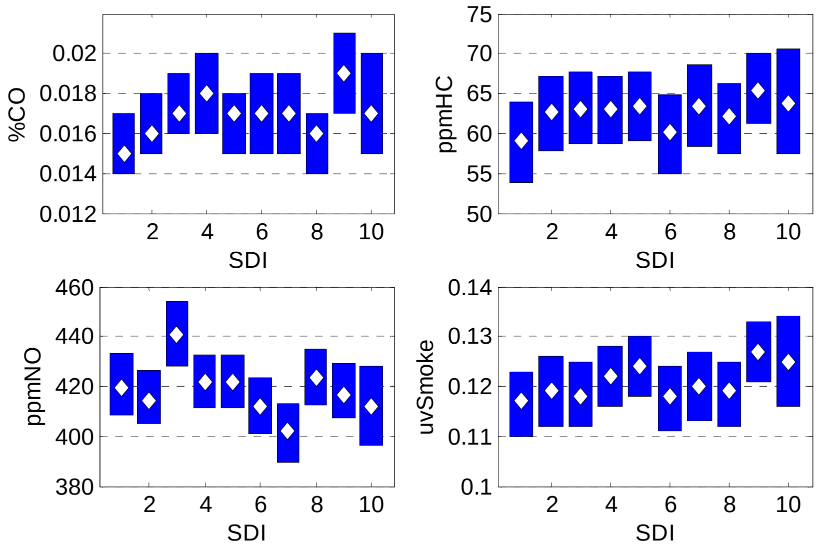
6.3 Diesel emission profiles by SDI

Figure 6.6 compares the emissions of CO, HC, NO and uvSmoke from diesel vehicles owned by people within the ten different SDI categories.

Unlike in the case of petrol vehicle emissions, Figure 6.6 shows that there was no statistically significant relationship between the SDI of diesel vehicle owners and emissions of CO, HC, NO or uvSmoke.

Figure 6.6

Emissions by SDI of owner for diesel vehicles monitored in 2005*



*6,711 vehicles, Kruskal-Wallis 95% significant difference ranges

6.4 Summary of influence of SDI on vehicle emissions

To reduce the impact of vehicle emissions on the environment, policy makers may consider implementing regulations that target high emitting vehicles. While these policies have positive environmental outcomes, they may result in unintended negative socio-economic impacts if they fall on the sector of society that can least afford to bear the additional costs of fixing or upgrading their vehicles. To investigate this, the vehicle emission database was used to assess whether there was any link between the socio-economic status of the area from which a vehicle came and its emissions. Social Deprivation Indices (SDIs) were successfully extracted for just over 80 per cent (39,500) of the vehicles monitored in 2005.

Vehicle owners came from areas covering the full range of SDIs but the number of monitored vehicles from the most deprived areas (SDI = 10) were approximately half the number of monitored vehicles from the least deprived areas (SDI = 1).

There was a trend for people from less deprived areas to own newer vehicles but this trend was not as strong as might have been anticipated. There was also a slight trend for people from more deprived areas to be more likely to own diesel vehicles.

For petrol vehicles, there was a strong relationship between the SDI of vehicle owners and vehicle emissions. Emissions of all four pollutants were significantly higher from petrol vehicles whose owners lived in more deprived areas than from vehicles whose owners lived in less deprived areas.

For diesel vehicles, there was no evidence of statistically significant trends for any of the four pollutants relative to the SDI of vehicle owners.

7 Trends in the fleet and emissions between 2003 and 2005

Data from 2005 were compared to 2003 to quantify any observable changes in fleet emissions. The analysis was carried out on the subset of the data using the "baseline" data only (sites used in both campaigns). The first part of this section covers the changes in fleet characteristics, whilst the second and third parts discuss the changes in fleet emissions for petrol and diesel vehicles respectively.

Although different RSD systems were used to undertake the monitoring in the two campaigns, the methods used to measure CO, NO and HC were technically identical and both sets of data were calibrated and audited using the same procedures. These factors mean that the 2003 and 2005 data for CO, NO and HC are directly comparable.

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 campaign, *uvSmoke* was used as the proxy for particulate emissions. As mentioned earlier in section 2.1.2 Measurement of particulate pollutants, uvSmoke was calculated based on the absorption and scattering of light beams at UV wavelengths (~232 nm) by the RSD 4000EN system. 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).

Cautionary note on comparing particulate emissions for 2003 and 2005. Because the measurement method changed between 2003 and 2005, the comparison between the two sets of particulate emissions data must be treated with some caution and the interpretation regarded as *indicative* rather than definitive. It should be noted that Stedman and Bishop (2002) suggest that particulate results calculated from uvSmoke readings (i.e. 2005 method) are greater than particulate results calculated from the opacity readings (i.e. 2003 method).

Between 2003 and 2005, the government introduced a series of regulations which may also have had an effect. Fuel specifications were tightened in early 2004 to reduce sulphur in diesel to 500ppm and benzene in petrol to 3 wt%[9]. At the same time, minimum emissions standards came into force requiring all new vehicles (diesel or petrol) to be Euro 2 compliant.

Dataset used for the analysis in this section: The analysis was carried out on the subset of the data using the "baseline" data only (sites used in both campaigns), comprising 52,747 vehicles in total for 2003 and 2005. The numbers of vehicles monitored at the baseline sites in 2003 and 2005 were 30,924 and 21,823 respectively.

[9] wt% is per cent by weight. For every kilogram of fuel contains 30 grams of Benzene.

7.1 Changes in fleet parameters

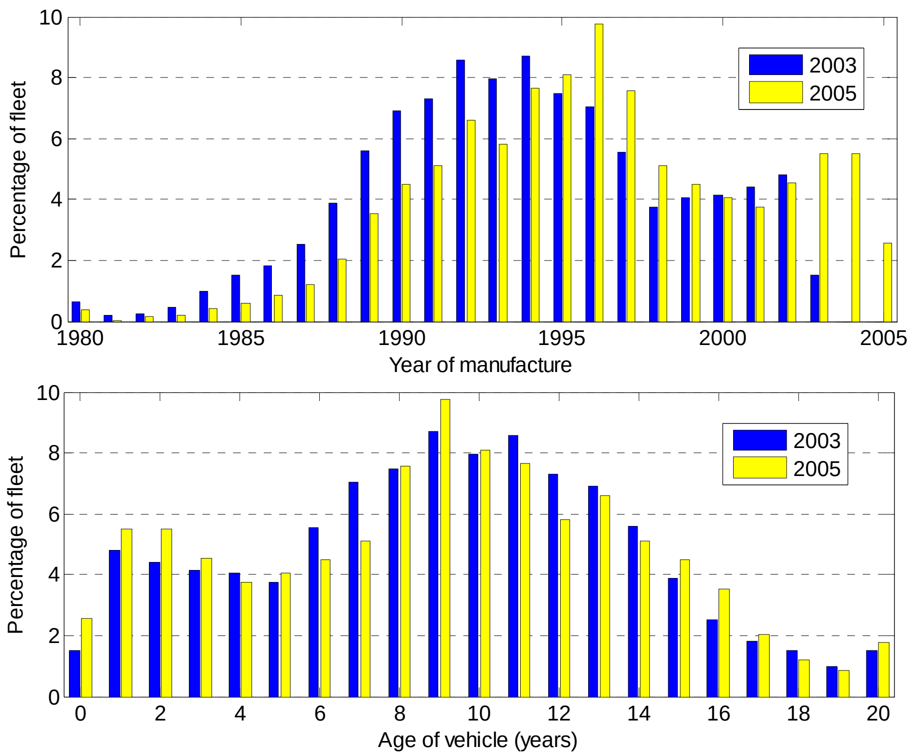
A comparison of the fleet characteristics of the vehicles monitored in 2003 and 2005 was undertaken.

7.1.1 Age and year of manufacture

Figure 7.1 shows there was little difference between the age profile of the petrol vehicle fleets monitored at the baseline sites in 2003 and 2005. Both fleets featured a bi-modal age profile. The first of the two observed peaks in the age profile is generated by Japanese imported used vehicles entering the fleet on average seven or eight years after manufacture. The second peak is generated by new vehicles entering the fleet each year. The addition of newer vehicles into the fleet and the natural attrition of older vehicles are clearly seen by comparing the two bars for any particular year.

Figure 7.1

Comparison of the age profiles of monitored petrol vehicles in 2003 and 2005*

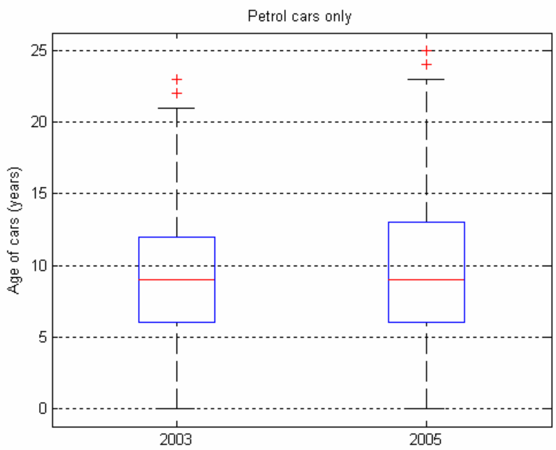


*43,555 vehicles

The overall average age of the two petrol fleets is compared in

Figure 7.2, with the median values noted by the red line, the box indicating the inter-quartile range and the whiskers showing the 95th percentile range.

Figure 7.2
Comparison of the age distribution of petrol vehicles monitored in 2003 and 2005

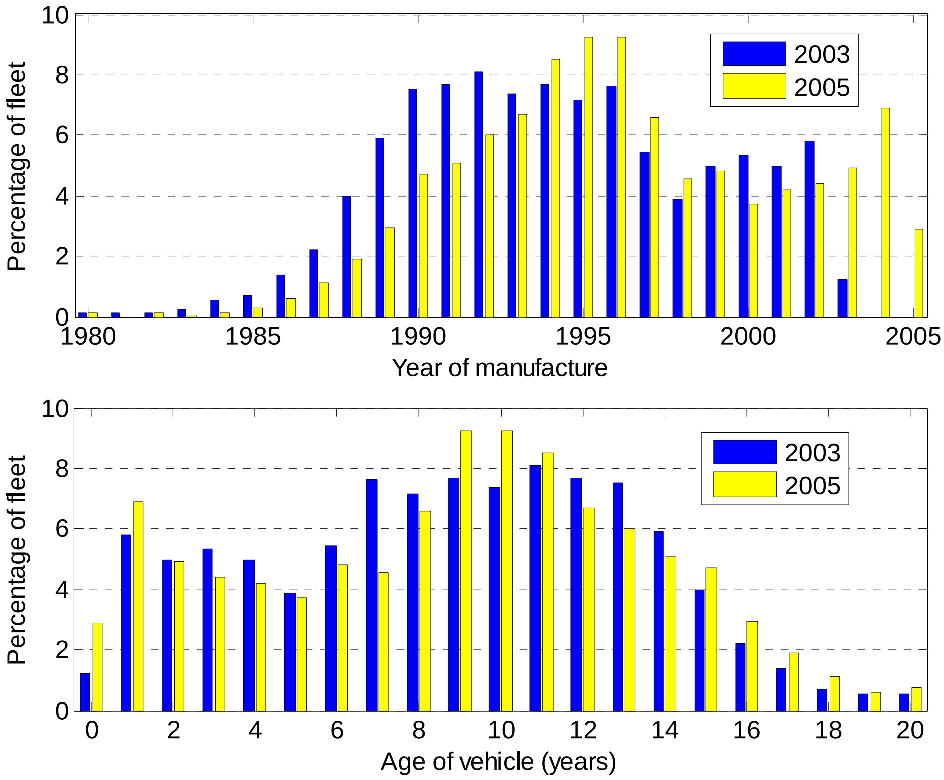


The average ages of the petrol vehicles monitored in 2003 and 2005 were essentially identical, with the mean value for 2003 being nine years and five months and 2005 being nine years and six months. These corresponded to average years of manufacture of October 1993 and October 1995, respectively.

