VALIDATION OF A VEHICLE EMISSION MODEL USING ON-ROAD EMISSION MEASUREMENTS

Jeff Bluett[1] and Gavin Fisher[2]
[1] NIWA, PO Box 109-695, Newmarket, Auckland, New Zealand
[2] Endpoint, PO Box 37-656, Parnell, Auckland, New Zealand

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. Good information on vehicle emission inventories and dispersion modelling assessments is largely dependent on knowing 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 the rate at which pollutants are discharged from vehicles. Vehicle emission models often do not provide accurate estimates of real-world emissions.

This paper undertakes a comparison between modelled and measured vehicle emissions of carbon monoxide (CO). In Auckland, during April 2003, the tailpipe emissions from over 35,000 vehicles were measured using remote sensing technology. The measured vehicle emissions of CO are compared to modelled emissions provided by the New Zealand Traffic Emission Rate database (NZTER).

Roadside air quality and traffic monitoring data and a roadway dispersion model (CALINE4) are used to assess the effect of the different sources of emission data (NZTER and measured emission factors). The results show that the effects of vehicle sourced air pollution can be quantitatively assessed with a reasonable degree of confidence using both measured and modelled CO emission data.

Keywords: Vehicle Emissions, Emissions Model, Measuring Emissions, Dispersion Modelling of Vehicle Emissions

1. Introduction

The quality of information on vehicle emission inventories and dispersion modelling assessments is largely 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. MOBILE6, USEPA, 2003) to estimate the quantity of pollutants discharged from vehicles. In New Zealand (NZ), a NZ Traffic Emission Rate database (NZTER), (MoT, 2000) has been developed and is widely used. The NZTER is based on chassis dynamometer test results of a small number of vehicles. Recent studies have shown that vehicle emission models do not always provide accurate estimates of real-world emissions.

A comparison between modelled (NZTER) and measured (remote sensor data) vehicle emission carbon monoxide (CO) rates is made in this paper. It is also possible to make comparisons of the emissions of oxides of nitrogen (NO_x) and hydrocarbons using the same methodology. However this paper focuses only on CO emissions.

The modelled and measured emission data are then applied to an example of roadway dispersion modelling.

Measured and modelled emission rates and dispersion modelling results are used to assess the quality of data provided by NZTER and to identify the potential issues of employing emission models when the quality of the data is not known.

2. Method

The methodology of this study consists of three discrete steps.

2.1. Modelling Vehicle Emissions

The NZTER database (MoT, 2000) 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 the VFEM is based are detailed in MoT, 1998(b). The 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. The 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.

The 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 quality of the information that it provides. The most significant concerns raised include the need for 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 the effect of proposals made to introduce vehicle emission testing.

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

In this study, single vehicle emission factors obtained from the 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. The NZTER provides emission rates in a g/km format for carbon monoxide (CO), oxides of nitrogen (NOx), particulate matter (PM) and volatile organic compounds (VOC). The NZTER does not provide complete drive cycle emission factors. The 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.

2.2. 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 details 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. These data were 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 in 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.

The NZTER provides emission data in the format g/km. To convert the RSD g/l emission factors to g/km they were multiplied by the fuel efficiency data used in the NZTER. Figure 1 illustrates the fuel efficiency of light duty petrol and diesel vehicles by year of manufacture, as defined in the NZTER.

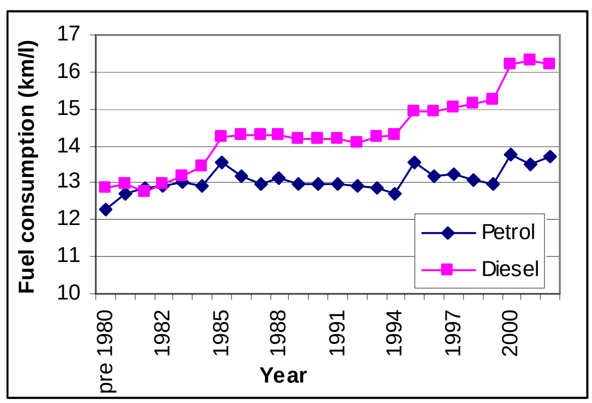

Figure 1. Fuel consumption for light duty petrol and diesel vehicles as defined in NZTER.

