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**Paper title:** **What is being discharged from that tailpipe? Modelling versus measurements**

**Authors names:** Jeff Bluett and Gavin Fisher

**Organisation:** National Institute of Water and Atmospheric Research (NIWA)

**Contact details:**
*Postal address:* PO Box 109-695, Newmarket, Auckland, New Zealand

*Telephone:* +64-9-375-2050
*Facsimile:* +64-9-375-2051
*Email:* j.bluett@niwa.co.nz

**Abstract:**

The effect emissions from roadways have on air quality is an increasingly important environmental issue. As a result, regulators and developers are being required to invest large amounts of resources into managing and assessing roadway effects on air quality. One of the most useful tools is the emissions inventory. The quality of information that this tools provides is dependent on the accuracy of estimating the amount of pollutants being discharged from the on-road vehicle fleet. It is common practice to use emission models (e.g. USEPA Mobile6) to estimate of the quantity of pollutants discharged from vehicles. Recent studies show that vehicle emission models often do not provide accurate estimates of real-world emissions. This paper undertakes a comparison between modelled and measured vehicle emissions. In Auckland, during April 2003, the tailpipe emissions from over 35,000 vehicles were measured using remote sensing technology. The on-road vehicle emissions are compared to modelled emissions provided by the New Zealand Traffic Emission Rate database (NZTER). The study provides the first attempt at validating a vehicle emissions model in New Zealand. The implications of the study results for air quality management, roading and health impact assessments are clear and show where some improvements could be achieved.

## Introduction

The effect emissions from roadways have on air quality is an increasingly important environmental issue. This trend is likely to continue as the body of knowledge on the sources and effects of roadway pollution grows. As a result, regulators and developers are being required to invest large amounts of resources into managing and assessing roadway effects on air quality. One of the most critical, but often not well defined, pieces of information needed is the accurate quantification of tailpipe emissions. This data plays a pivotal role in numerous air quality management tools and processes such as; emission inventories; roadside and regional environmental impact studies; identification of effective vehicle pollution mitigation strategies; and design of successful air quality management plans.

The mobile nature number and variety of vehicles within fleets, makes obtaining fleet or site-specific representative emission data problematic. Vehicle emissions have been measured using chassis dynometer testing and defined vehicle drive cycles. This is a time consuming and relatively expensive process and therefore the number of vehicles tested is often small. The practical implication is that chassis dynometer testing - vehicle drive cycle testing has limited ability to provide fleet representative fleet data.

In an attempt to overcome this issue a number of environmental agencies have undertaken comprehensive chassis dynometer - vehicle drive cycle testing and used this information to build a vehicle emission database. These databases are then made available for users to estimate vehicle emissions from the fleet that is of interest to them. An example of a vehicle emission database is the United States Environmental Protection Agency's Mobile6 emission model (USEPA, 2003).

Applying these generic emission models to specific fleets is always accompanied by the question, "*How well does this model represent real word emissions*?" Obviously there are significant issues associated with applying vehicle emission models from another country mainly due to differing fuel specifications and emission control regulations. However, even country specific models still have uncertainties associated with them. These uncertainties include accounting for the effects of gross emissions from badly tuned vehicles, vehicles running in cold start conditions and, in New Zealand (NZ), the effect of a large portion of imported used vehicles on fleet emissions. The ability of emission models to predict the effects of improvements in fuel quality and emission controls over time adds uncertainty.

In summary vehicle emission data is a very important piece of information, which is more often than not, derived from model output which contains a number of uncertainties.

A case study comparison between modelled and measured vehicle emission data is used to refine and understand these uncertainties. The comparison uses modelled emission data obtained from the New Zealand Transport Emission Rate (NZTER) database (Ministry of Transport (MoT), 2000) and measured on-road emission data from a remote sensing campaign undertaken in Auckland in 2003. While the case study employs data specific to NZ, the conclusions of the study are generic and equally applicable to other countries.

The purposes of undertaking this comparison are to highlight the:

- Potential effect of the uncertainties associated with modelled emission data; and
- Benefits of having accurate and representative vehicle emission data.

## Method

Modelling vehicle emissions

The New Zealand Traffic Emission Rates (NZTER) database (MoT, 2001) provides access to the vehicle emission rates produced by the Vehicle Fleet Emissions Model (VFEM). The VFEM development is described in MoT, 1998(a). The chassis dynometer tests upon which VFEM is based are detailed in MoT, 1998(b). VFEM was developed as a means of projecting the performance of the national vehicle fleet, as it evolves through time in response to varying policy and market influences that shape the design and emissions technology profile of the fleet. VFEM and NZTER were developed under the Ministry of Transport's (MoT) Vehicle Fleet Emissions Control Strategy (VFECS), the details of which can be found at http://www.mot.govt.nz/publications/vfecs/index.shtml.

In this study single vehicle emission factors obtained from NZTER were used. Single vehicle emission rates give the characteristic emissions rate by vehicle design and fuel type, as a weighted average across all ages and manufacturing sources in the fleet, for any year between 1979 and 2021. To extract data from NZTER the user first defines the year, road type, and driving condition and vehicle type of interest. NZTER then provides emission rates in a g/km format for carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM) and volatile organic compounds (VOC). NZTER does not provide complete drive cycle emission factors. NZTER requires the user to choose one of four driving conditions: free flow, interrupted, congested and cold start. In this study the emission measurements were made in free flowing traffic. Therefore of the options available in NZTER, free flow was the most appropriate selection.

NZTER is the only freely available source of emission factors that provides information specifically on NZ's vehicle fleet. This database is widely used in NZ for planning and assessment purposes. Despite its wide use and general acceptance there have been a number of concerns voiced about the information that it provides. The most significant concerns raised include accounting for the "real world" effects of; gross emitting vehicles; the large proportion (50%) of imported used cars in NZ's fleet; and the implementation of regulations to improve fuel specifications; and to proposals to introduce vehicle emission testing.

Despite the concerns, NZTER is the most useful tool available to estimate vehicle emissions in NZ. However to date it has not been subjected to any real world validation.

