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REMOTE SENSING OF VEHICLE EMISSIONS (IT'S MONITORING, JIM - BUT NOT AS WE KNOW IT!)

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ABSTRACT

This paper outlines the results of a remote sensing measurement programme undertaken in Auckland with Auckland Regional Council in April/May 2003 to measure exhaust emissions of a large number of motor vehicles. Based on a technique used extensively overseas, the study measured tailpipe emissions from over 40,000 vehicles at 15 sites across the Auckland region. Measurements of the emissions of carbon monoxide (CO), nitric oxide (NO), unburned hydrocarbons (HC), and opacity (as an indicator of particulate emissions) were made in the exhausts of vehicles as they drove along the road. This was the first time such a system had been used in New Zealand to provide comprehensive real-world characterisation of vehicle fleet emissions.

A statistically significant and representative sample of most vehicle types found in the Auckland motor vehicle fleet was obtained. The one vehicle type under-represented was the "heavy duty vehicle", as these often have exhausts located above the cab beyond the range of the roadside sensor. Analyses were conducted in order to characterise the nature and source of emissions as comprehensively as possible. Emissions results were broken down by vehicle age, fuel type, year of manufacture, country of origin, and were compared with similar remote sensing studies undertaken overseas.

This paper presents the results and analysis of the emissions for a subset of 15,000 vehicles (for which complete datasets were available at time of writing) and focuses on CO emissions. CO was chosen as it is a good indicator of the state of tune of the vehicles. The full analysis for all valid readings and all contaminants is currently pending and will be released later this year but preliminary processing indicates that the conclusions presented here are unlikely to be altered substantially.

The remote sensing campaign has yielded significant information about emissions from the New Zealand fleet. The data provide a baseline for emissions performance of the fleet so that the effectiveness of proposed policies to reduce vehicle emissions can be assessed. The data are also being used to raise public awareness about vehicle emissions and the need for vehicle maintenance.

Keywords: remote sensing, vehicle emissions, fleet characterisation, air quality, gross emitters

1. MOTOR VEHICLES AND AIR QUALITY

1.1 AMBIENT LEVELS AND HEALTH EFFECTS

Poor air quality can seriously affect people's health and well being. Major cities in New Zealand such as Auckland (see **Table 1**), often record exceedences of the Ministry for the Environment guidelines for ambient air quality (MfE, 2002), which are intended to protect human health and the environment. Many of these exceedences are caused by motor vehicle emissions. Auckland Regional Council (ARC) started monitoring traffic-related air quality at Queen St in 1991, where regular exceedences of the guideline for carbon monoxide (CO) were recorded. The ARC now monitors air quality at peak traffic, residential and remote sites all around the region.

Table 1 Number of days of exceedence of the ambient air quality guidelines in Auckland (source: ARC).

	Number of Days in a Year Where At Least One Exceedence Has Occurred				
	1998	**1999**	**2000**	**2001**	**2002**
PM_{10}	2	4	4	7	3
NO_2	23	27	23	38	30
CO	32	31	3	3	2
Total *	**53**	**57**	**30**	**48**	**35**

* The total number of days on which an exceedence of any of the air quality guidelines for fine particulate (PM_{10}), nitrogen dioxide (NO_2), or carbon monoxide (CO) occurred at one site or more (calculated from the sum of the separate days during which an exceedence was recorded, with no day being counted twice due to multiple exceedences).

Although most of the guideline exceedences occur at peak traffic monitoring sites, we now know that even very low levels of air pollution can damage health. A recent report to the Ministry of Transport (Fisher *et al*, 2002) estimates that particulate air pollution alone results in 436 premature deaths per annum in the Auckland Region, and that 253 of these are attributable to motor vehicle emissions.

Survey work undertaken by the ARC in 2001 suggested that air pollution was regarded as an environmental problem for the region by 47% of respondents (Forsyte Research, 2001). A national survey in 2000 by Lincoln University found that clean air ranks more highly for public spending than many other environmental issues and is exceeded only by people's desires for better health, education and crime prevention (Hughey *et al*, 2001).

1.2 EMISSIONS ESTIMATES AND REDUCTION STRATEGIES

Clearly, air pollution is a serious issue in the Auckland Region. As with all of Auckland's environmental issues, the ARC recognises that the solution will require action from central and local government as well as the community but in order for the Council to develop effective reduction strategies, the actual contribution arising from vehicles needs to be quantified.

However, New Zealand has very limited regulation of vehicle emissions. Although Central government is now planning to implement emissions requirements for new vehicles and developing in-use emissions requirements, one consequence of the historical lack of regulation is limited information surrounding the emissions performance of the fleet in New Zealand. This makes it almost impossible to develop targeted policies to reduce emissions, and to monitor the effectiveness of any policy that is implemented.