Figure 7.3 shows there was little difference between the age profile of the diesel vehicle fleets monitored at the baseline sites in 2003 and 2005. Both diesel fleets mirrored the bi-modal age profiles observed in the petrol vehicle fleets.

Figure 7.3

Comparison of the age profiles of monitored diesel vehicles in 2003 and 2005*

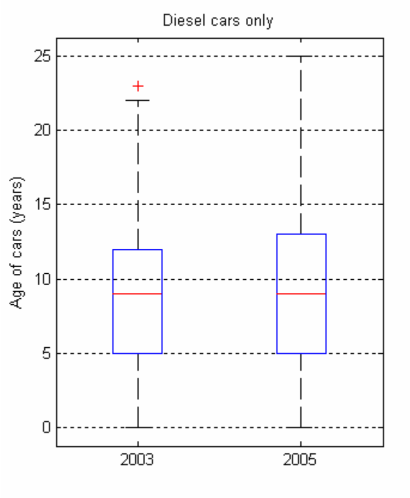


*8,464 vehicles

The overall average age of the two diesel fleets is compared in Figure 7.4, with the median values noted by the red line, the box indicating the inter-quartile range and the whiskers showing the 95th percentile range.

Figure 7.4

Comparison of the average age distribution of diesel vehicles monitored in 2003 and 2005



The average ages of the diesel vehicles monitored in 2003 and 2005 were essentially identical, with the mean value for 2003 being nine years and two months and 2005 being nine years and four months. These corresponded to average years of manufacture of February 1994 and January 1996 respectively.

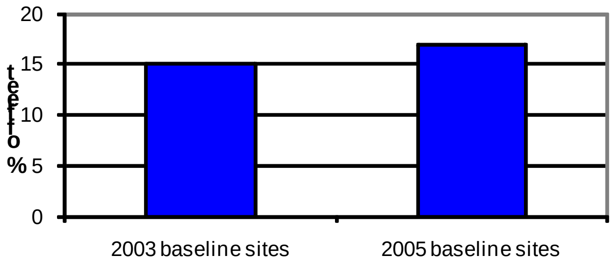
There was no appreciable difference between the average age of petrol vehicles and the average age of diesel vehicles for either the 2003 or the 2005 monitored fleets.

7.1.2 Fuel type

Figure 7.5 compares the proportion of diesel vehicles in the fleets monitored at the 2003 and 2005 baseline sites. The proportion of diesel vehicles in the monitored fleet increased from 15 per cent to 17 per cent over the period 2003 to 2005 at the baseline sites. A two-sample *z*-test for proportions showed that this difference was statistically significant at the 95% level.

Figure 7.5

Comparison of the percentage of diesel vehicles monitored at the baselines sites in 2003 and 2005

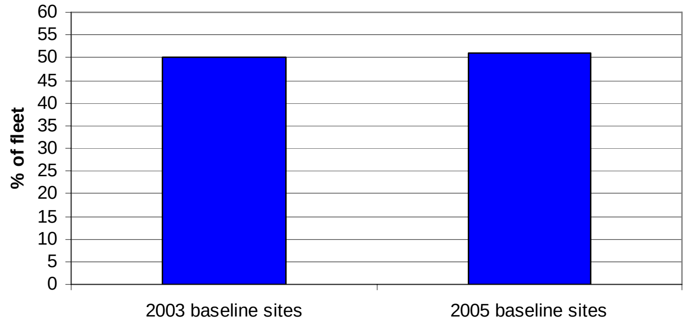


7.1.3 Country of first registration

Figure 7.6 compares the proportion of Japanese used imported vehicles in the fleets monitored at the 2003 and 2005 baseline sites. The proportion of used imported vehicles in the monitored fleet increased slightly from 50 per cent to 51 per cent over the period 2003 to 2005 at the baseline sites but this difference was not statistically significant when tested using a two-sample z-test for proportions at the 95% confidence level.

Figure 7.6

Comparison of the percentage of Japanese used imports monitored at the baselines sites in 2003 and 2005



7.2 Changes in petrol vehicle emissions

A comparison of the petrol vehicle emission measurements made at the baseline sites in 2003 and 2005 was undertaken. A total of 43,555 petrol vehicles were considered in this analysis - 25,608 monitored in 2003 and 17,947 monitored in 2005.

Table 7.1 shows the median and mean values for each pollutant measured in 2003 and 2005. Note that the means are much higher than the medians because of the strong skew in the data. Vehicle emissions data are not normally distributed so the mean value does not give a useful indication of the centre of the data.

Table 7.1

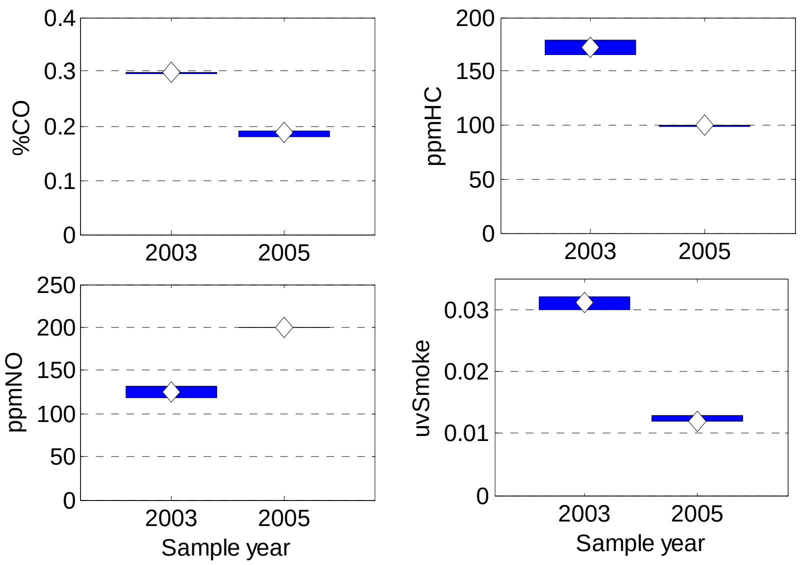
Comparison of petrol vehicle emissions monitored at the baselines sites in 2003 and 2005

Pollutant	2003	2005
CO (%) - median (mean)	0.32 (0.80)	0.16 (0.63)
HC (ppm) - median (mean)	200 (364)	55 (246)
NO (ppm) - median (mean)	100 (640)	211 (605)
uvSmoke - median (mean)	0.06 (0.45)	0.02 (0.07)

Figure 7.7 shows the Kruskal-Wallis 95th percentile significance difference ranges for the pollutants to establish whether or not there is a statistically significant difference between the emissions measured in 2003 and 2005. Note the diamonds do not show either the median or the mean values of the monitored pollutants but are included to clearly indicate the location of the 95th percentile boxes which can be difficult to see if they are narrow, e.g. the per cent CO reading for 2003.

Figure 7.7

Comparison of petrol vehicle emissions monitored at the baselines sites in 2003 and 2005*



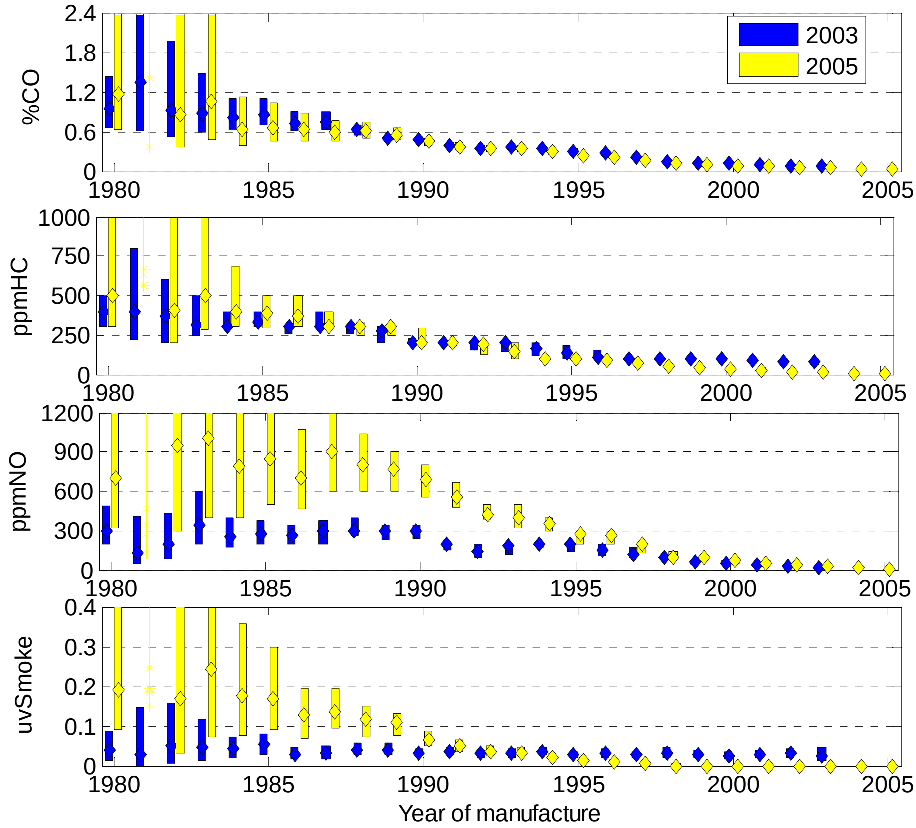
*43,555 vehicles, Kruskal-Wallis 95% significant difference ranges

Table 7.1 shows that the emissions of CO, HC and uvSmoke from petrol vehicles were significantly lower in 2005 than in 2003. However, the trend in emissions of NO was less conclusive. The comparison of median NO values and results of the Kruskal-Wallis test (K-W) suggest that the fleet emissions of NO may have increased between 2003 and 2005 In contrast the comparison of the mean NO values suggest there may have been a slight decrease between the two monitoring campaigns. The large difference between the median and mean concentrations of NO in 2003 is the influence of a small number of very high measurements which disproportionately influence (increase) the mean NO 2003 value. This explains why the comparison of 2003 and 2005 petrol NO mean and median concentrations do not appear to provide a consistent outcome. Given the highly skewed nature of the NO data it is more appropriate to undertake the comparison of the petrol concentration profiles using the median values and K-W test rather than relying on the mean values. So while the trend in NO emissions is less certain than for CO, HC and uvSmoke, these results suggest that NO emissions may have increased over the two campaigns.

The differences seen in Figure 7.7 could have been caused by changes in the fleet or changes in measurement technique. In particular uvSmoke was measured quite differently in 2005 than it was in 2003. Therefore, to try and establish the most likely cause, comparisons were made between the petrol emissions monitored in 2003 and 2005 by year of vehicle manufacture as shown in Figure 7.8.