Measuring vehicle emissions

A remote sensing device (RSD) was used to measure the tailpipe emissions from over 35,000 vehicles at 16 roadside sites throughout the Auckland region during April 2003. The RSD consists of an infrared (IR) component for detecting CO, carbon dioxide ($CO_2$) and VOC, 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. The IR and UV beams are focused into a detector that quantifies pollutant concentrations by measuring absorbance at the respective frequency and comparing it to a calibration spectrum. Further detail on the RSD and the Auckland monitoring campaign have been published by the Auckland Regional Council (ARC, 2003).

The remote sensor used in this study reports the %CO, %HC and %NO in the exhaust plume, corrected for water and excess oxygen not used in combustion. This data was converted into vehicle gram per litre of fuel (g/*l*) emission factors using the method developed by the Fuel Efficiency Automobile Test Data Centre (FEAT), University of Denver (http://www.feat.biochem.du.edu). The methodology is described in detail by Williams, Bishop and Stedman, (2003). This methodology was adapted for use in NZ by adjusting the original US fuel related coefficients to reflect the specifications of the local fuel. Members of the FEAT team were provided with NZ fuel specifications and from these calculated NZ specific coefficients.

NZTER provides emission data in the format g/km. To convert the RSD g/*l* emission factors to g/km they were multiplied by an estimated fuel efficiency of the type of vehicle under consideration. The fuel efficiency of petrol cars was estimated using data collected from the Australian Greenhouse Office, Fuel Consumption guides 1986 to 2003 (http://www.greenhouse.gov.au/fuelguide). It was estimated that the average fuel efficiency of the NZ petrol car fleet manufactured in 2003, driving in suburban free flow conditions was approximately 11.5 km/l. The fuel efficiency of diesel cars and light commercial vehicles (LCV) was estimated using data collected from the United Kingdom's Vehicle Certification Agency's, Car Fuel database (www.vcacarfueldata.org.uk). It was estimated that the average fuel efficiency of the NZ diesel cars and LCV fleet manufactured in 2003 driving in suburban free flow conditions was just under 14 km/l. The fuel efficiency of heavy-duty diesel vehicles was taken from the fuel consumption rates used in the Auckland Regional Council's emission inventory (Joynt, Ng, Metcalfe, Yan, Rolfe and Chilton, 2002). This emission inventory suggests that fuel efficiencies for small (3.5 to 7. 5 tonnes), medium (7.5 to 12 tonnes) and large (greater than 12 tonnes) diesel vehicles are 5, 4 and 2 km/*l* respectively under suburban free flow traffic conditions. The fuel efficiency of vehicles manufactured before 2003 was estimated to reduce by 0.9 % per year from the 2003 benchmark.

As noted above the conversion of g/l to g/km emission factors is dependant on the assumed fuel efficiency for each vehicle type and year of manufacture. The uncertainty contained in the assumed fuel efficiency will also be exhibited in the RSD measured emission factors. Therefore the RSD measured emission factors presented in this paper must be considered as a best estimate rather than a definitive quantity containing no error. The uncertainty contained in the fuel consumption for light duty vehicles is estimated to be +/- 10% while for heavy duty vehicles the uncertainty increases to +/- 25%.

A primary contaminant of concern, nitrogen dioxide ($NO_2$) is not measured by the RSD. NZTER estimates NOx (total NO and $NO_2$) emissions from vehicles. To facilitate the comparison between NZTER and RSD emission rates the measured NO emissions were increased so that the total NOx contained 10, 20 and 30% $NO_2$ (by mass) for petrol, LCV diesel and HCV diesel vehicles respectively.

The RSD hydrocarbon measurements were calibrated with propane. Using this calibration gas, RSD measurements have been shown to be underestimate the total amount of volatile organic compounds (VOC) discharged by vehicles by a factor of approximately two when compared to flame ionisation detectors (Singer, Harley, Littlejohn, Ho and Vo, 1998). In this study the RSD VOC measurements have been scaled up by a factor of two to take this issue into account.

The RSD cannot measure the particulate content of vehicle exhaust plumes. However it does measure the opacity of the plume, which can be used as a qualitative indicator of particulate emissions. The RSD opacity measurement is indicative only, and subject to greater interference and uncertainty than the gaseous measurements. It therefore should be interpreted with caution. In this study the trends in RSD opacity data and modelled particulate emission rates with vehicle fleet year have been compared to provide a qualitative indicator of the relative trends over time of observed and modelled PM emissions.

A number of assumptions have been made to enable the conversion of the RSD data into a g/km emission factor. When these assumptions are considered together with the precision of the RSD data, it is clear that the RSD measured emission factors cannot be considered exact. The uncertainty contained in the measured g/km emission factors is likely to be in the order of +/- 10% (*pers. comm.* Donald Stedman, FEAT). No information is provided on the uncertainty contained in the NZTER emission factors. For these reasons the conclusions reached from the comparison of modelled and measure emission factors should be viewed as best available indications rather than precise answers. This caution is particularly pertinent to the diesel heavy vehicle and bus results, where the sample size of vehicles measured by the RSD is significantly smaller than for petrol of LCV diesel vehicles.

## Comparing measured and modelled vehicle emissions

### Carbon monoxide emissions

The NZTER modelled, and RSD measured, CO emissions from petrol cars operating in on suburban roads under free flowing traffic conditions are compared. The CO emission rate for a specific fleet year refers to all vehicles within the fleet operating at that year. This should not be confused with year of vehicle manufacture. Approximately 30,000 petrol vehicles were measured in the RSD programme. Figure 1 compares fleet averaged NZTER modelled and RSD measured CO emission rates for petrol cars for the years 1980 to 2002.

Figure 1 shows that both modelled and measured CO emission rates decrease as the fleet year progresses in time. The measured rate of decrease is more rapid than is predicted by the emission model. Figure 1 also shows that for early fleet years (pre-1996) the model is consistently higher (by a factor of approximately 1.25) than modelled free flow emission factors. For more recent fleet years the measured and modelled emission factors are within +/- 10% of each other. The data displayed in Figure 1 suggests that if the observed rate of decrease in CO emission rates continues then for future fleet years NZTER may over predict fleet average emission rates.