Figure 1 shows that according to the NZTER, the efficiency of both petrol and diesel vehicles has improved over time. Figure 1 also shows that diesel vehicles tend to consume less fuel per kilometre travelled than petrol vehicles.

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, nor has (until now) any validation of the model been undertaken. However, it is probable that the uncertainty contained in the NZTER emission factors are in the same order as those calculated from the RSD data. 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 or light commercial diesel vehicles.

2.3. Modelling Roadway Dispersion

The atmospheric dispersion model CALINE4 (Benson, 1989) was used in this study. CALINE4 was configured to model the emissions from an arterial feeder road located in suburban West Auckland. An ambient air quality-monitoring site was located adjacent to the roadside. Figure 2 shows a schematic diagram of the roadway and monitoring site.

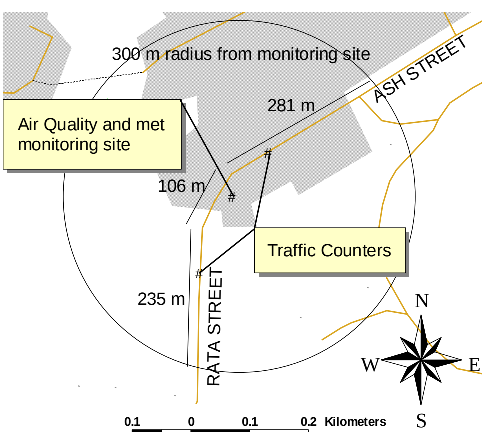

Figure 2 Schematic diagram of the monitoring site.

Some of the area surrounding the site is residential (indicated with grey shading in Figure 2). There are a small number of light industries in the area, but the majority of the remaining area (shown as the white region in Figure 2) consists of parks, recreational areas and some waterways.

The monitoring site was located adjacent to the 4-lane arterial feeder road. Approximately 34,000 vehicles per day pass the monitoring site with traffic flows peaking at approximately 3000 vehicles per hour. The traffic is relatively free flowing except during rush hour. No other major roadways are contained within a 500m radius of the monitoring site.

The trial was undertaken over a 6-week period in March and April 2001 when background levels from other CO sources (mainly home heating) would be relatively low. Continuous measurements of carbon monoxide (CO) and meteorological variables were made. Vehicle numbers, class and speed were measured using traffic counters.

The road link dimensions and geometry of the site were taken from an electronic topographical map.

Two composite vehicle emission factors were used. One calculated from the RSD data and another using NZTER emission factors. The driving conditions were assumed to be free-flow.

The meteorological data recorded on site was reformatted and used as model input. A modelling receptor was located at the inlets for the air quality instrumentation located approximately 15 m from the roadside.

CALINE4 was run in batch mode for the six-week monitoring programme. Background levels were assumed to be zero. The total 6-week monitoring programme provided 1008 hours of data. The comparison of modelled and monitored results was only carried out for the 870 hours that the model predicted non-zero concentrations.

3. Comparision of Measured and Modelled Emission Rates

3.1. Petrol Vehicles

The NZTER modelled and RSD measured CO emissions from petrol cars operating on suburban roads under free flowing traffic conditions in Auckland are compared. The CO emission rate for a specific fleet year refers to all vehicles within the fleet operating at that year. In other words, Figure 3 shows emissions from vehicles of all ages (the fleet) for one year. It also demonstrates how emissions evolve over time. The X axis in Figure 3 should not be confused with the year of vehicle manufacture. I.e. Figure 3 does NOT show the emissions as a snapshot in time (the present) and the year does not represent vehicles of different ages.