From the Auckland Air Emissions Inventory, vehicles in 2003 are estimated to produce up to 83% of the carbon monoxide (CO), 82% of the nitrogen oxides (NOx) and 46% of the volatile organics (VOCs) through exhaust and evaporative emissions (ARC, 1997). These estimates are based on emission factors that have been developed from a limited number of chassis dynamometer drive cycle tests undertaken for selected New Zealand vehicles then extrapolated to the whole vehicle fleet (MoT, 1998).

Studies (e.g. Walsh *et al*, 1996), however, show that dynamometer testing programmes tend to under-estimate "real-world" emissions. This is due to a number of possible factors – such as not adequately representing a true drive cycle, not estimating emissions properly, or not accounting for all vehicles - but the main reason is that the bulk of emissions generally come from a small proportion of vehicles known as the "gross emitters".

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). A remote sensing system has been tested in several New Zealand cities in recent years, using infrared to measure carbon monoxide (CO) and hydrocarbon (HC) emissions (Gong, 2002). In these trials however, measurements were undertaken on a limited number of vehicles. Consequently, the study reported in this paper represents the first time that significant remote sampling has been implemented to provide a representative picture of the "real-world" emissions of the New Zealand fleet.

2. MEASURING VEHICLE EMISSIONS

2.1 WHY USE REMOTE SENSING?

Knowing the quantity of pollutants that the vehicle fleet is emitting to the air has become a vital question for many people and organizations. Currently in New Zealand, the estimation of the quantity of pollutants discharged by our vehicle fleet is done indirectly. For instance, emissions are determined by putting selected vehicles on a dynamometer, running them through a typical "drive cycle" and then collecting and analysing the exhaust stream. From these measurements, extrapolations are made to the whole fleet, or to particular scenarios.

Recent studies, however, show that such methods tend to under-estimate real-world emissions. This is due to a number of possible factors – such as not adequately representing a true drive cycle, not estimating emissions properly, or not accounting for all vehicles - but the main reason is that the bulk of emissions generally come from a small proportion of vehicles known as the "gross emitters". It is difficult to capture the effect of gross emitters adequately in a selected dynamometer testing programme.

One way around this is to use a remote sensing device (RSD) to sample the actual exhaust emissions of a large number of vehicles in a real world situation. Such devices are used extensively overseas in Europe and USA, and provide more accurate, more comprehensive and more representative information on vehicle emissions than previously possible. In addition to directly measuring emissions, these systems can also be linked to a real-time display giving each driver a message as to whether their vehicle has "good", "fair" or "poor" emissions. The message is tied to the implication that "poor" emissions indicate a badly tuned, and inefficiently run vehicle, which costs the motorist money.

2.2 HOW DOES REMOTE SENSING WORK?

Remote sensing refers to measuring vehicle exhaust emissions as the vehicle passes using equipment located on the roadside (known as a remote sensing device or RSD). Unlike traditional equipment used to measure emissions, RSDs do not need to be physically connected and therefore do not interfere with the progress or operation of the vehicle.

The remote sensor used in this study was developed at the University of Denver, USA (see http://www.feat.biochem.du.edu/whatsafeat.html). The instrument consists of an infrared (IR) component for detecting carbon monoxide (CO), carbon dioxide (CO_2) and hydrocarbons (HC), and an ultraviolet (UV) spectrometer for measuring nitric oxide (NO). The source and detector units are positioned on opposite sides of the road. Beams of IR and UV light are passed across the roadway into the IR detection unit, and are then focused onto a beam splitter, which separates the beams into their IR and UV components. The IR light is then 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 ultraviolet spectrometer. The UV unit is then capable of quantifying NO by measuring an absorbance band in the ultraviolet 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, %HC and %NO in the exhaust gas, corrected for water and excess oxygen not used in combustion.

Quality assurance calibrations are performed as dictated in the field by atmospheric conditions and traffic volumes. A puff of gas containing certified amounts of CO, CO_2, propane and NO is released into the instrument's path, and the measured ratios from the instrument are then compared to those certified by the cylinder manufacturer. These calibrations account for hour-to-hour variations in instrument sensitivity and variations in ambient CO_2 levels caused by atmospheric pressure and instrument path length. Since propane is used to calibrate the instrument, all hydrocarbon measurements reported by the remote sensor are given as propane equivalents.

Some commercially available RSD systems also incorporate speed and acceleration detectors together with a digital camera. This allows the licence plate details, the vehicle driving conditions, and the exhaust emissions data to be simultaneously recorded with a time and date stamp stored on the video image. All these data are sensed and stored, with each remote sensing test taking less than one second.