In any fleet there will be a proportion of vehicle operating under cold start conditions or vehicles that are badly out of tune and emitting a disproportionate (gross) amount of pollutants. These high emitting vehicles must be accounted for when estimating fleet average emissions. Figure 2 compares petrol vehicle RCD measured CO emission rates with NZTER modelled rates that have been adjusted to account for 10% of the fleet operating under cold start conditions.

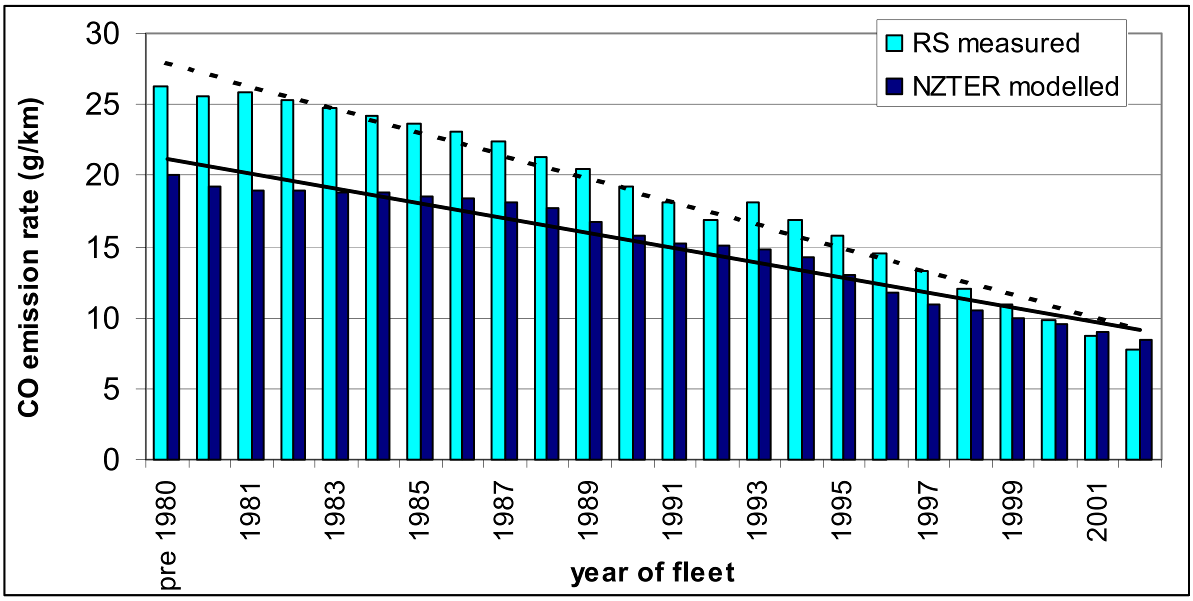


**Figure 1 Comparison of modelled and measured CO emission rates for petrol cars**

Figure 2 shows that when modelled emissions are adjusted to account for 10% of the petrol vehicles operating under cold start conditions the model tends to over-predict measured emissions. In earlier fleet years the model over prediction is relatively small (less than 10%) but for newer vehicles (post 1995) the difference increases to an average factor of 1.25. In the most recent year (2002) the model over predicts by about 50%.

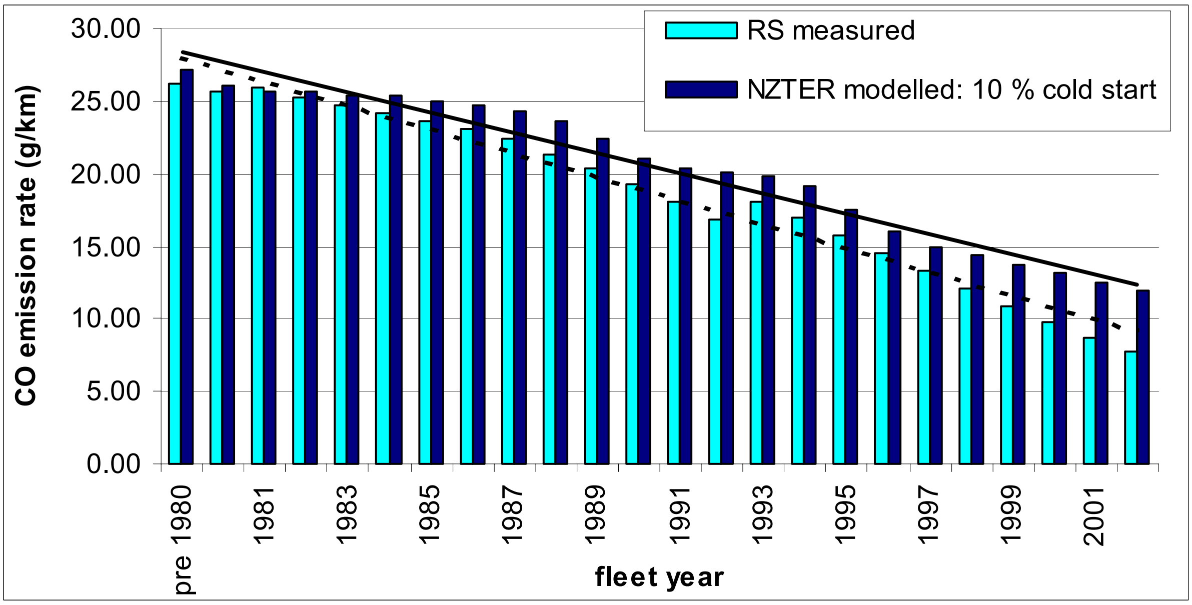


**Figure 2 Comparison of modelled (including 10% cold start) and measured CO emissions for petrol cars**

For Figure 3 the RSD measured emission data has been filtered to remove the highest 10% of emitters. Figure 3 compares NZTER modelled rates with the measured emissions from the petrol vehicle fleet with the top 10% of gross emitters removed.