Figure 7.8

Comparison of monitored petrol vehicle emissions by year of manufacture in 2003 and 2005*



*43,555 petrol vehicles, Kruskal-Wallis 95% significant difference ranges

Figure 7.8 shows:

- CO emissions by vehicle year were similar in 2003 and 2005. Therefore, the reduction in average CO seen in Table 7.1 is more likely to be due to fleet improvements, such as the gradual addition of more modern vehicles to the fleet and the natural attrition of older vehicles.
- HC emissions were generally consistent between the 2003 and 2005 datasets. The emissions measured from newer than 1994 vehicles were slightly lower in the 2005 dataset than in 2003. Although there appears to be some slight influence caused by the change in the instrument used in the two campaigns, most of the reduction in average HC seen in Table 7.1 is likely to be due to the influence of the more modern fleet.
- NO emissions were the least consistent of the gaseous emissions measured between 2003 and 2005. In theory the measurement technique was identical for both instruments used. Nonetheless the results deviate markedly for the 1985 to 1995 vehicles (the majority of the two fleets). Consequently, it is not possible to verify that the increase in average NO seen in Table 7.1 is genuine or attribute it to any fleet trends.
- uvSmoke measurements showed more variation in 2005 than in 2003. More smoke was measured for older (pre-1990) vehicles and less from newer (post-1995). The decrease in average uvSmoke seen in Table 7.1 could be due to the change in measurement technique. However, given that the new method is more likely to yield higher values, part of the decrease may well be attributable to fleet improvements.

The comparison of the 2003 and 2005 emissions data suggests that, with the exception of NO, emissions from the petrol fleet are improving with "business as usual" fleet trends and technology improvements. However, due to differences in monitoring technology between 2003 and 2005 it is not possible to draw firm conclusions and further monitoring and investigation is needed to validate these findings especially the observed trend in NO emissions.

7.3 Changes in diesel vehicle emissions

A comparison of the light duty diesel vehicle emission measurements made at the baseline sites in 2003 and 2005 was undertaken. A total of 8,464 diesel vehicles were considered in this analysis (4,623 monitored in 2003 and 3,841 monitored in 2005).

Table 7.2 shows the median and mean values for each pollutant measured in 2003 and 2005. Note that the means are much higher than the medians because of the strong skew in the data. Vehicle emissions data are not normally distributed so the mean value does not give a useful indication of the centre of the data.

Table 7.2

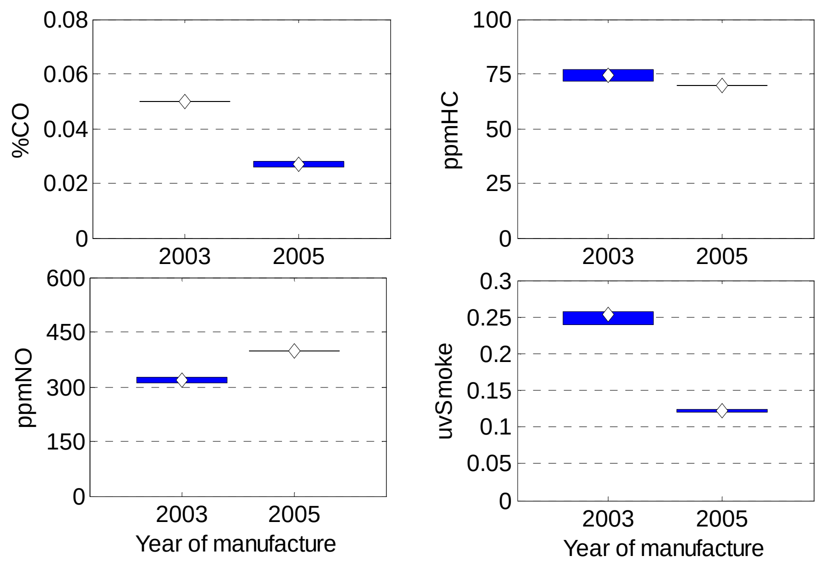
Comparison of light duty diesel vehicle emissions monitored at the baselines sites in 2003 and 2005

Pollutant	2003	2005
CO (%) -median (mean)	0.06 (0.13)	0.02 (0.05)
HC (ppm)- median (mean)	90 (180)	61 (108)
NO (ppm) - median (mean)	300 (393)	420 (513)
uvSmoke- median (mean)	0.58 (0.96)	0.12 (0.19)

Figure 7.9 shows the Kruskal-Wallis 95th percentile significance difference ranges for the pollutants to establish whether or not there is a statistically significant difference between the emissions measured in 2003 and 2005. Note the diamonds on Figure 7.9 do not show either the median or the mean values of the monitored pollutants but are included to clearly indicate the location of the 95th percentile boxes which can be difficult to see if they are narrow (as in the case of 2003 CO).

Figure 7.9

Comparison of light duty diesel vehicle emissions monitored at the baselines sites in 2003 and 2005*



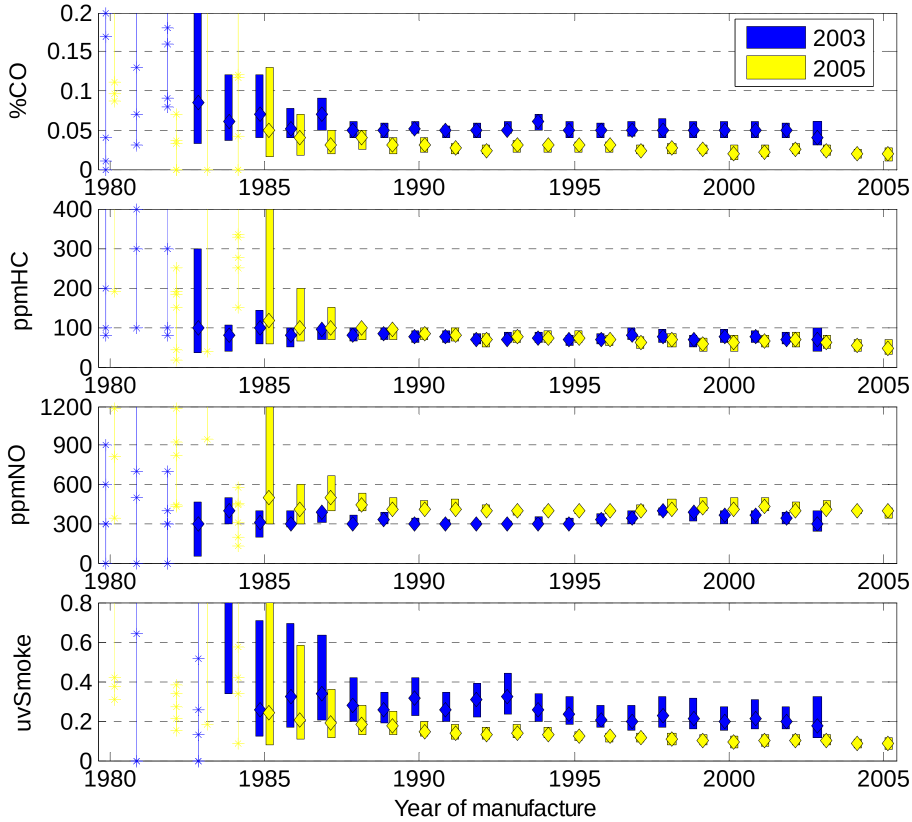
*8,464 diesel vehicles, Kruskal-Wallis 95% significant difference ranges

Both Table 7.2 and Figure 7.9 show that the average emissions of CO, HC and uvSmoke were significantly lower in 2005 than in 2003. However, emissions of NO were significantly higher in 2005.

The differences seen in Figure 7.9 could have been caused by changes in the fleet or changes in measurement technique. In particular uvSmoke was measured quite differently in 2005 than it was in 2003. Therefore, to try and establish the most likely cause, comparisons were made between the diesel emissions monitored in 2003 and 2005 by year of vehicle manufacture as shown in Figure 7.10.

Figure 7.10

Comparison of monitored light duty diesel vehicle emissions by year of manufacture in 2003 and 2005*



*8,464 diesel vehicles, Kruskal-Wallis 95% significant difference ranges

Figure 7.10 shows that:

- Although the CO emissions by vehicle year appear to be significantly lower in 2005 than in 2003 they are much closer to the detection limit of the instrument (because diesel CO emissions are much lower than petrol CO emissions) and it is likely that the variability seen is exaggerated. Therefore the cause of the reduction in average CO seen in Table 7.2 is less conclusive but may well be due to fleet improvements.
- HC emissions were generally consistent between the 2003 and 2005.Therefore the reduction in average HC emissions seen in Table 7.2 is most likely due to fleet improvements, such as the gradual addition of more modern vehicles to the fleet and the natural attrition of older vehicles.
- NO emissions for vehicles manufactured after 1985 were generally higher in 2005 than in 2003 and therefore the increase in average NO seen in Table 7.2 may be due to the different instrumentation used between campaigns. Consequently, it is not possible to verify that the increase in average NO seen in Table 7.2 is genuine nor is it possible to attribute it to changes in the fleets.

- uvSmoke measurements for vehicles manufactured post-1990 were significantly lower in 2005 compared to 2003. For vehicles manufactured pre-1990, there was no significant difference between the uvSmoke measurements in 2003 compared to 2005. The measurement method of uvSmoke changed substantially between 2003 and 2005, so any observed differences in emission values may be due, at least in part, to the change in measurement method. The method used in 2005 is more sensitive to the higher emissions and picks up more variation in the amount of smoke emitted by the sampled vehicles. It is not possible to verify that the reduction in average uvSmoke seen in Table 7.2 is genuine nor is it possible to attribute it to improvements or otherwise in the fleet.

The comparison of the 2003 and 2005 emissions data suggests that, with the exception of NO, emissions from the diesel fleet are improving with "business as usual" fleet trends and fuel and technology improvements. However, due to differences in monitoring technology between 2003 and 2005 it is not possible to draw firm conclusions and further monitoring and investigation is needed to validate these findings especially the observed trends in NO and uvSmoke emissions.

7.4 Summary of trends between 2003 and 2005

Data from 2005 were compared to 2003 to quantify any observable changes in fleet emissions. This analysis was carried out on the subset of the data using the "baseline" data only (sites used in both campaigns), comprising 52,747 vehicles in total for 2003 and 2005. The number of vehicles monitored at the baseline sites in 2003 and 2005 was 30,924 and 21,823 respectively.

The respective petrol and diesel fleets monitored at the baseline sites in 2003 and 2003 were very similar. The average vehicle age and the proportion of Japanese imported used vehicles monitored during the two campaigns were more or less unchanged at nine years and approximately 50 per cent respectively. The proportion of diesel vehicles within the fleet increased from 15 to 17 per cent. However, because the emissions from petrol and diesel vehicles were compared separately, this change in fleet characteristics did not affect the results.

- Average petrol vehicle emissions reduced for CO, HC and uvSmoke, but may have increased for NO. Further investigation is needed to confirm the trend observed in NO emissions.

- Average diesel vehicle emissions reduced for CO, uvSmoke and, to a lesser extent, HC but increased for NO. However, further monitoring and investigation is needed to validate these findings.

Potential factors that contributed to the changes in emissions included:

- Although the average age of both fleets was similar, the average year of manufacture was two years later for the 2005 fleet (1996 versus 1994 for 2003).
- Fuel specifications were tightened in early 2004 to reduce sulphur in diesel to 500ppm and benzene in petrol to 3 wt%. At the same time, minimum emissions standards came into force requiring all new vehicles (diesel or petrol) to be Euro 2 compliant.
- There was also a change in the technique used to measure proxy particulate emissions in 2003 (opacity for the RSD-3000) and in 2005 (uvSmoke for the RSD-4000EN). The newer technique (uvSmoke) tends to give higher values than the original (opacity) measurement.

Considering the impacts of these factors, the conclusions were:

- For petrol vehicles, the reductions in CO, HC and uvSmoke emissions were most likely as a result of fleet turnover and improvements in fuel and technology.
- For diesel vehicles, the results were less conclusive. The reductions in CO and HC emissions may have been due to fleet turnover and improvements in fuel and technology but the measured decrease in uvSmoke emissions could be in part at least due to the change in particulate measurement technique.
- There was no obvious explanation for the increase in NO emissions seen for both petrol and diesel vehicles.