Figure 1 shows a schematic diagram of a remote sensing system that measures CO, CO_2, HC, NO, and opacity set up along a single lane of road. The registration plate of the vehicle is recorded on video and make and model year of the vehicle are later identified from the video picture.

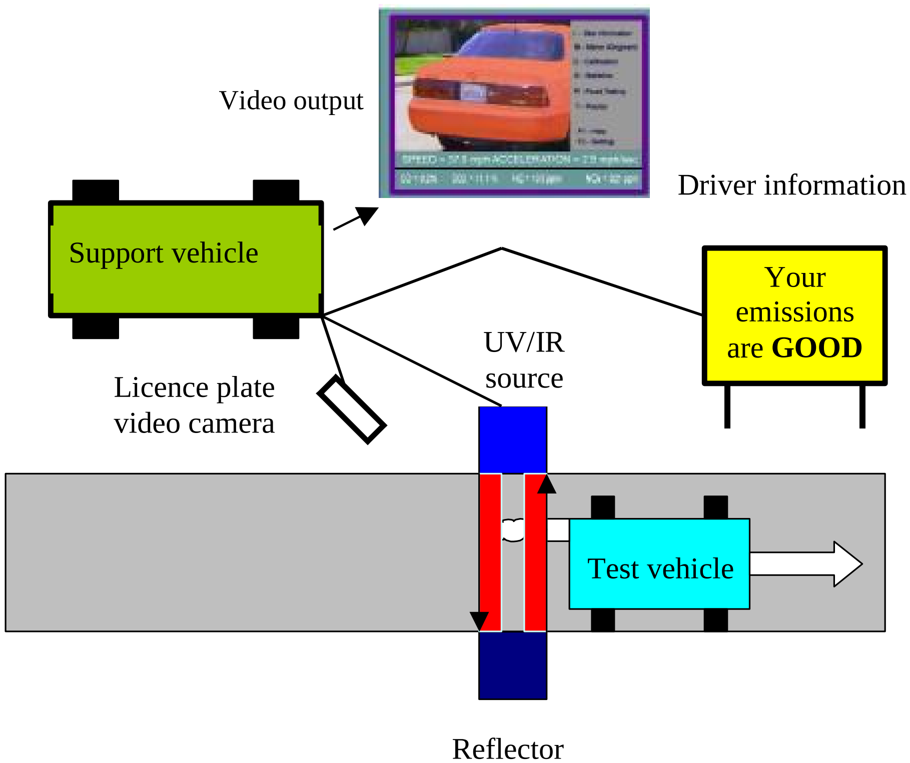

Figure 1 Schematic diagram showing a remote sensing system in operation.

Remote sensing is now used extensively in the US and has been trialled in Europe and Japan for roadside enforcement of emissions standards.

3. THE AUCKLAND ON-ROAD REMOTE SENSING STUDY

3.1 OBJECTIVE

As part of the 'Big Clean Up' campaign in 2003, the Auckland Regional Council (ARC) commissioned an "On-Road Remote Sensing of Automobile Emissions" project to investigate the actual emissions from the fleet on the road network. The monitoring programme was carried out by the National Institute of Water and Atmospheric Research (NIWA) Limited with assistance from the University of Denver, USA who developed the original RSD technique in the early 1990s. The project was funded primarily by the ARC with a contribution from the Foundation for Research Science and Technology via the Urban Air Quality Processes Programme (C01X0216).

The project aim was to obtain emissions information for up to 40,000 vehicles, sampling across a wide sector of the fleet, to obtain a representative profile of vehicles in the Auckland region. The measured pollutants included CO, CO_2, NO, HC, opacity (as a qualitative indicator of particulates).

Educating motorists on the need to properly maintain vehicles was a major focus of the campaign so the remote sensing system was coupled to an on-road display, giving drivers immediate feedback on the state of tune of their vehicles (see **Figure 2**). Based on the CO emissions of the vehicles (Bishop *et al*, 2000), the display provided an immediate indication of the vehicle's emissions as follows:

- "Good" - your vehicle is performing well (%CO $\leq$1.3)
- "Fair" - your vehicle could do with a tune up (1.3< %CO $\leq$ 4.5)
- "Poor" - your vehicle is badly tuned and costing you money (%CO > 4.5)

Figure 2 The remote sensing system in action with the on-road display showing a "fair" reading in the background.

CO was chosen as it is a good indicator of the state of tune and the trigger levels for each of the categories were based on levels set in other countries, allowing for the age of the New Zealand fleet.

3.2 MONITORING SITES

The sampling campaign was carried out in April 2003 at 15 sampling sites across seven territorial local authorities: Auckland City; Manukau City; Waitakere City; North Shore City; Franklin District; Rodney District; and Papakura District. The remote sensor was deployed on single lane roads, including motorway on ramps and off ramps, so that emissions from individual vehicles could be measured.