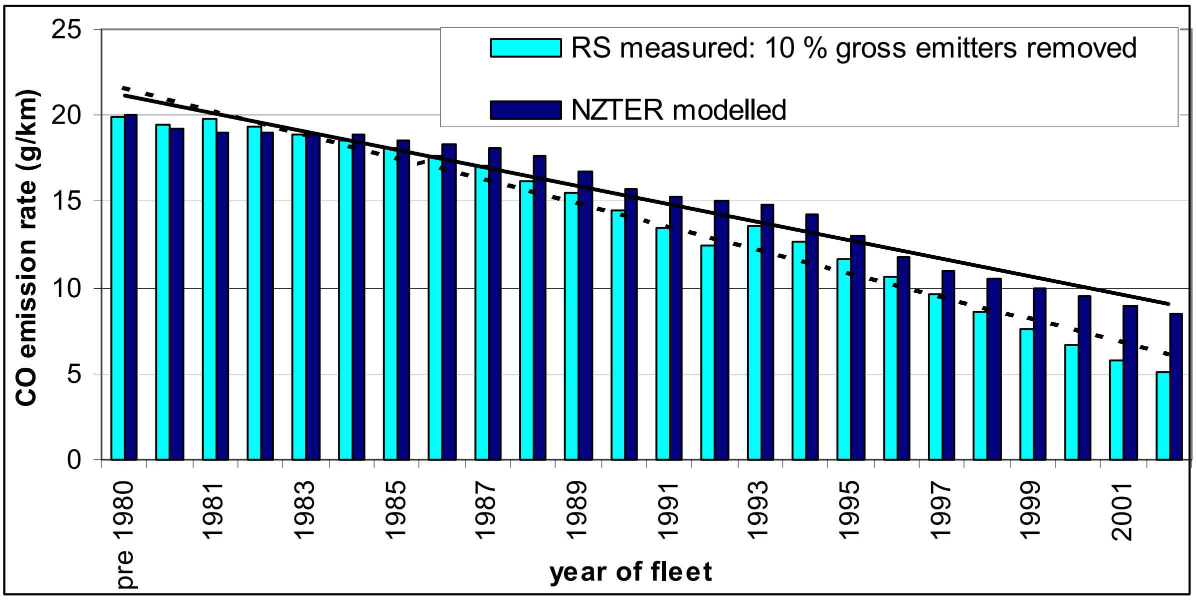


**Figure 3** **Comparison of modelled and measured (top 10% gross emitters removed) CO emissions for petrol cars**

Figure 3 shows that when RSD measured CO emissions are filtered to remove the highest 10% of emitters, NZTER tends to over predict measured emissions. The tendency for the model to over predict increases with more recent fleet years.

Figures 2 and 3 demonstrate that fleet averaged vehicle emissions are significantly affected by a relatively small number of high emitting vehicles. It follows that it is important to account for the relatively small number of gross emitting vehicles running caused by cold start or badly tuned motors. Figures 2 and 3 suggest that for more recent fleet years, incorporating the effect of cold start vehicles into NZTER exaggerates the model's tendency to over predict CO emission rates.

Effects of imported Japanese used vehicles on fleet emissions

Approximately 50% of New Zealand's petrol vehicle fleet are imported used vehicles from Japan. In New Zealand it was commonly thought that these were highly polluting vehicles, as they were generally 4-7 years old. Before the RSD monitoring campaign the actual effect of the imported vehicles on NZ's fleet average emissions had not been established. The users of NZTER debated whether this issue increased the uncertainty contained in the model outputs. Figure 4 compares the fleet modelled CO emissions with the measured emissions of New Zealand new (NZN) and Japanese used (JPN) petrol vehicles for fleet year 2002.

Figure 4 shows measured petrol vehicle CO emission rates from NZN vehicles are approximately 3% higher than JPN vehicles for fleet year 2002. Both NZN and JPN CO emission rates are lower than the NZTER modelled emission rate. The data displayed in Figure 4 shows the influence of CO from JPN vehicles is to reduce the fleet average CO emissions by a small amount.

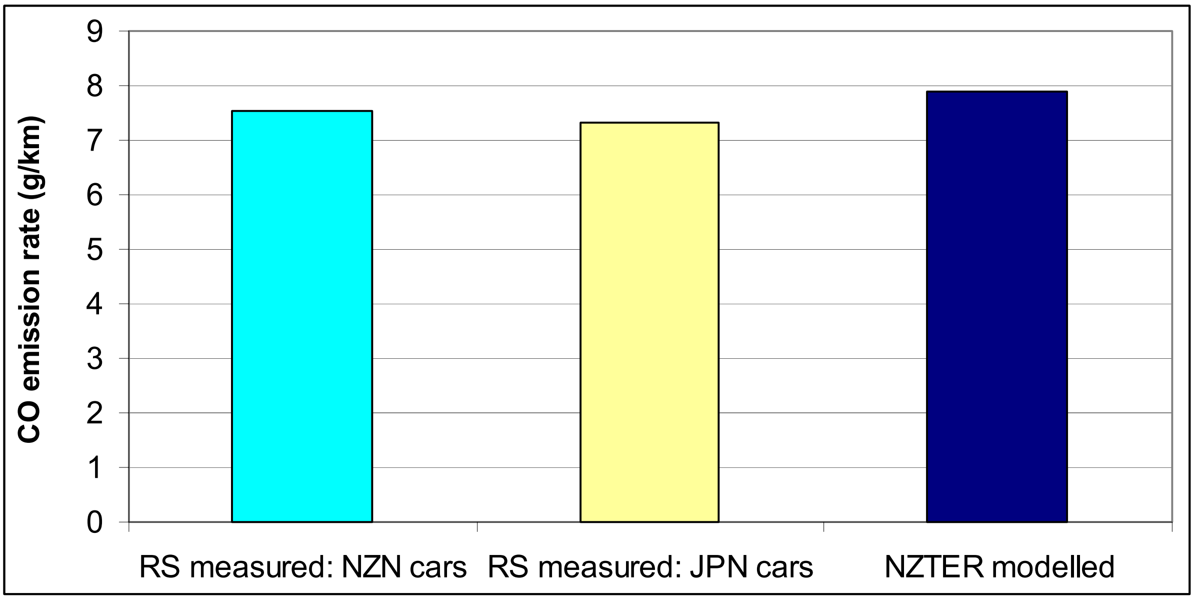


**Figure 4** **Comparison of modelled and measured New Zealand new (NZN) and Japanese used (JPN) CO emissions for petrol cars for fleet year 2002**