The comparison of the 2003 and 2005 emissions data suggests that, with the exception of NO, emissions from the petrol and diesel fleets are improving with "business as usual" fleet trends and fuel and technology improvements. However, it is recommended that further investigation be undertaken to firm up these conclusions.

Data from another road-side monitoring campaign at the base line sites using the RSD 4000EN would help confirm the conclusions reached.

8 Summary of results

8.1 Features of the 2005 fleet

The average vehicle in the monitored fleet was manufactured in late 1998 and was 9.2 years old. In comparison the average age of the whole of the Auckland passenger vehicle fleet was 10.6 years. Across the sampled fleet, 83 per cent of the vehicles were petrol-fuelled and 17 per cent used diesel. Approximately half of the vehicles monitored were New Zealand new and the other half of the vehicles entered the fleet as used vehicles imported from other countries (mainly Japan).

The average total mileage increased as vehicles got older, peaking at just over 200,000kms for vehicles manufactured in 1987-1988. The rate of mileage increase was greatest for new vehicles indicating that newer vehicles on average travelled further each year than older vehicles. Paradoxically, the total mileage was less as vehicles got older than 1987 but this was most likely due to these vehicles having been driven less frequently on average in the past and therefore they were yet to reach the end of their operational life.

Table 8.1 compares the emission from the monitored petrol and diesel fleets.

Table 8.1

Comparison of median emissions from petrol and diesel vehicles

	CO (%)	HC (ppm)	NO (ppm)	uvSmoke
Petrol	0.16	50	200	0.025
Diesel)	0.03	60	400	0.125
Highest emitting fuel	Petrol	Similar	Diesel	Diesel

8.2 Factors that influence emissions

The emissions discharged by vehicles are determined by a large number of factors. For the 2005 campaign, the response variables (emission results) were matched to 25 predictor variables (vehicle characteristics) to create a vehicle emissions database. This database was then interrogated and regression tree models fitted for each of the four pollutants – CO, HC, NO and uvSmoke.

The single most influential vehicle factor was year of manufacture. Fuel type contributed strongly to emissions of CO, NO and uvSmoke but was not significant for HC.

Other significant factors included engine size, engine power and gross vehicle mass. The purpose of vehicle use and country of first registration did not appear to have a significant influence on emissions for any of the monitored contaminants.

Table 8.2 shows the relative importance of vehicle characteristics on determining vehicle emissions. The relative importance of each characteristic on a particular pollutant is indicated by the rank number shown in brackets.

Table 8.2

Influence of vehicle characteristics on emissions

Pollutant	Year of manufacture	Fuel type	Vehicle make	Engine size	Engine power	Gross vehicle mass
CO	✓ (1)	✓ (2)	✓ (3)		✓ (4)	
HC	✓ (1)		✓ (2)	✓ (3)	✓ (5)	✓(4)
NO	✓ (1)	✓ (3)	✓ (2)			✓ (4)
uvSmoke	✓ (2)	✓ (1)	✓ (3)		✓ (4)	

This information highlights the key vehicle factors that need to be considered in the development of emissions reduction policies and vehicle emissions models.

8.3 Characterisation of "gross emitters"

The total amount of emissions from the on-road vehicle fleet tends to be dominated by a relatively small number of vehicles with very high emissions known as "gross emitters". The vehicle emissions database was interrogated to identify and profile these high emitting vehicles.

The gross emitting fleets contained a much greater proportion of older vehicles (mainly manufactured pre-1996) and a lower proportion of newer vehicles (mainly manufactured post 1999) than the overall monitored fleet. Approximately 40 per cent of the monitored vehicles that were manufactured before 1985 were classified as gross emitters of CO, HC and uvSmoke, whereas less than five per cent of vehicles manufactured after 2000 were classified as gross emitters.

Gross emitters of CO, HC, NO and uvSmoke were more likely to be petrol vehicles than diesel vehicles. Gross emitters of CO, HC, NO and uvSmoke were more likely to be petrol vehicles than diesel vehicles. However relative to their fleet proportions, petrol vehicles were over-represented in the gross emitters for CO, HC and NO (96 per cent versus 83 per cent in the fleet) and diesel vehicles were over-represented in the gross emitters of uvSmoke (40 per cent versus 17 per cent in the fleet).

The vehicle characteristics which were most strongly associated with gross emitters of CO were older (pre-1998), smaller (less than 2275cc) petrol-fuelled vehicles.

The characteristics which were most strongly associated with gross emitters of HC were older (pre-1998), smaller (less than 2158cc and less than 95 kW) vehicles of both fuel types.

The characteristics which were most strongly associated with gross emitters of NO were either:

- older (pre-1998), smaller (less than 2400cc) vehicles of both fuel types, or
- newer (manufactured post 1997) petrol-fuelled vehicles.

The characteristics which were most strongly associated with gross emitters of uvSmoke were either:

- low powered (less than 60kW) diesel-fuelled vehicles; or
- heavy (greater than 4.000kg) diesel-fuelled vehicles.

An analysis of the photographs of gross emitting vehicles showed that the uvSmoke measurements made in this programme did not compare well to visible plume indicators and that there is limited potential for using these photographs to develop a Ringelmann-type scale for vehicle emissions.

8.4 Effect of social deprivation index

Vehicle owners came from areas covering the full range of SDIs but the number of monitored vehicles from the most deprived areas (SDI = 10) were approximately half the number of monitored vehicles from the least deprived areas (SDI = 1).

There was a trend for people from less deprived areas to own newer vehicles but this trend was not as strong as might have been anticipated. There was also a slight trend for people from more deprived areas to be more likely to own diesel vehicles.

For petrol vehicles, there was a strong relationship between the SDI of vehicle owners and vehicle emissions. Emissions of all four pollutants were significantly higher from petrol vehicles whose owners lived in more deprived areas than from vehicles whose owners lived in less deprived areas.

For diesel vehicles, there was no evidence of statistically significant trends for any of the four pollutants relative to the SDI of vehicle owners.

8.5 Trends from 2003 to 2005

The respective petrol and diesel fleets monitored at the baseline sites in 2003 and 2005 were very similar. The average vehicle age and the proportion of Japanese imported used vehicles monitored during the two campaigns were more or less unchanged at nine years and approximately 50 per cent respectively. The proportion of diesel vehicles within the fleet increased from 15 to 17 per cent. However, because the emissions from petrol and diesel vehicles were compared separately, this change in fleet characteristics did not affect the results.

The comparison of the 2003 and 2005 emission data showed that:

- Petrol vehicle emissions reduced for CO, HC and uvSmoke, but may have increased for NO. Further investigation is needed to confirm the trend observed in NO emissions.
- Diesel vehicle emissions reduced for CO, uvSmoke and, to a lesser extent, HC but increased for NO. Further monitoring and investigation is needed to validate these findings.

Potential factors that contributed to the changes in emissions included:

- Although the average age of both fleets was similar, the average year of manufacture was two years younger for the 2005 fleet (1996 versus 1994 in 2003).
- Fuel specifications were tightened in early 2004 to reduce sulphur in diesel to 500ppm and benzene in petrol to 3 wt%. At the same time, minimum emissions standards came into force requiring all new vehicles (diesel or petrol) to be Euro 2 compliant.
- There was also a change in the technique used to measure proxy particulate emissions in 2003 (opacity for the RSD-3000) and in 2005 (uvSmoke for the RSD-4000EN). The newer technique (uvSmoke) tends to give higher values than the original (opacity) measurement.

Considering the impacts of these factors, the conclusions were:

- For petrol vehicles, the reductions in CO, HC and uvSmoke emissions were most likely as a result of fleet turnover and improvements in fuel and technology.
- For diesel vehicles, the results were less conclusive. The reductions in CO and HC emissions may have been due to fleet turnover and improvements in fuel and technology but the increase in uvSmoke emissions was most likely due to the change in particulate measurement technique.
- There was no obvious explanation for the increase in NO emissions seen for both petrol and diesel vehicles.

The comparison of the 2003 and 2005 emissions data suggests that, with the exception of NO, emissions from the petrol and diesel fleets are improving with "business as usual" fleet trends and fuel and technology improvements. However, it is recommended that further investigation be undertaken to firm up these conclusions.

Data from another road-side monitoring campaign at the base line sites using the RSD 4000EN would help confirm the conclusions reached.

8.6 Outcomes of the education campaign

The 2005 remote sensing campaign was conducted in tandem with an education campaign highlighting to motorists the importance of tuning their vehicles. The primary messages came from radio advertising, motorway billboards and a "smart sign" connected to the remote sensor which gave motorists an immediate indication of whether their emissions were "good", "fair" or "poor". Out of the total of 48,333 vehicles which drove past the monitor over seven weeks, 4,090 (8.5 per cent) received a "poor" rating and were followed up with a letter from the ARC informing them that their car was causing pollution and might need tuning. The proportion of "poor" readings was consistent with the previous monitoring that had been undertaken in 2003.

The 2005 campaign received a high level of awareness with the regional public:

- In a follow up survey, 55 per cent of respondents recalled the campaign without being prompted. A further 14 per cent recalled it after prompting.
- Respondents were most likely to be aware that air pollution causes asthma and other respiratory problems, with 59 per cent citing this effect. This is consistent with the campaign messages that were used in the radio advertising and motorway billboards.
- Just over a quarter of respondents who were aware of the air quality campaign (26 per cent) stated that they had taken some action (e.g. tuned their vehicle) as a result of the campaign.

9 Conclusions and recommendations

In conclusion, the 2005 "Big Clean Up Tune Your Car" remote sensing campaign has achieved its objectives and produced a valuable vehicle emissions database which will assist the ARC in developing and progressing their vehicle emission reduction policies and strategies.

The main conclusions from this work were that:

- Diesel vehicles had higher emissions of NO and smoke than petrol vehicles, whereas petrol vehicles had higher emissions for CO. Both had similar emissions of hydrocarbons.
- The main factors influencing vehicle emissions were the year of manufacture, fuel type and the make of the vehicle. The order of importance for each of these factors was different for each pollutant.
- The diesel vehicle fleet had a higher proportion of uvSmoke gross emitters than petrol vehicles, whereas petrol vehicles were more likely to be gross emitters of CO, NO and hydrocarbons.
- Older vehicles were more likely to be gross emitters, but some new vehicles can also be gross emitters.
- Petrol vehicles owned by people living in areas with higher Social Deprivation Index were more likely to have higher emissions.
- The results suggest that, with the exception of NO, emissions from the petrol and diesel fleets are improving with fleet changes (i.e. newer less polluting vehicles entering the fleet), technology and fuel improvements. However, further investigations are recommended to confirm the observed trends and firm up these conclusions.

The comparison between the results of this campaign in 2005 and the earlier one, undertaken in 2003, highlights the advantages of regular remote sensing. The information assists with confirming whether real-world emissions are reducing and, if so, at a rate fast enough to meet emission reduction targets. In addition, the data bring to light trends in fleet characteristics, such as increases in the proportion of diesel-fuelled vehicles, which can be used to predict likely future emissions.

The principal recommendation of this work is that remote sensing be conducted on a regular basis using the same equipment. Overseas, other agencies have adopted annual surveys but it would still be valuable to repeat monitoring less frequently if funding is limited.

In the 2005 campaign, technical monitoring was combined with public education initiatives. From the high level of awareness generated, it would be beneficial to run another combined campaign in future. Involving the public through education is more likely to secure buy-in for any policies that are triggered by the monitoring as the public will have a greater appreciation of the problem and how they can contribute to its solution.