Around 52,000 vehicles were sampled resulting in approximately 42,000 valid readings, (80.55% of the total sample). The licence plates of these vehicles were recorded on videotape. At the time of writing this paper, plates from 15,000 vehicles had been transcribed from the video recordings. Records for each of these vehicles were extracted from the Land Transport Safety Authority's (LTSA) Motochek vehicle database (LTSA, 2003) to gain details on year of manufacture, fuel type, country of first registration and odometer readings. This information was linked to the emissions data and was used to make comparisons and identify trends in vehicle emissions.

3.3 KEY FINDINGS

This paper presents the results and analysis of the emissions from the subset of approximately 15,000 vehicles (for which data have been extracted from Motochek) and focuses on CO emissions under the following topics:

- the fleet profile by age and fuel type
- CO emissions by year of manufacture
- CO emissions by fuel type (diesel vs petrol)
- CO emissions by country of origin (Japanese import vs NZ new)
- CO emissions by category of "good", "fair", "poor"
- CO emissions versus US values

The full analysis for all valid readings and all contaminants is currently pending and will be released later this year but preliminary processing indicates that the conclusions presented here are unlikely to be altered substantially.

3.3.1 Fleet Profile by Age and Fuel Type

Figure 3 shows the age profile of the vehicles in the Auckland fleet subset. The distribution displays a bi-modal pattern with a peak around 1994 and another around 2002. This is most likely due to the two time points where vehicles can enter the fleet – the first as Japanese used imports (generally around 7 years of age) and the second as New Zealand new vehicles. The average age of the vehicles in the sample Auckland fleet is 9 years old (manufactured in 1994) which is the same as that estimated for the New Zealand national fleet using published statistics (MED, 2001) and compares to an average age of approximately 10 years for the Australian vehicle fleet in 2001 (AAA, 2003).

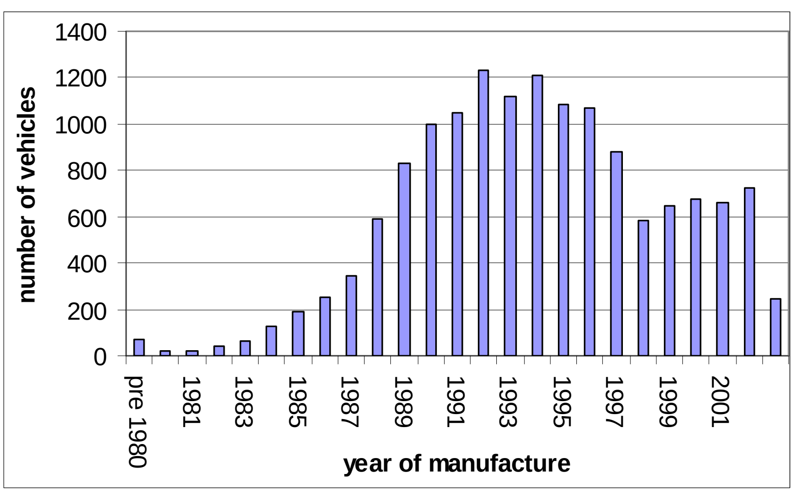

Figure 3 Age profile of the Auckland fleet subset.

Overall, the proportions of vehicles using petrol and diesel fuel were 86% and 14% respectively. **Figure 4** shows that there has been a general increase in the proportion of diesel-fuelled vehicles in each year of manufacture moving from 1980 to 2003. The data show that approximately 10% of older vehicles are diesel-fuelled and this has increased to approximately 20% for recently manufactured vehicles.

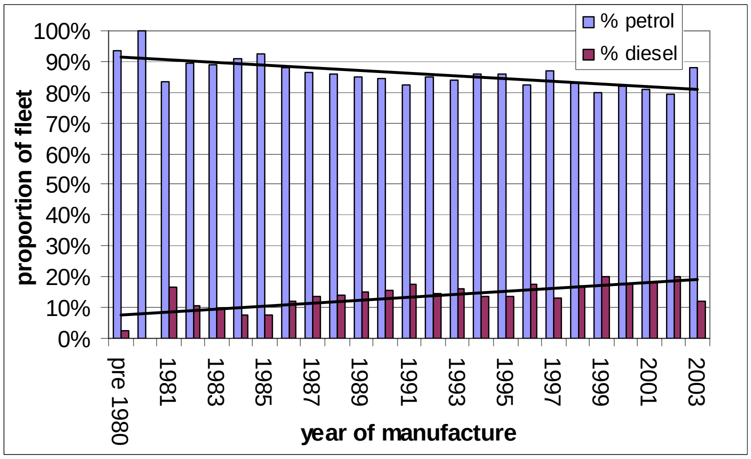

Figure 4 Proportion of petrol- and diesel-fuelled vehicles with year of manufacture.