Figure 5 compares measured diesel vehicle CO emission rates to modelled emissions of diesel cars and light commercial vehicles (LCV) adjusted to account for 10% of the fleet operating under cold start conditions. Approximately 5,000 diesel vehicles were measured during the RSD monitoring campaign. There were relatively small numbers of diesel vehicles manufactured pre-1990 in the RSD sampled fleet. Therefore the comparison of fleet years displayed in Figure 5 is limited to the years 1993 to 2002.

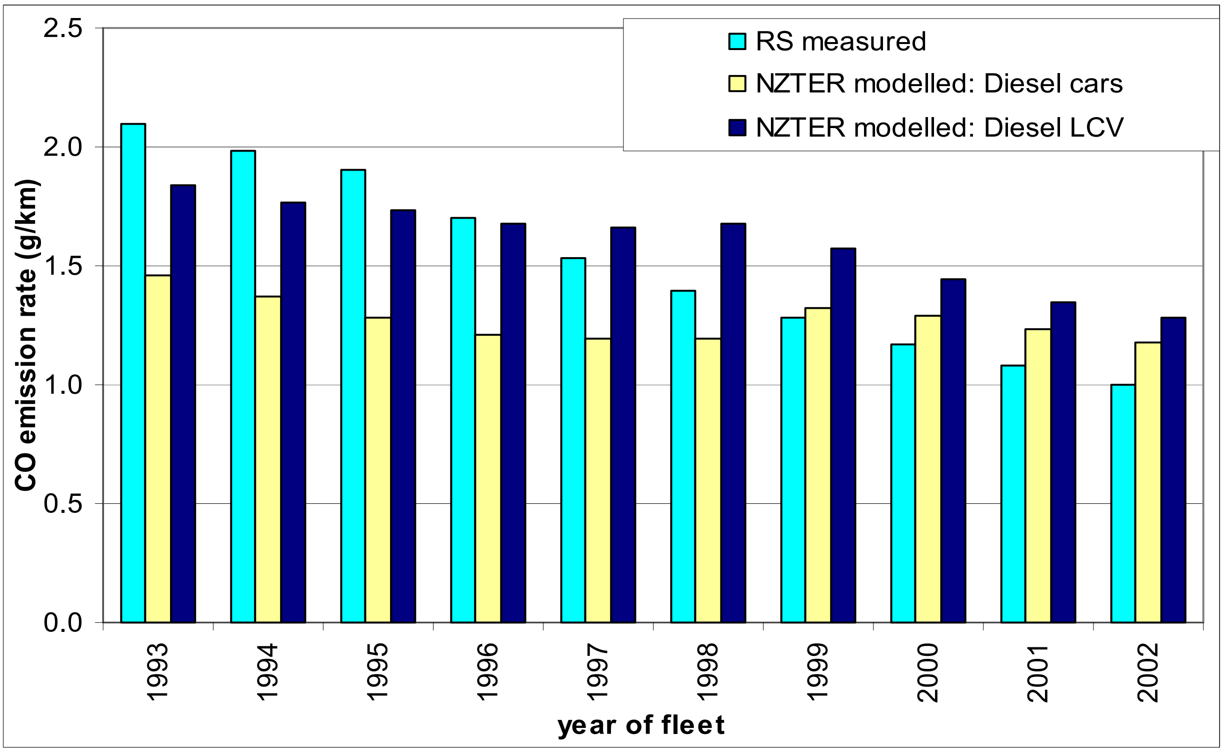


**Figure 5** **Comparison of NZTER modelled diesel car and light commercial vehicles CO emissions with RSD measurements**

Figure 5 shows that RSD measured CO emissions decrease with more recent fleet years. The modelled data generally follows the same general trend but unexpected increases are observed in the modelled LCV and car data in 1998 and 1999 respectively. The monitored diesel fleet was not split into diesel cars and LCV. The measured emission rate decrease is more rapid than is predicted by the NZTER. For pre-1997 fleet years the measured emission rate is greater the modelled emission factors for both diesel cars and LCV. From 1999 onwards the measured emission rate are lower than the modelled rates for diesel cars and LCV.

As with the petrol fleet a significant proportion of NZ's diesel vehicles are Japanese used vehicles. A comparison of the measured CO emissions from NZN and JPN diesel vehicles shows that JPN vehicle emissions are approximately 12% lower than NZN vehicles. This finding is consistent with the difference observed between NZN and JPN petrol vehicles.

Figure 6 compares measured diesel vehicle CO emission rates to modelled emissions for the small (3.5 to 7.5 tonnes), medium (7.5 to 12 tonnes) and large (greater than 12 tonnes) of diesel heavy commercial vehicles (HCV). Figure 6 also compares modelled and measured emissions from buses. The NZTER emission rates displayed in Figure 6 are adjusted to account for 10% of the fleet operating under cold start conditions. This comparison should be treated with some caution and regarded as indicative rather than precise. There are two reasons for this. Firstly, the RSD sampled fleet of HCV and buses was small. Approximately 450 small, 200 medium and 200 large HCV and 46 buses were measured by the RSD. In addition to this the diesel fuel use of these can only be approximated due to the large variation of fuel use within each class. The fuel efficiency for small, medium and large HCV was assumed to 5, 4 and 2 km/*l* respectively (Joynt *et. al.* 2002) The fuel efficiency for buses was assumed to 3 km/*l* (Joynt *et. al.* 2002).