10 References

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11 Glossary

Terms	Definition
ARC	Auckland Regional Council
ARTA	Auckland Regional Transport Authority
BCU	The Big Clean Up, an education initiative undertaken by the ARC
CO	Carbon monoxide
CoF	Certificate of Fitness, a mandatory check to ensure the roadworthiness of commercial vehicles
CO_2	Carbon dioxide
CVA	Computer verified audit
Gross emitter	Vehicle whose emissions fall in the top 10 per cent of the readings for the fleet it is part of
GVM	Gross vehicle mass, kg
HC	Hydrocarbons
HDD	Heavy duty diesel vehicle, usually with a GVM over 3,500kg
IM240	The IM240 test is a chassis dynamometer schedule used for emission testing of in-use light duty vehicles in inspection & maintenance programs.
IR	Infrared light, includes wavelengths in the range 750 nm and 100 μm
K-W test	Kruskal-Wallis test of significant difference
Light duty vehicles	Vehicles with a GVM under 3,500kg
MoH	NZ Ministry of Health
MoT	NZ Ministry of Transport
MRT	Multivariate regression tree
MTA	Motor Trade Association
NIWA	National Institute of Water and Atmospheric Research Ltd
NO	Nitric oxide, a precursor to the formation of NO_2
NO_2	Nitrogen dioxide
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
ppm	Parts per million
Ringelman Scale	The Ringelman scale was developed to give a repeatable visual reference at the stack exit point of the amount of smoke emitted by boilers
RSD	Remote sensing devise
SDI	Social deprivation index, a measure of the socio-economic status of an area based on nine dimensions of social deprivation
SDM	Source detector module
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.
wt%	per cent by weight

Appendix 1: The "Big Clean Up" air education campaign

A1.1 Aims and objectives of the vehicle emissions education initiative

The Big Clean Up (BCU) Air education campaign ran during May/June 2005. This section highlights the results of the campaign. The key objectives of the campaign were to:

- put air quality front of mind for the Auckland public once again;
- show how individuals and businesses could take action; and
- help people understand what they could do to reduce air pollution.

The campaign received a high level of awareness with the regional public with 55 per cent of those surveyed recalling the campaign unprompted. A further 14 per cent recalled it after prompting. Respondents were most aware that air pollution caused asthma and other respiratory problems with 59 per cent citing this effect. This was consistent with the campaign messages that were used in the radio advertising and motorway billboards. Just over a quarter of respondents who were aware of the air quality campaign (26 per cent) stated that they had taken some action (e.g. tuned their vehicle) as a result of the campaign.

From 16 May to 30 June 2005, a drive-by emissions monitor was moved around the region. The monitor tested vehicles at 23 different sites. Vehicles that drove through the monitor received a "good", "fair" or "poor" rating for their exhaust emissions. This was displayed on a sign that motorists saw immediately after driving past the monitor. A total of 48,333 vehicles drove past the monitor over seven weeks, and 4,090 (8.5 per cent) received a 'poor' rating. The number of "poor" emissions was consistent with previous monitoring that had been undertaken in 2003 by the Auckland Regional Council (ARC).

Those motorists who received a "poor" rating were followed up with a letter from the ARC informing them that their car was causing pollution and might need tuning. They were encouraged to join The Big Clean Up whereby they would receive a ten per cent discount on tune-ups from selected MTA members. Enclosed with the letter was a Big Clean Up join up form and a list of MTA members providing the discount to BCU members. As an added incentive, owners were invited to get their vehicle tuned, send in a copy of their receipt and go in the draw to be reimbursed up to $500 towards the cost of tuning their vehicle. Five prizes were available.

During the duration of the campaign:

- A total of 4,090 letters were sent out to vehicle owners.
- 124 new members joined The Big Clean Up.
- 68 people who received a letter got their car fixed and entered the competition to be reimbursed a proportion of the repair costs.
- The ARC responded to 15 letters that were sent in from owners who received a 'poor' rating. Of those four requested further information and 11 were concerned about the effect their vehicle may be having on the environment.
- The ARC received a total of 60 phone calls during the campaign. Approximately one third of those were supportive, a third requested further information and another third were concerned about the effect their vehicle may be having on the environment.

A1.2 Communications to Big Clean Up members

A Big Clean UpDATE newsletter that focused on air pollution was sent to all 41,000 BCU members during the first week of June 2005. This listed the sites where the drive-by emissions monitor would be located over the coming weeks. It reminded BCU members that selected MTA members would provide them with an ongoing ten per cent discount on tune-ups and listed all those MTA members throughout the region who provide the discount. The newsletter was used to advertise an added incentive to BCU members. If they got their car tuned during the campaign and sent in a copy of the receipt they could also go in the draw to be reimbursed up to $500 towards the cost of repairs. There were five prizes available for existing BCU members in addition to the five available to motorists who received a letter after driving through the monitor.

Three specific campaign related eConnect emails were sent out to the 16,000 BCU members on the email address database. These introduced the campaign, provided information on the health effects of vehicle emissions, and advertised the prize draw for members who tuned their car. They also contained links through to the BCU pages on the website where people could find a calendar with the locations where the drive-by monitor would be during the campaign. Further into the campaign the eConnects were used to update members on the number of cars that had been tested and the numbers that were receiving a 'poor' rating plus remind members to get their own cars checked when the monitor was in their area. The eConnects were successful in directing people to the relevant web pages as website activity coincided with eConnect timing.

A1.3 Media

The BCU Air campaign generated a lot of interest from the media. Prior to the campaign launching the New Zealand Herald ran two stories on air pollution, one of which quoted Kevin Mahon (2 and 7 May 2005). This provided a very good lead in to the campaign. During the campaign stories on air pollution and the drive-by monitor appeared on 3 News, Maori Television, World TV (Chinese, Sky Digital channel) and Family TV. Dr Gerda Kuschel and Cr Dianne Glenn were interviewed on Radio NZ, Radio Live, and Newstalk ZB. The campaign also received positive coverage in the print media: 25 articles in community newspapers; two stories in Consumer magazine; a story in Coach and Bus magazine; the Green Party issued their own press release in support; an article appeared in "Radiator" the magazine for MTA members and there were two supportive letters to the editor.

A1.4 Schools programme

Three schools took part in the drive-by monitoring component of the campaign (Lynfield College, Auckland Girls Grammar School and Rangitoto College). The monitor was located in each school for a day. This was advertised to the pupils, their parents, teachers and the local community who were encouraged to take their cars through. The opportunity was also taken to explain the science behind the monitor to pupils, e.g. all Lynfield College students came down to see the monitor during the day and had two of the ARC Air Quality team and a NIWA technician give them an overview of the monitor and air pollution issues.

A teaching resource "Smog Busters" was made available to all intermediate and primary schools during the campaign. A total of 20 kits were requested and issued to schools.

The BCU team worked with the Auckland Regional Transport Authority (ARTA) and the Walking School Bus co-ordinator to design new fluoro safety vests that were printed with the campaign related message "Our Walking School Bus Clears the Air". In total 432 vests were produced and 16 primary schools participated incorporating 36 walking school buses. The adult "drivers" and "conductors" wore the vests and in some cases the children on the bus also wore them. In addition to this "Maxx the Pukeko" (the ARTA mascot) went out to visit five walking school buses as part of the air campaign. This received coverage in the local media. Feedback from the adult walkers was that they supported the campaign and loved being involved.

A1.5 Video and information evening

At the conclusion of the BCU air campaign a new initiative for BCU members was trailed – a video and information evening. The evening took place on 5 July 2005 and was advertised via the Big Clean UpDATE newsletter and an eConnect email. Over 80 people attended which was encouraging considering it was a stormy cold winter's night and it was held on the same date that the Lions rugby team were playing Auckland. The evening was introduced by Cr Dianne Glenn and two international videos were shown with presentations from Dr Gerda Kuschel in between. The evening was a great success with very positive feedback received via an evaluation form. Those attending were asked what topics they would like to see covered at future evenings and transport featured strongly.

The second video and information evening took place on 17 August 2005. It covered transport and was well attended by over 100 people. Cr Joel Cayford spoke on transport and growth issues, two international videos were shown and ARTA's Anna Percy gave a presentation on sustainable transport options. Again the event received very positive feedback.

A1.6 Campaign evaluation

A telephone survey of 505 residents was undertaken to assess perceptions of air pollution in the region, awareness of the campaign and the uptake of the campaign messages. Contained within the survey was a sub-sample of 252 people, who were motorists who actually drove past the emissions monitor. This was to allow for a comparison between those who drove past the monitor with the general population.

Perceptions of air quality in the region - When asked how they felt about the quality of the air in the region, the greatest share of respondents (49 per cent) described the air pollution as moderate but noted that it was becoming a serious issue for the region. Fourteen per cent stated that Auckland's air was polluted and it was a serious issue for the region.

By far the most frequently mentioned perceived cause of air pollution was emissions from cars (73 per cent). This was consistent with the survey results obtained in 2000 at the conclusion the 0800 Smokey campaign.

Campaign messages - Respondents were most aware that air pollution caused asthma and other respiratory problems with 59 per cent citing this effect. This was consistent with the campaign messages that were used in the radio advertising and motorway billboards.

Perceptions and attitudes to air pollution – Respondents were asked to evaluate seven perceptual/attitudinal statements indicating their level of agreement/disagreement for each one. The seven statements were:

Statement	Total Agreeing / Strongly Agreeing
Every car owner has a personal responsibility to reduce the amount of air pollution from their car.	95%
I believe I can reduce air pollution by maintaining/tuning my car.	91%
New Zealand should have laws about the levels of emissions permitted from cars.	87%
Reducing traffic congestion will reduce the air pollution problem.	83%
A better public transport system will reduce the air pollution problems.	82%
Air pollution is a central government issue.	64%
Scientists/technology will solve the air pollution problem so what I do now is irrelevant.	16%

Levels of agreement were highest for the perception that every car owner has a personal responsibility to reduce the amount of air pollution from their cars (95 per cent *agreeing* or *strongly agreeing* with this statement). Levels of agreement were also high for the perception that maintaining/tuning vehicles reduces air pollution (91 per cent *agreeing/strongly agreeing*), and that New Zealand should regulate the level of emissions permitted from cars (87 per cent *agreeing/strongly agreeing*). The understanding among respondents that they needed to take personal responsibility for reducing air pollution was also reflected in the fact that levels of agreement were lowest for the perception that scientists and technology would solve the air pollution problem so what people did now was irrelevant (only 16 per cent *agreeing/strongly agreeing* with this statement).

Awareness – 55 per cent of the regional public were aware of the air campaign unprompted. A further 14 per cent stated that they were aware of The Big Clean Up air quality campaign, when prompted with the main messages of the campaign. Those who drove past the monitor during the campaign were significantly more likely to be aware of the campaign (94 per cent) than those who did not (63 per cent).

Level of support for campaign – Almost all respondents aware of the campaign (96 per cent) stated that they "supported" or "strongly supported" the campaign. Only three per cent expressed any opposition to the campaign.

Behaviour change – Just over a quarter of respondents who were aware of the air quality campaign (26 per cent) stated that they had taken some action as a result of the campaign. Actions taken included:

- Tuned my vehicle more regularly/often (17 per cent of those aware of the campaign);
- Don't use my vehicle as often/use public transport more/walk more (five per cent);
- More aware of pollution issues (two per cent); and
- Buying a new car (two per cent).

For the remaining 74 per cent of those aware of the campaign, the reasons for not taking any actions as a result of the campaign included:

- Already doing everything I can/already tune my car regularly (58 per cent of those aware of the campaign);
- Don't believe I contribute to/cause air pollution (five per cent);
- Don't know enough about the campaign (three per cent);
- Too busy (two per cent);
- Can't afford to take action (two per cent); and
- Don't believe air pollution is a significant problem (two per cent).