3.3.2 Emissions By Year Of Vehicle Manufacture

Figure 5 shows how the sample fleet average emissions of CO vary with the year of vehicle manufacture. The error bars represent the 95% confidence intervals. These are very large for vehicles manufactured before 1984 because of the smaller number of vehicles in these age categories and the relatively large degree of variation in measurements from vehicles of this age.

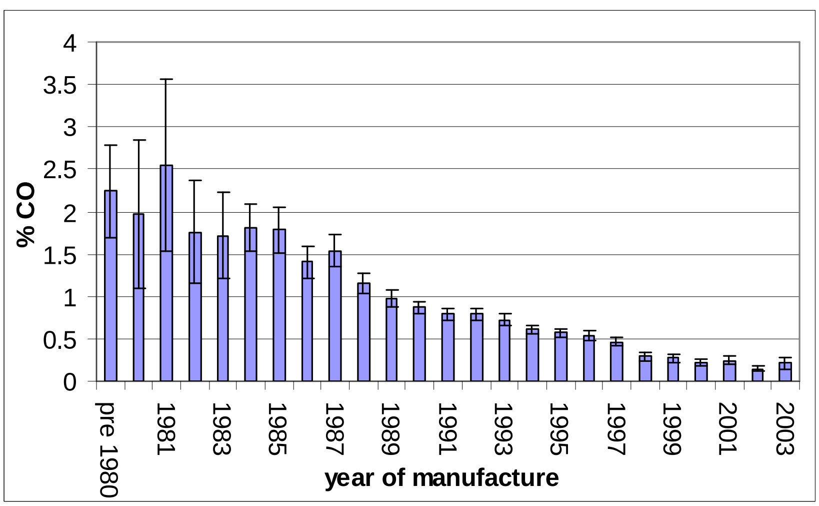

Figure 5 Variation of sample fleet average CO emissions with year of vehicle manufacture.

Overall, the sample fleet average emissions of CO decrease significantly over time as the vehicles become newer, most likely due to improvements in vehicle technology and the advent of emission control technology. It is possible that the trend shown is also due to the mileage travelled – with older vehicles tending to be of higher mileage – but we were unable to separate the effect of mileage from age at time of writing and are currently investigating this further.

3.3.3 Emissions By Fuel Type (Diesel vs Petrol)

To investigate how emissions vary with fuel type, the data were disaggregated according to fuel type. The sample fleet contained approximately 13,000 and 2,000 petrol and diesel vehicles respectively. Only 25 of the 15,000 vehicles in the sample fleet listed their primary or alternative fuel as LPG or CNG. Therefore, this analysis only considers petrol and diesel fuels.

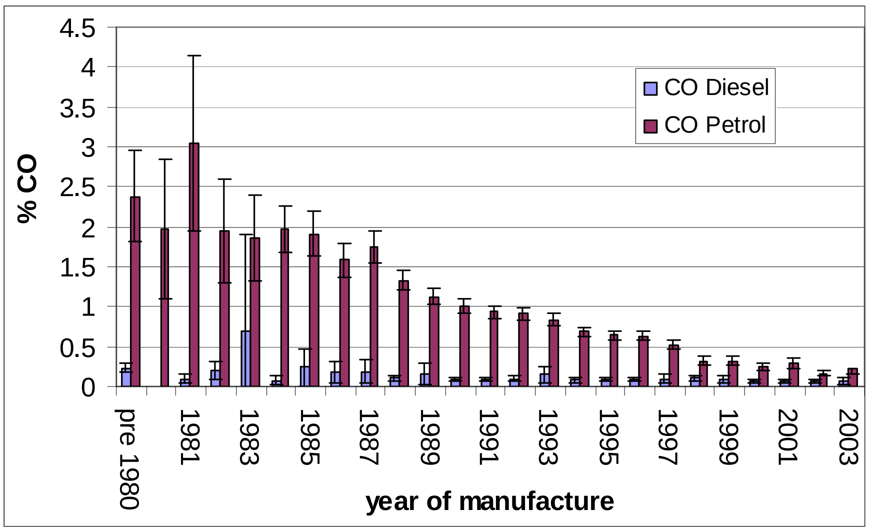

Figure 6 Variation of diesel and petrol fuelled vehicles average CO emissions with year of manufacture

On average, emissions of CO from petrol vehicles are approximately 10 times higher than those from diesel vehicles. However, the performance of petrol vehicles has improved dramatically with time whereas emissions from diesel vehicles have remained relatively static (see **Figure 6**). The comparison of the fuel types suggests that the improvements observed in the sample fleet average CO emissions are mostly because of the improvements gained in the petrol-fuelled vehicles, especially the developments in emissions control technology.