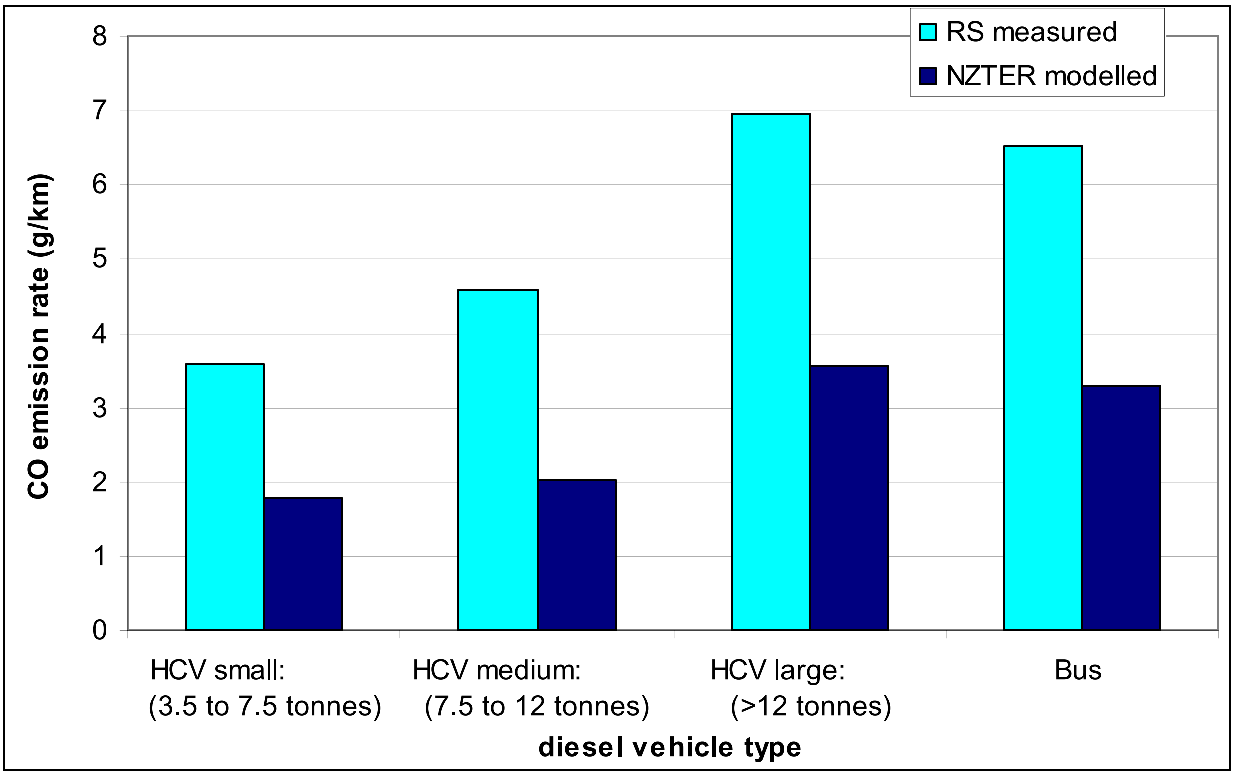


**Figure 6** **Comparison of NZTER modelled and RSD measured CO emissions for diesel HCV and buses**

Figure 6 suggests that NZTER underestimated the CO emissions from all classes of HCV and buses. With the fuel efficiencies employed in this study the measured emissions of HCV and busses are approximately a factor of two larger than the respective NZTER modelled emissions. Even with the uncertainty in the fuel use of HCV, Figure 6 suggests that NZTER under predicts CO emissions from HCV and buses.

Volatile organic compound emissions

The NZTER modelled (including 10% cold start) and RSD measured emissions of volatile organic compound (VOC) emissions have been compared. A summary of the comparison for fleet year 2002 is provided in Table 1.

The information contained in Table 1 shows that in fleet year 2002, NZTER predicts a higher VOC emission rate (+60%) than have been measured for petrol cars. When the years 1980 to 2001 are considered, both the measured and modelled VOC emission rates decrease with as the fleet year moves toward 2001 and the modelled emission rate is consistently higher than the measured rate. However, observed emission rates have decreased more rapidly in recent fleet years than was predicted by the model. The accelerating decrease results in a significant over prediction by NZTER in the most recent petrol vehicle fleet years.

Table 1 shows that NZTER has a tendency to under predict VOC measured emission rates for diesel cars, LCV, HCV and buses. For fleet year 2002, NZTER's under prediction of measured emission rates ranges from 15 to 60 %. For diesel cars and LCV over fleet years 1993 to 2001, the decrease in VOC emission rates in the measured data for is much steeper than is predicted by NZTER.

**Table 1 Comparison of NZTER modelled and RSD measured VOC emission rates for fleet year 2002**

| Fuel and Vehicle type | NZTER modelled emissions (g/km) | RSD measured emissions (g/km) | Difference between NZTER and RSD. | Influence of Japanese used vehicles |
|---|---|---|---|---|
| **Petrol cars** | 1.80 | 1.10 | NZTER higher than RSD by approx 60% | JPN approximately 5% lower than NZN emissions |
| **Diesel Cars and LCV** | Car 0.35<br>LCV 0.35 | 0.40 | NZTER is lower than RSD by approx 15% | JPN approximately 25% lower than NZN emissions |
| **Diesel HCV** | Small 0.82<br>Med. 0.99<br>Lge. 1.79 | Small 1.61<br>Med. 2.26<br>Lge. 3.60 | NZTER lower than RSD by 50%-60% | NA |
| **Buses** | 1.79 | 2.72 | NZTER is lower than RSD by approx 35%*. | NA |

*Bus comparison must be treated with caution due to the small number of vehicles sampled.

Oxides of nitrogen ($NO_x$) emissions

The NZTER modelled (including 10 % cold start) and RSD measured emissions of $NO_x$ emissions have been compared. A summary of the comparison of the fleet year 2002 is provided in Table 2.