Awareness and impact of drive-by monitor – Just less than a third of respondents who owned a motor vehicle could recall having driven past the monitor. Forty-six per cent of the respondents who could recall having driven past the monitor stated that their vehicle received a 'good' rating. Sixteen per cent recalled a 'fair' rating with only seven per cent reporting that they received a 'poor' rating. This was consistent with the actual measurement data that showed that 8.5 per cent of those who drove past the monitor received a 'poor' rating.

Of the 11 respondents who reported receiving a 'poor' rating when driving past the monitor, seven (64 per cent) could recall receiving a letter from ARC encouraging them to have their vehicle tuned. Eight out of the 11 respondents reported having taken some action as a direct result of their 'poor' reading and/or the follow up letter. These actions include:

- Had vehicle tuned (n=4);
- Booked in vehicle to have it tuned (n=3); and
- Sold vehicle (n=1).

The remaining three respondents who received a 'poor' rating but had not taken any action at the time of their interview all stated that they intended to get their vehicle tuned in the near future.

A1.7 Conclusion

The Big Clean Up Air campaign was successful in creating/enhancing awareness among motorists of the role vehicle emissions played in creating air pollution and also in encouraging motorists to take personal responsibility for the air pollution problem in the region (irrespective of how significant they perceived this problem to be) by having their vehicles tuned regularly. While the findings suggested that residents wanted to see organisations such as central government more involved in addressing the air pollution issue through implementing vehicle pollution regulations, they also acknowledged that they needed to – and could – take steps themselves to reduce the problem.

The physical presence of the emissions monitor had an impact on enhancing the awareness of the campaign (those who saw/drove past the monitor were more likely to be aware of the campaign than those who did not, and also more likely to be aware of the ARC's involvement). The campaign was also relatively successful in encouraging changes in behaviour, with just over a quarter of those aware of the campaign having taken some action – the greatest share of these actions heeding the campaign's main message and tuning their vehicle, or taking steps to reduce vehicle emissions generally. The readings from the emissions monitor and the follow-up letters were particularly helpful in encouraging behavioural change.

Appendix 2: Skewed (non-normal) nature of vehicle emission data

The purpose of this appendix is to illustrate the skewed nature of the of the RSD vehicle emission data (i.e. it does not form a normal distribution). The information contained in this appendix explains the need to use non-parametric statistical methods to analyse the data.

Figure A2.1 shows a box plot of carbon monoxide (CO) emissions from petrol and diesel vehicles measured in the 2005 road-side vehicle emission monitoring campaign. This box plot is a basic way of graphically showing that 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 that the data are skewed to the right.

Figure A2.1

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

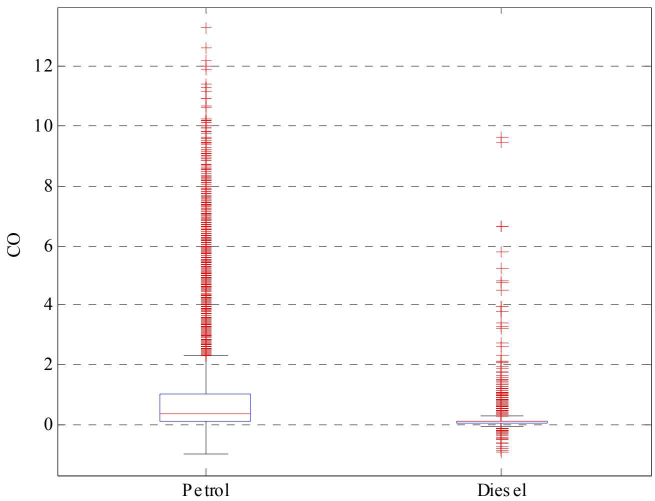
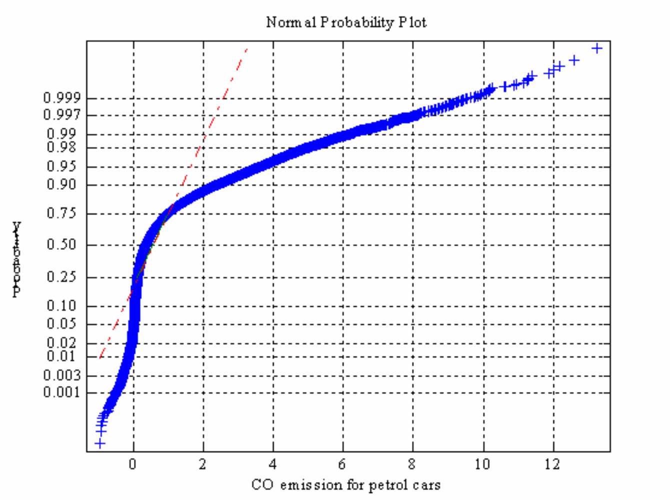


Figure A2.2 shows a normal probability plot for the CO emissions from petrol cars. A normal probability plot is a statistical way of comparing the actual distribution of the data to a normal distribution. If the data are normally distributed then the blue crosses should line up along the red line. For this dataset, the blue crosses deviate far from the red line so the data are not normally distributed.

Figure A2.2

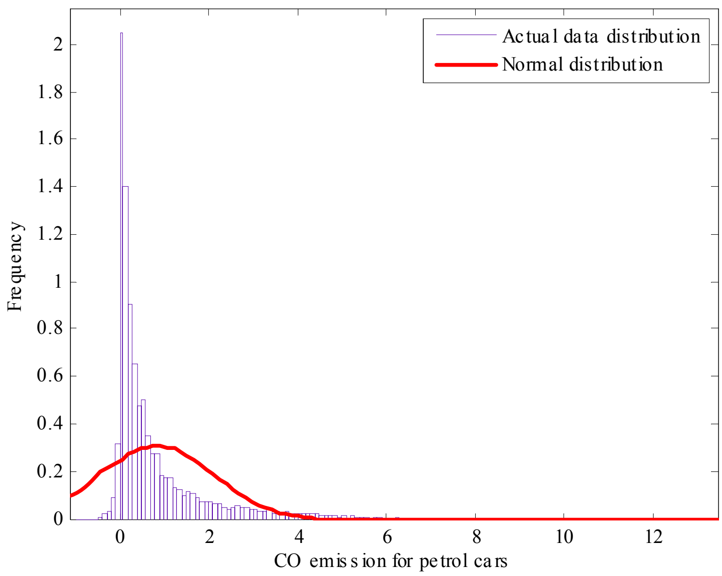
Normal probability plot of CO emissions from petrol vehicles



A histogram is another way to show graphically the distribution of the data. Figure A2.3 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 were 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 A2.3

Histogram of CO emissions from petrol vehicles



The Lilliefors test is another statistical test of whether data are 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 are definitely not normally distributed.

Skewed datasets can be analysed using the Kruskal-Wallis (K-W) test (a non-parametric[10] one-way analysis of variance). This test does not assume that the data come from a *normal* distribution (though it does assume that all data come 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.

The results from the K-W test can be displayed as error-bars for visual comparison (e.g.Figure 3.7). If the error bars of two groups that are being compared do not overlap, then the two groups are significantly different. The significance level used for all K-W tests in this report was 95 per cent.

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

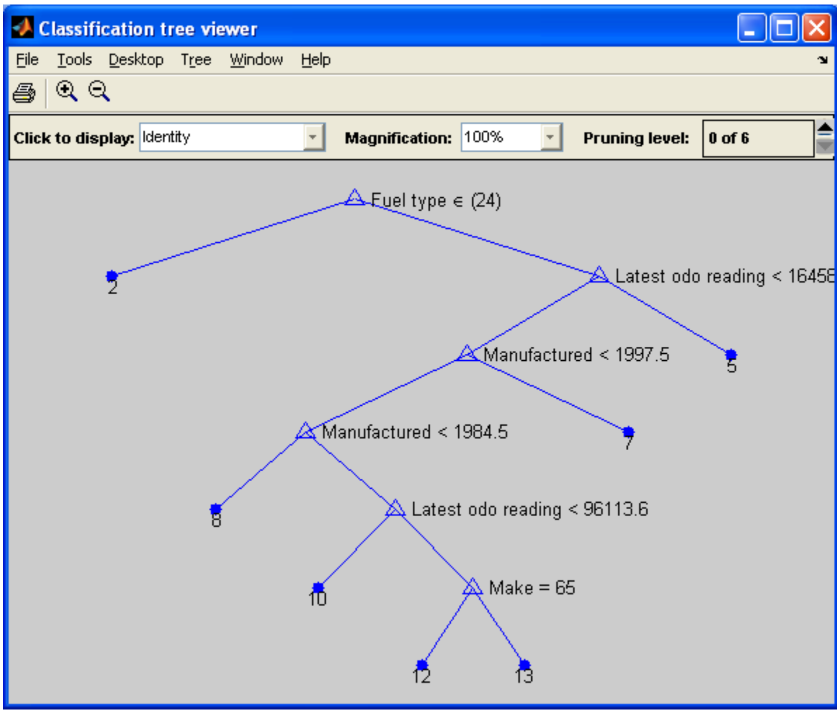
Appendix 3: Description of multivariate regression trees

Multivariate regression trees, also known as tree models, can be used to look for relationships in complex data with very few assumptions about data distribution and interactions. Tree models can handle more than one *response* variable at a time so it is possible to identify a group of vehicle characteristics that explain differing emission profiles.

A tree model identifies which *predictor* variables explain the most variation in the *response* data. In the example in Figure A3.1, the predictor variables are vehicle characteristics including fuel type, year of manufacture, odometer reading and vehicle make. A full list of the predictor variables used by the tree model is listed in Appendix 3.1. The response variables are the vehicle emission data for CO, HC, NO and opacity (uvSmoke). The tree model clusters the vehicles into groups with similar emission values using rules based on the 'predictor' variables. Figure A3.1 illustrates the graphical output from the tree model used in this example.

Figure A3.1

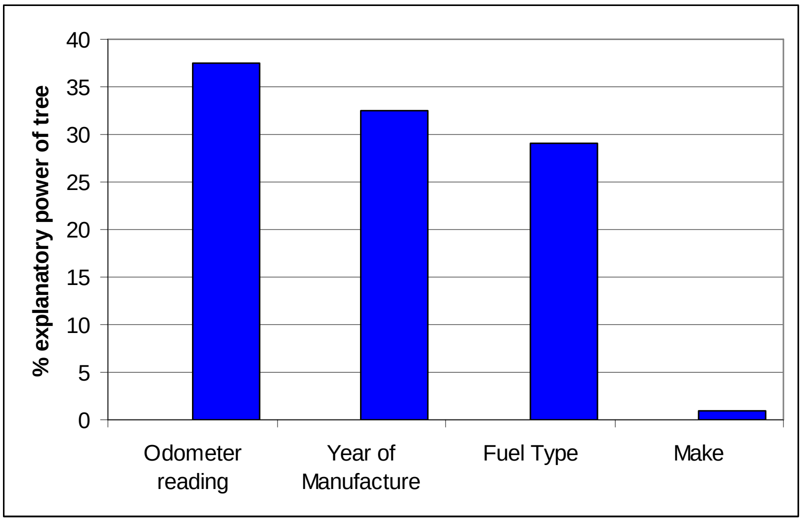
Graphical example of a tree model output



All data starts in one group at the top node. This tree clusters the data into seven groups (there are seven terminal nodes on the tree). The clustering criteria are defined by the predictor variables (in this case, fuel type, odometer reading, year of manufacture and vehicle make). The model evaluates the data then splits the dataset automatically. The first split is on fuel type (cars with fuel type = 2 or 4 go to the left and all other cars go to the right). The left node does not split again and these cars form final group 2. The cars that go right are next split on their odometer reading. Cars with low odometer readings (<160,000km) go left and all others go right. The cars with high odometer readings are not split again and form final group 5. Vehicles not either of group 2 or 5 are then split on year of manufacture and so on.