3.3.4 Emissions By Country Of Origin (Japanese Import vs NZ New)

New Zealand's vehicle fleet contains a significant proportion of imported used vehicles. The sample fleet comprised approximately 8,000 New Zealand new vehicles i.e. first registered and only driven in New Zealand (52.8%) and 7,000 imported used vehicles (47.2%). Around 97% of the imported vehicles originated in Japan therefore the comparisons that follow were confined to Japanese vehicles versus New Zealand vehicles only.

The comparison of petrol-fuelled vehicles was based on subset of vehicles manufactured between 1992 and 1999 to achieve statistically representative numbers of vehicles by each country of origin. This yielded 6,500 vehicles, of which 3,000 were New Zealand new vehicles and 3,500 were Japanese imported used vehicles. As seen in **Figure 7**, fleet average CO emissions are generally higher for New Zealand new vehicles. However, emissions for vehicles from both countries improve over time and toward the later end of the sample emissions from New Zealand new vehicles are of a comparable level to those of the Japanese used vehicles.

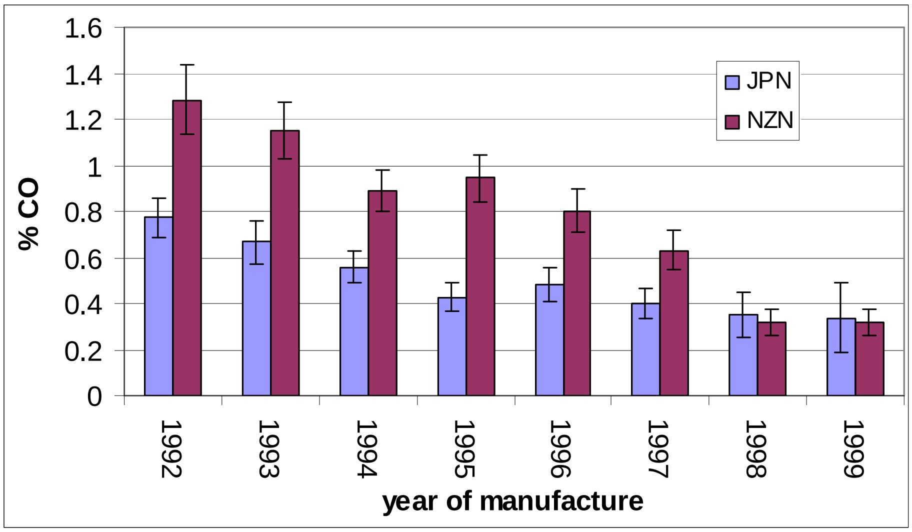

Figure 7 Comparison of average CO emissions for New Zealand new and Japanese imported petrol-fuelled vehicles against the year of manufacture.

The difference shown between New Zealand new and Japanese used vehicles is consistent with the results of an earlier New Zealand study of idle emissions undertaken in the Waikato region and Waitakere city (Raine et al, 1999). The investigation concluded that the lower emissions recorded for Japanese used vehicles were principally due to a higher technology level (such as fuel injection and catalysts) being required for vehicles to meet Japanese emissions regulations. As New Zealand has no emission regulations, New Zealand vehicles could consequently employ a lower level of emission control technology.

For diesel vehicles, the comparison was based on a subset of vehicles manufactured between 1993 and 1997. This included 800 vehicles, of which 300 were New Zealand new vehicles and 550 were Japanese imported used vehicles. As seen in **Figure 8**, it is difficult to draw any firm conclusions for differences between CO emissions for Japanese and New Zealand diesel vehicles. However, it is likely that any differences in diesel vehicles based on country of origin are also decreasing, as the vehicles get newer.

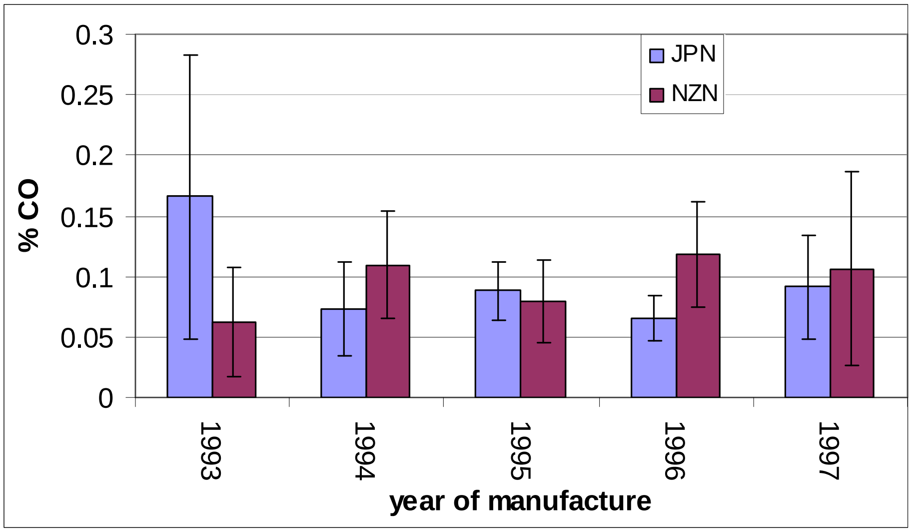

Figure 8 Comparison of average CO emissions for New Zealand new and Japanese imported diesel-fuelled vehicles against the year of manufacture