The information contained in Table 2 suggests that NZTER tends to predict higher emission rates of $NO_x$ than were measured for petrol cars for fleet year 2002. When the years preceding 2002 are compared the difference between NZTER and the RSD data increases to around 60% for early year fleets. This shows that NZTER predicts a greater rate of decrease over time in $NO_x$ emissions than is observed in RSD data.

Table 2 also shows that NZTER has a tendency to slightly over predict $NO_x$ measured emission rates for diesel cars and LCVs for fleet year 2002. For the years 1993 to 2001 the measured $NO_x$ emission rates for diesel cars and LCV are reasonably constant with fleet year. The model significantly over predicts $NO_x$ emissions for the years 1993 to 1999. However due to the large improvements in $NO_x$ emissions over time that NZTER predicts (but these are not observed in the measured data) the model approaches the measured emission rates for recent year fleets.

Finally Table 2 shows that NZTER has a tendency to significantly over predict $NO_x$ measured emission rates for HCVs and buses.

**Table 2 Comparison of NZTER modelled and RSD measured $NO_X$ emission rates for fleet year 2002**

| Fuel and Vehicle type | NZTER modelled emissions (g/km) | RSD measured emissions (g/km) | Difference between NZTER and RSD | Influence of Japanese used vehicles |
|---|---|---|---|---|
| **Petrol cars** | 1.15 | 0.94 | NZTER higher than RSD by approx 20% | JPN approx 40% lower than NZN emissions |
| **Diesel Cars and LCV** | Car 0.64<br>LCV 0.68 | 0.61 | NZTER higher than RSD by 5 to 10% | JPN approx 34% lower than NZN emissions |
| **Diesel HCV** | Small 8.07<br>Med. 9.93<br>Lge. 21.54 | Small 3.06<br>Med. 5.10<br>Lge. 11.49 | NZTER higher than RSD by 190%- 260% | NA |
| **Buses** | 21.54 | 8.21 | NZTER higher than RSD by approx 260%* | NA |

*Bus comparison must be treated with caution due to the small number of vehicles sampled.

Particulate emissions

As noted in the methodology of this paper the RSD cannot measure the particulate content of vehicle exhaust plumes. However it does measure the opacity of the plume, which can be used as a qualitative indicator of particulate emissions. In this section the trends in RSD opacity data and modelled particulate emission rates with vehicle fleet year have been compared. The aim of this comparison is to provide a qualitative reality check of NZTER modelled PM emissions.

The opacity of petrol fuelled vehicle plumes is relatively low and the data collected is often lower than the detection limit of the RSD. The opacity of diesel fuelled vehicles tends to be much higher. This subset of the measured fleet data provides a much more robust set of RSD opacity data. To ensure that a representative number of vehicles are considered, the comparison has been undertaken for light duty diesels (LCV and cars). Figure 7 compares the trend in RSD measured opacity of light duty diesel vehicles to the trend in NZTER particulate emission rates for diesel cars and LCV over the years 1990 to 2002.

Figure 7 shows that both the measured opacity of diesel plumes and modelled particulate emission rates decrease for newer vehicles. The relative rates of decrease are different. The measured opacity of plumes decreases approximately 45% between the fleet years 1990 and 2002. The NZTER modelled emission rates for diesel cars and LCV decrease 31% and 36% respectively over the years 1990 to 2002. The trends in measured opacity and modelled emission rates are both downward and but the model predicts a slightly lower rate of reduction than is observed in the opacity data.

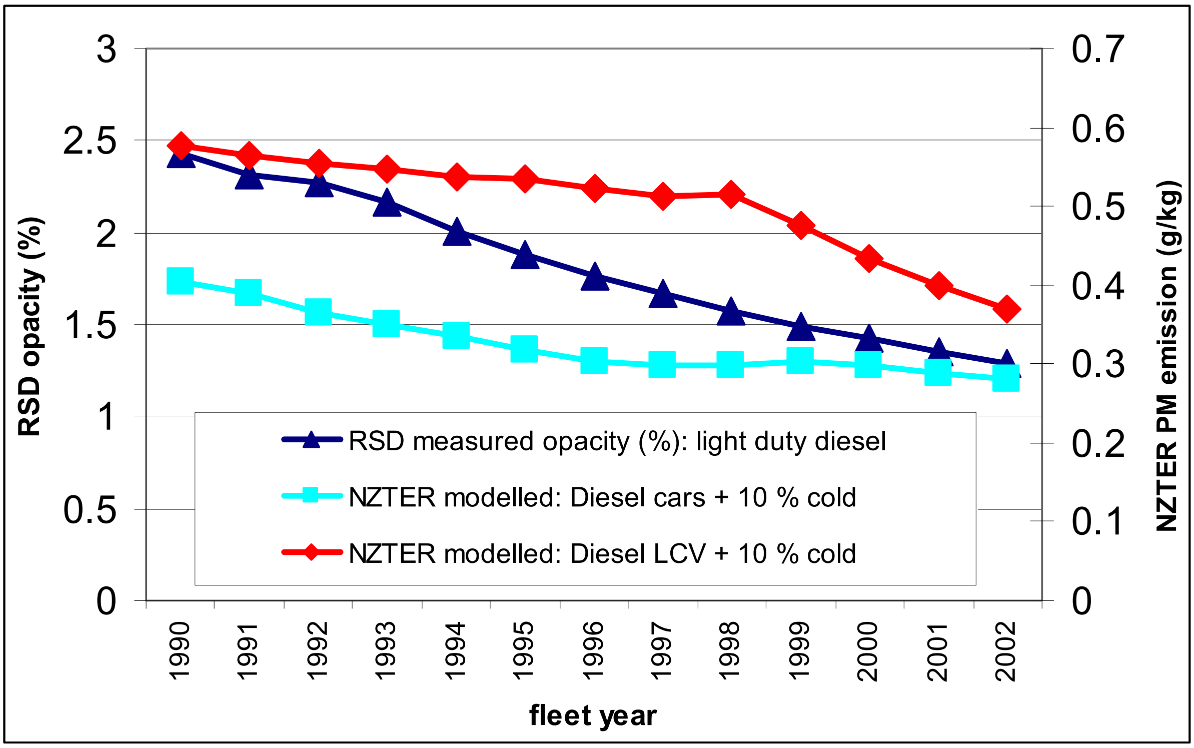


**Figure 7 Comparison of trends in measured opacity and modelled particulate emission rates for light duty diesel vehicles**

**Conclusions**

Vehicle emission data is a very important piece of information for emission inventories, roadside and regional environmental impact studies, identification of effective vehicle pollution mitigation strategies and design of successful air quality management plans. More often than not emission data is derived from model output that contains a number of uncertainties.