The tree can be dissected to obtain a breakdown of the contribution that each predictor variable makes to the explanatory power of the tree (Figure A3.2). Here the first three predictors make considerable contributions to the predictive power of the tree. However vehicle make does not contribute much predictive power.

Figure A3.1
Breakdown of explanatory power of tree model



The models were pruned using ten-fold cross validation. The final tree size was chosen by selecting the smallest cross-validation tree that yielded a cost within one standard error of the minimum cost achieved. A tree of this size was then fitted to the complete dataset to create the final model. Cost in this context is defined is a measure of the error in the predictions when a tree model is applied to a new dataset.

The data in any final group can be analysed to establish the emission profiles of the vehicles within this group. For example, node 5 contains petrol cars with high mileage. Nineteen cars from the random 1,000 cars used in this model ended up in this group. The median value of the emissions measured from the vehicles contained within node 5 is shown in Table A3.1.

Table A3.1

Median value of the emissions measured from the vehicles contained within node 5

Pollutant	Median value
CO (%)	0.7
HC (ppm)-	300
NO (ppm) -	600
UVsmoke	0.1

The emission profile of vehicles within each node can then be compared to other nodes to establish what effect different combinations of vehicle characteristics have on determining emissions.

A3.1 Predictor variables

The full list of predictor variables used for the multivariate tree analysis undertaken on the remote sensing data included:

- year of manufacture;
- fuel type;
- vehicle make;
- engine power (kW);
- gross vehicle mass (kg);
- latest odometer reading (km);
- engine capacity (cc);
- location of monitoring site;
- purpose of vehicle use; and
- country of first registration (if not New Zealand new).

With the response variables being:

- carbon monoxide (CO) emissions;
- hydrocarbon (HC) emissions;
- nitric oxide (NO) emissions; and
- opacity as uvSmoke (which is a proxy for particulate emissions).

Multivariate tree analysis takes into consideration any correlation that may exist between different predictor variables by first selecting the one variable that best explains the variation then performing the rest of the assessment on the remainder of unexplained variation, thereby ignoring any duplicate information in any correlated predictor variables.

A3.2 Gross emitter multivariate regression trees

A3.2.1 CO gross emitters

Figure A3.3 shows the Regression tree model for CO. The number below each dot (terminal node) is the average square root of CO emissions for the vehicles in that node. The regression tree terminal nodes 26 and 27 (circled in red) contain 684 vehicles. This group captures 40 per cent of the CO gross emitting vehicles and only three per cent of the CO typical emitting vehicles. The groups of vehicles in the circled nodes (28 and 29) are discussed in Section 5.4.1.

Figure A3.3

Regression tree model for CO

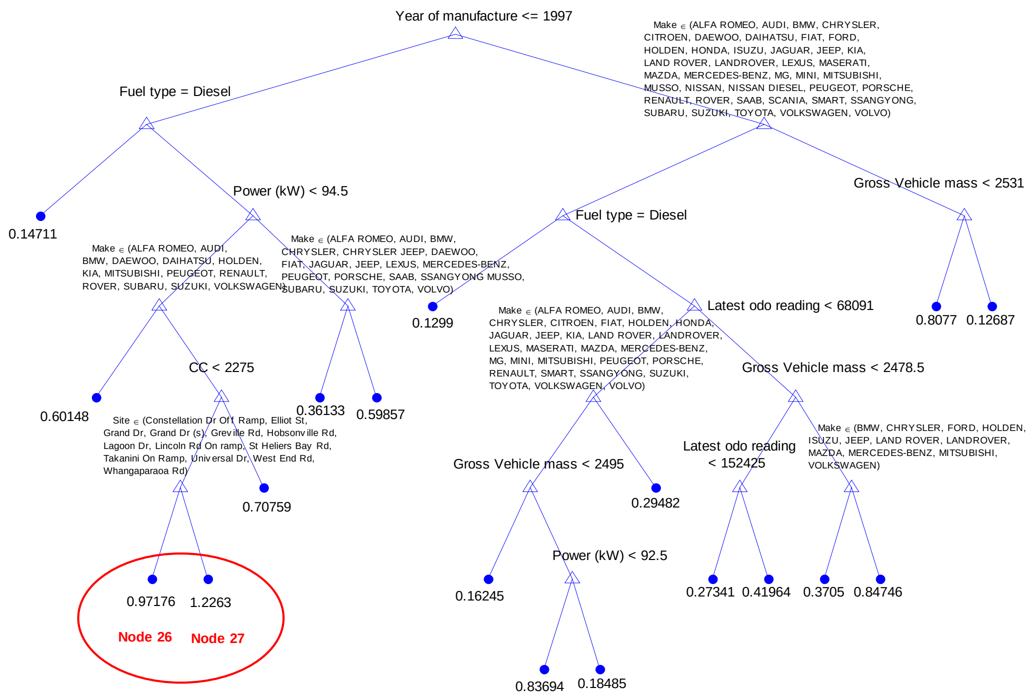
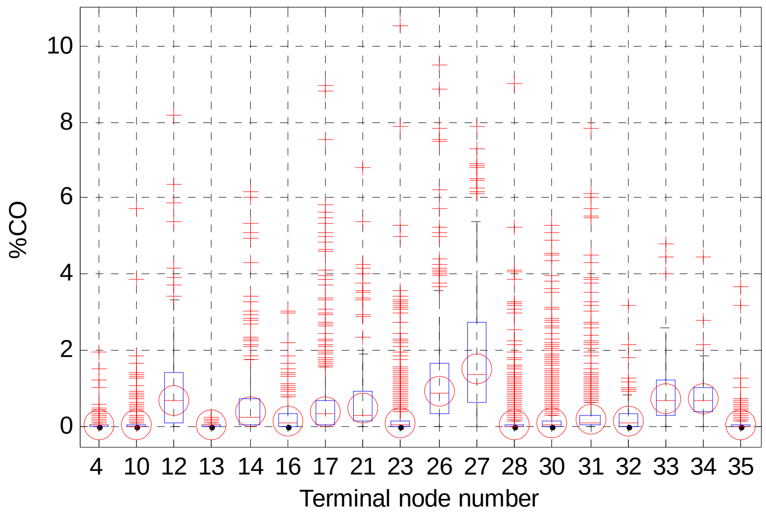


Figure A3.4 shows the distribution of CO emissions in the vehicle classes created by the regression tree model. The red line shows the median, boxes show the quartiles, and red circles indicate the CO reading from the tree for each node.

Figure A3.4

Distribution of CO emissions for vehicles in terminal nodes created by the regression tree model



A3.2.2 HC Gross Emitters

Figure A3.5 shows the Regression tree model for HC. The number below each dot (terminal node) is the average square root of HC emissions for the vehicles in that node. The regression tree terminal nodes 7 and 14 (circled in red) contain 1,200 vehicles. This group captures 41 per cent of the CO gross emitting vehicles and only seven per cent of the CO typical emitting vehicles. The groups of vehicles in the circled nodes (7 and 14) are discussed in Section 5.4.2.

Figure A3.5

Regression tree model for HC

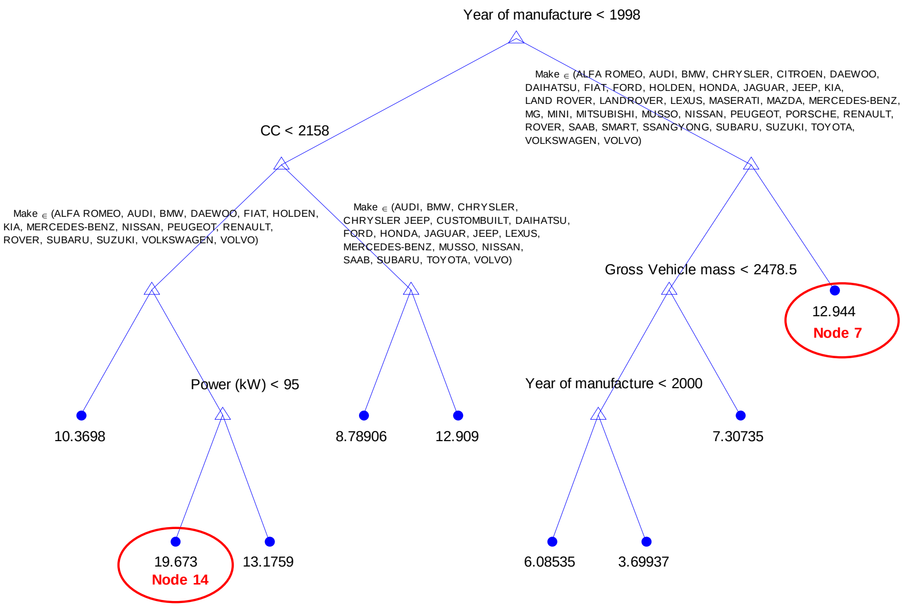
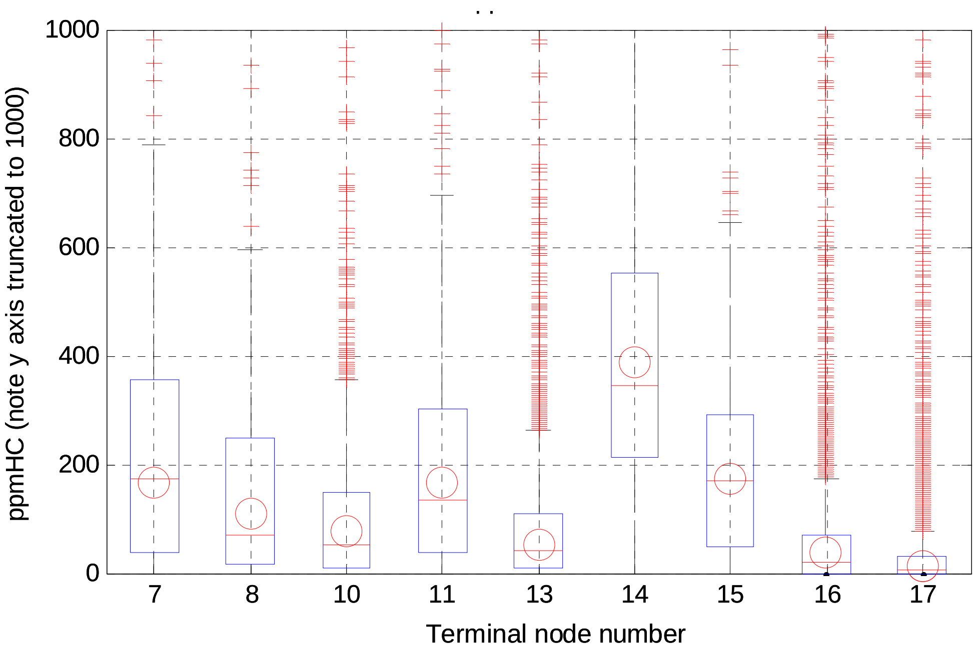


Figure A3.6 shows the distribution of HC emissions in the vehicle classes created by regression tree model. The red line shows the median, boxes show the quartiles, and red circles indicate the HC reading from the tree for each node.

Figure A3.6

Distribution of HC emissions for vehicles in terminal nodes created by the regression tree model



Note that y axis has been truncated to show the boxes more clearly.
The highest reading is ~15,000ppm and 1.0% of the HC readings are above the 1,000ppm limit of the y axis

A3.2.3 NO gross emitters

Figure A3.7 shows the regression tree model for NO. The number below each dot (terminal node) is the average square root of NO emissions for the vehicles in that node. The regression tree terminal nodes 24, 25, 34-37, 20 and 46-49 (circled in red) contain 1,551 vehicles. This group captures 54 per cent of the NO gross emitting vehicles and seven per cent of the NO typical emitting vehicles. The groups of vehicles in the circled nodes (20, 24, 25, 34-37 and 46-49) are discussed in Section 5.4.3.