3.3.5 Emissions By Category and the "Gross Emitters"

High CO emissions are particularly useful indicator of poor vehicle maintenance and poor fuel economy. Finding and fixing the "gross emitters" is possibly the most cost-effective tool available for reducing urban air pollution (USEPA, 1996-1998 and USEPA, 2002). **Figure 9** presents the portion of vehicles in each emissions category of "poor" (%CO > 4.5), "fair" (1.3< %CO ≤ 4.5), and "good" (%CO ≤ 1.3) (Bishop *et al*, 2000), and the proportion of the total CO emissions arising from each category.

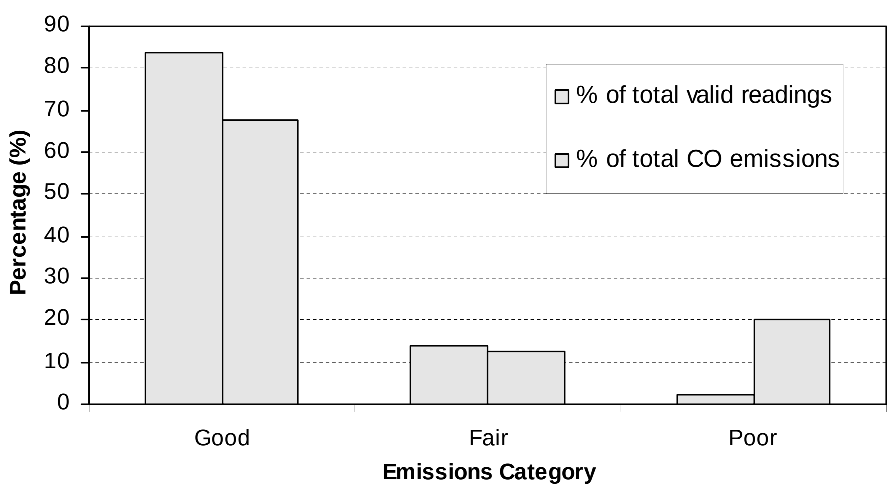

Figure 9 Breakdown of CO measurements into the assessment categories shown with their relative contributions to the total CO emissions

The figure implies that although badly maintained vehicles ("poor") account for only 2.3% of the fleet, they are responsible for 20.0% of the total CO emissions (based on the assumption that all vehicles travel equal mileage.) By comparison, fairly maintained vehicles ("fair") at 13.9% of the fleet are responsible for 12.4% of the total CO emissions, and well-maintained vehicles ("good") at 83.8% of the fleet are responsible for 67.5% of the total CO emissions. Further investigation shows that the top 10% most polluting vehicles (the "gross emitters") are responsible for 53% of the total CO emissions (see **Figure 10**).

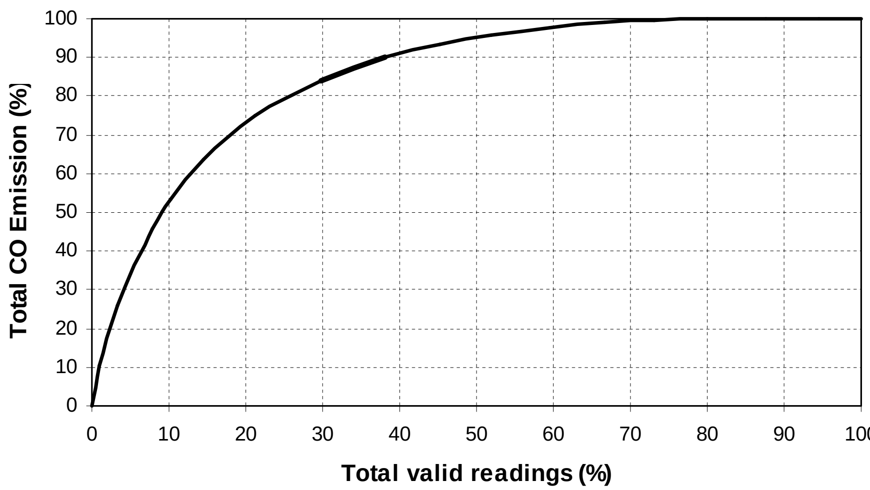

Figure 10 Cumulative fleet average CO emissions based on the worst to the best in terms of valid vehicle readings (assuming all vehicles travel equal mileage).