This paper presented a case study comparison between modelled and measured vehicle emission data. The comparison uses modelled emission data obtained from the New Zealand Transport Emission Rate (NZTER) database and on-road emission data from 35,000 vehicles measured by a remote sensor in Auckland during 2003. The study provides the first comprehensive validation of a vehicle emissions model in New Zealand. One of the purposes of undertaking this comparison is to highlight the potential uncertainties associated with modelled emission data.

As noted in the methodology the conversion of RSD data to g/km emission factors is dependant a number of assumptions. These assumptions introduce uncertainty into the resulting RSD measured emission factors. Therefore the RSD measured emission factors presented in this paper must be considered as a best estimate rather than a definitive quantity containing no error. The conclusions presented below should be considered in this light.

The RSD measured CO, VOC and $NO_x$ emission rates from petrol vehicles for fleet year 2002 were lower (-10% to -60%) than NZTER predictions when the effects of the small proportion of gross (cold start or badly tuned) emitters were accounted for. The measured CO, VOC and $NO_x$ emissions from NZ new petrol vehicles are higher than Japanese imported used vehicles.

The RSD measured CO emissions from light duty diesel vehicles for the fleet year 2002 are over predicted (+30% to +40%) by NZTER if the effects of the small proportion of gross emitters are accounted for. The RSD measured emission rates of VOC and $NO_x$ are predicted reasonably well (+/- approx 10%) by NZTER for light duty diesel vehicles of fleet year 2002. The measured CO, VOC and $NO_x$ emissions from NZ new light duty diesel vehicles are higher than Japanese imported used vehicles.

The RSD measured CO and VOC emissions from heavy-duty diesel vehicles are significantly higher than NZTER predictions. The RSD measured $NO_2$ emissions from heavy-duty diesel vehicles are significantly lower than NZTER predictions.

While it is not possible to use RSD data to calculate PM emission rates, the observed trends in measured opacity over time, suggest that the rate at which NZTER predicts PM emissions to decline with time may be slightly pessimistic.

In summary, the emissions from petrol vehicles of recent fleet years appear to be over predicted by NZTER. The same conclusion is reached for emissions of CO from light duty diesel vehicles. NZTER predictions of VOC and NOx from light duty diesel vehicles compare reasonably well to RSD measured emission rates. The RSD measured emissions from heavy-duty diesel vehicles (HDV) do not compare well to NZTER. However, it must be noted that in this study the assumed fuel efficiency of HDV may not be an accurate representation of the actual fleet average. Also the HDV RSD data set is significantly smaller than those of either the petrol or light duty diesel fleets. The representativeness of HDV RSD measured emission of the actual on road fleet needs further investigation.

Implications

The results of this study have important implications for various air quality management tools and processes including:

- Emission inventories
- Roadside and regional environmental impact studies
- Human health effect studies
- Identification of effective vehicle pollution mitigation strategies
- Design of successful air quality management plans

The implications are summarised briefly below.

The quality of information provided by emission inventories, roadside and regional environmental impact studies, and human health studies are all heavily dependant on the accurate quantification of vehicle emissions. The results of the comparison undertaken here suggest that the quality of the outcome of any study which has used NZTER emission factors, is likely to vary depending on the pollutant under consideration and relative contribution of different vehicle types to the fleet under consideration.

Using NZTER emission factors for a fleet with a small proportion of HDVs is likely to result in an over estimation of the total amount of CO discharged. Examples where this finding could have ramifications include roadside environmental impact assessment, health effects studies and emission inventories for suburban/residential areas.

In contrast, using NZTER VOC emission factors for a fleet that contains a significant proportion of HDVs is likely to result in an under prediction the total amount of VOC discharged. Examples where this finding could have ramifications include roadside environmental impact assessment, health effects studies and emission inventories for any district that contains significant amounts of industrial traffic.

Identification of effective vehicle pollution mitigation strategies and successful air quality management plans are strongly dependant on understanding and anticipating how vehicle emissions vary as time progresses. For example NZTER suggests that $NO_x$ emissions from petrol vehicles will decrease relatively rapidly. If environmental regulators were to depend wholly on this information, they may be tempted to progress with a "*business as usual*" approach and assume that improving vehicle technology will solve the $NO_x$ issue. However the RSD data suggest that the "on-road" reduction of petrol vehicle $NO_x$ emission is much slower than the model suggests. This information may justify the need for a more interventionist management strategy, such as targeting gross emitters or new vehicle inspection and maintenance programmes.

The application of RSD technology to quantify on-road vehicle emissions and the use of this data to the validation vehicle emission models has applications in many environmental jurisdictions, especially those where vehicle emissions are a significant issue. For example, if it is assumed that NZ and Australia have compliable vehicle fleet and fuel quality, the New Zealand RSD emission factors suggest that the Australian National Pollutant Inventory (Environment Australia, 2000), may overestimate the CO from petrol cars (22 vs. 7.8 g/km), and underestimate NOx from heavy diesel vehicles (8.73 vs. 11.49 g/km).

Summary

This study has used the data from a remote sensing programme to establish representative on-road vehicle emission factors. The measured emission factors have been used to validate a widely used emission model. The results have numerous implications for managing the effects on urban air quality from roadway vehicle emissions. The results show where improvements can be achieved and the benefits of having accurate and representative vehicle emission data have been identified. The case study presented has implications for other environmental jurisdictions within New Zealand and overseas.

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