Figure A3.7

Regression tree model for NO emissions

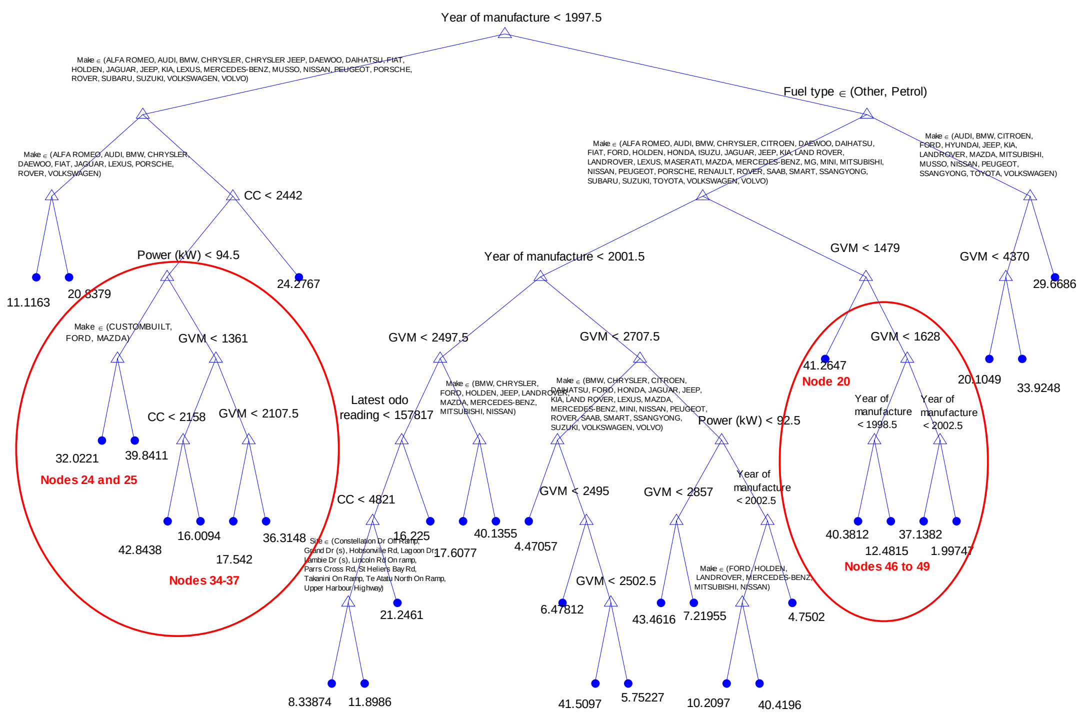
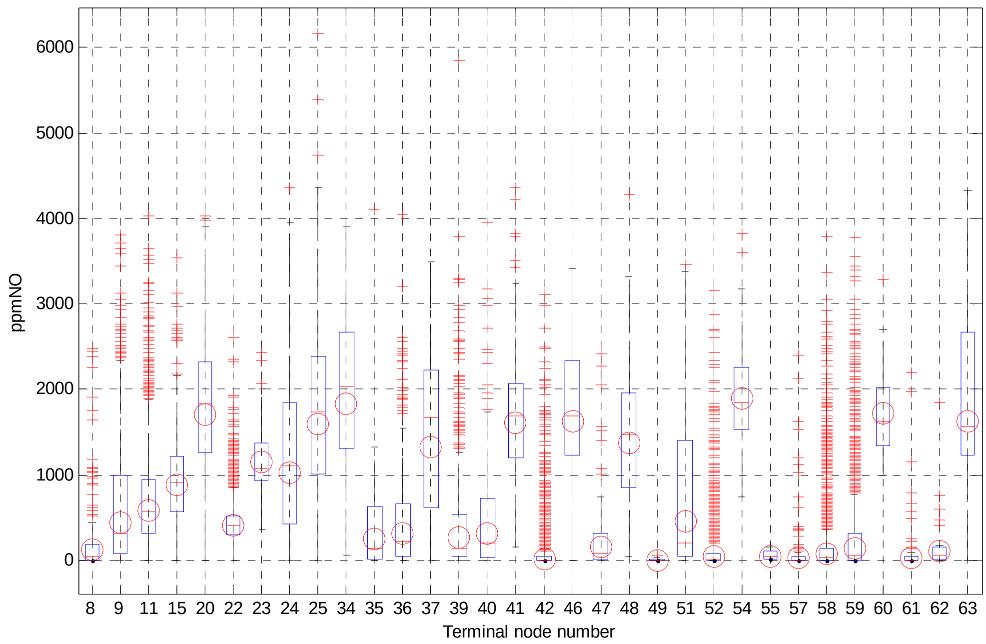


Figure A3.8 shows the distribution of NO emissions in the vehicle classes created by regression tree model. The red line shows the median, boxes show the quartiles, and red circles indicate the NO reading from the tree for each node.

Figure A3.8

Distribution of NO emissions for vehicles in terminal nodes created by regression tree model



A3.2.4 uvSmoke gross emitters

Figure A3.9 shows the regression tree model for uvSmoke. The number below each dot (terminal node) is the average square root of uvSmoke emissions for the vehicles in that node. The regression tree terminal nodes 6, 13, 20, 24, 25 and 27 (circled in red) contain 3,446 vehicles. This group captures 81 per cent of the uvSmoke gross emitting vehicles and 20 per cent of the uvSmoke typical emitting vehicles. The groups of vehicles in the circled nodes (6, 13, 20, 24, 25 and 27) are discussed in Section 5.4.4.

Figure A3.9

Regression tree model for uvSmoke emissions

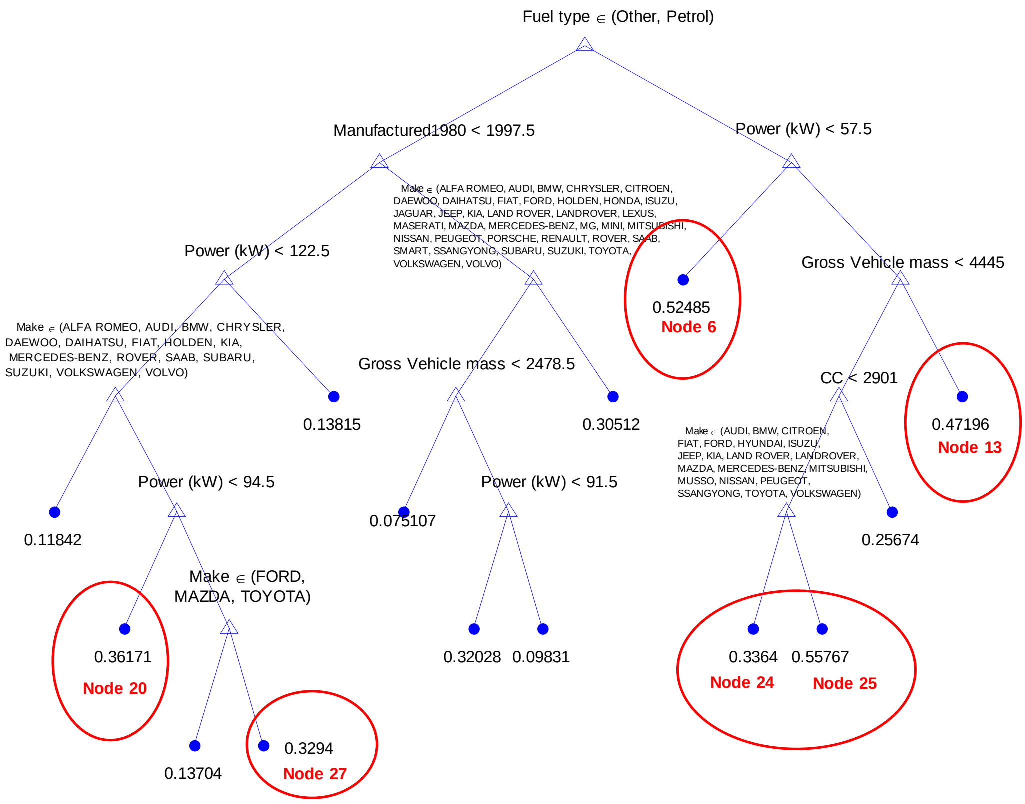
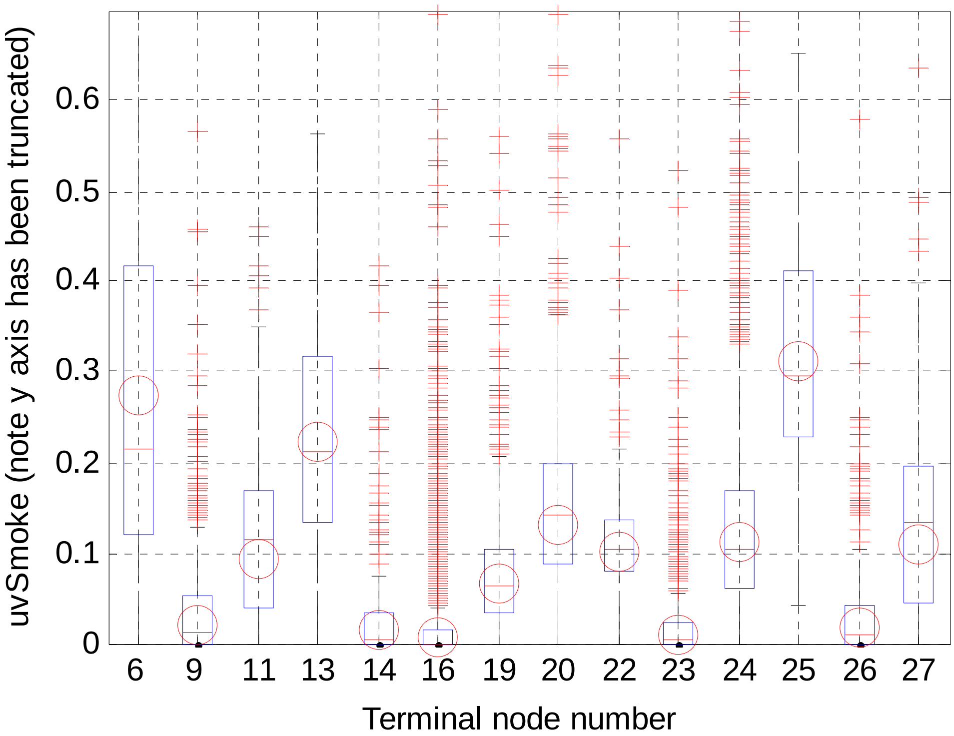


Figure A3.10 shows the distribution of uvSmoke emissions in the vehicle classes created by regression tree model. The red line shows the median, boxes show the quartiles, and red circles indicate the uvSmoke reading from the tree for each node.

Figure A3.10

Distribution of uvSmoke emissions for vehicles in terminal nodes created by the regression tree model.

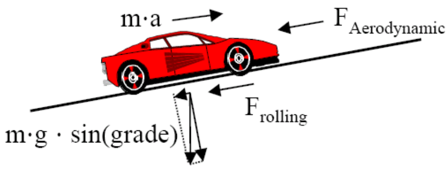


Note that the y axis has been truncated to show the boxes more clearly.

The highest uvSmoke reading is 8.9 and 0.6% of the uvSmoke readings are above the 0.7 limit of the y axis.

Appendix 4: Calculation of vehicle specific power

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 following diagram.



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

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

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

Where:

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

a is the vehicle acceleration (m/s2)

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

vw 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 results of different methods and conditions, such as IM240 drive cycle tests and remote sensing.