3.3.6 Auckland Emissions vs US Values

Table 2 compares emissions measured in the Auckland sampling campaign to similar measurements made in a number of cities in the United States. Data exist for Los Angeles (2001), Denver (2001), Phoenix (2000) and Chicago (2000) (taken from http://www.feat.biochem.du.edu/whatsafeat.html). The number of vehicles tested at each site has been included in **Table 2** an indicator of the sample size. The range of the average values recorded for the 15 Auckland sites is also shown.

Table 2 Comparison of the fleet average emissions measured in Auckland with selected cities in the United States

Location	Vehicle Number*	Average CO
Los Angeles (La Brea) 2001	24,751	0.44%
Los Angeles (Riverside) 2001	24,381	0.39%
Denver 2001	27,702	0.34%
Phoenix 2000	26,458	0.27%
Chicago 2000	26,054	0.26%
Auckland 2003	**42,057**	**0.71%** site averages (0.49 -0.92%)

*Valid readings for CO emissions.

Assuming the site characteristics were similar, the data suggest that on average the Auckland vehicle fleet emits approximately twice the amount of CO produced by vehicles in the US.

4. DISCUSSION AND SUMMARY OF KEY RESULTS

This is the first time such a comprehensive on-road vehicle monitoring programme has been conducted in New Zealand. It has used equipment and experience from collaborators who have conducted similar studies elsewhere but there are a number of issues that warrant further clarification.

Firstly, this is a preliminary analysis, based on a sub-sample of the total number of vehicles analysed. The final analysis is not anticipated to have different conclusions, but some of the more subtle trends may need to be revised.

Secondly, the sampling strategy attempted to obtain a representative sample of vehicles on Auckland roads, but this may have been biased by several factors. One is that only certain types of roads are amenable to being monitoring – single lane, no obstructions, reasonable traffic flows etc. Another is that large heavy-duty vehicles are under-represented because their exhausts are often aligned vertically and above the cab height – beyond the reach of the monitor used. Another is that the measurements are a snapshot of the situation in April (autumn) – there may be different emissions characteristics at other times of year, or when other fuel batches are in the system. These are the obvious ones that spring to mind but there are likely to be others.

Despite these cautionary notes, a very large number of vehicles have been sampled, and the results are considered valid within normal sampling constraints. No attempt has been made here to compare these results with other types of measurements (e.g. dynamometer checks on the vehicles sampled), or emissions models (e.g. NZTER from the Ministry of Transport). These will be part of the next stage of the research programme associated with this measurement campaign.

In summary, the key results from the preliminary analysis of the sample subset of 15,000 vehicles are:

- The average vehicle age is 9 years (manufactured 1994)
- The proportions of fuel types are 14% diesel and 86% petrol
- The proportion of diesel vehicles in any year of manufacture in the fleet has grown from less than 10% in the early 1980s to nearly 20% in the early 2000s
- The most polluting 10% vehicles (“gross emitters”) produce 53% of the total CO emissions (assuming all vehicles undertake equal mileage)
- CO emissions drop steadily with year of manufacture from 1980 to 2003
- Diesel vehicles emit less CO than petrol vehicles
- Approximately half (47%) the Auckland fleet is non NZ-new with the bulk of the imported vehicles coming from Japan (97%)
- Imported vehicles generally have lower emissions than NZ-new vehicles, for both petrol and diesel
- Compared to similar remote sensing studies undertaken overseas, the average vehicle in Auckland appears to emit double the amount of CO of an average vehicle in the US

5. THE FUTURE

The remote sensing campaign has yielded significant "real world" information about emissions from the New Zealand fleet for the first time. The data have provided a baseline for emissions performance of the fleet so that the effectiveness of policies to reduce vehicle emissions can be monitored. The results have also directly contributed to ARC's objective to raise awareness about vehicle emissions and the need for vehicle maintenance.

In future, we see the results being used in a number of applications, including:

- To formulate more directed policy targeting emissions reductions
- To assess future trends in fleet emissions
- As input to other studies, including air shed modelling, run-off effects and health risk analysis
- To validate emissions models
- As input to the assessments of effects of new roads projects
- To assess the effectiveness of any future inspection and maintenance programmes that may be proposed

The results enable us to significantly advance our urban air quality modelling research as well as offering the opportunity to undertake greenhouse gas monitoring/energy efficiency research in response to the Kyoto Protocol and thereby move our understanding into the 21st century and beyond. Remote sensing offers benefits not possible with other methods and very definitely signals the way forward in the on-going future battle to manage vehicle emissions.

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