The emissions of approximately 30,000 petrol vehicles were measured in the RSD programme. Figure 3 compares the fleet averaged NZTER modelled and RSD measured CO emission rates for petrol cars for the years 1980 to 2002.

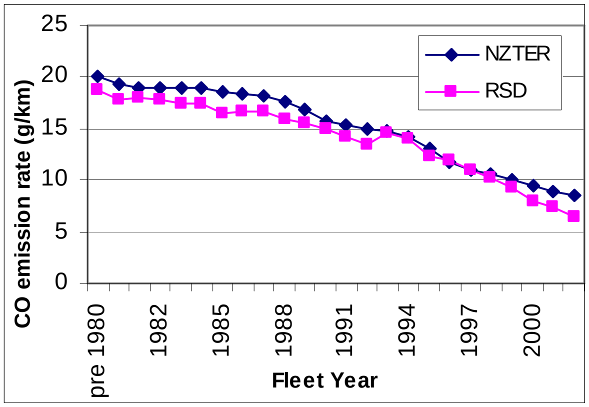

Figure 3. Modelled and measured CO emission rates for petrol vehicles.

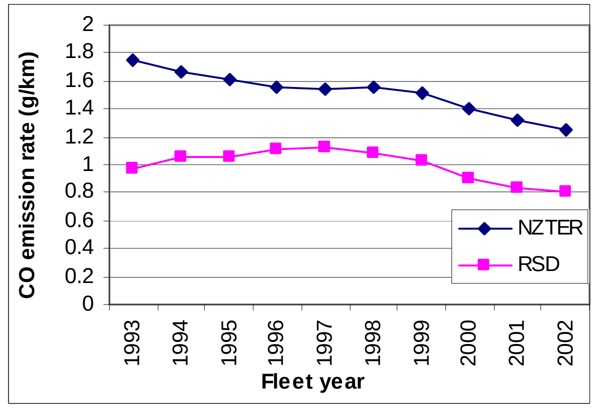

Figure 4. Modelled and measured CO emission rates for light duty diesel vehicles.

Figure 3 shows that both modelled and measured CO emission rates decrease at approximately the same rate. Figure 3 also shows that the modelled and measured emission rates are very similar although modelled rates are generally higher by a factor of approximately 1.1 than measured emission factors. The data displayed in Figure 3 suggests that the NZTER may overestimate CO emission rates for recent year (1999-2002) fleets during which time petrol vehicles had formed a significant part of the fleet.

3.2 Light Duty Diesel Vehicles

Figure 4 compares measured diesel vehicle CO emission rates to modelled emissions of diesel cars and light commercial vehicles (LCV). Approximately 5,000 diesel vehicles were measured during the RSD monitoring campaign. There were relatively small numbers of diesel vehicles manufactured pre-1993 in the RSD sampled fleet. Therefore the comparison of fleet years displayed in Figure 4 is limited to the years 1993 to 2002.

Figure 4 shows that for light duty diesel vehicles, CO emissions have generally decreased with time (newer vehicles have lower emission rates than older vehicles). The rate of decrease for the measured emissions is very similar to the rate decrease predicted by the NZTER for the years 1998 to 2002. However, the modelled emission rates are consistently higher than the measured CO emissions rates by a factor of approximately 1.5. The data displayed in Figure 4 suggest that NZTER over-predicts CO emission rates for light duty diesel vehicles.

3.2 Heavy Duty Diesel (HDD) Vehicles

Figure 5 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) diesel heavy commercial vehicles (HCV) for the fleet year 2002. Figure 5 also compares modelled and measured emissions from buses. These comparisons should be treated with some caution and regarded as indicative rather than precise because the RSD sampled fleet of HDD and buses was small. Approximately 450 small, 200 medium and 200 large HCV and 46 buses were measured by the RSD.

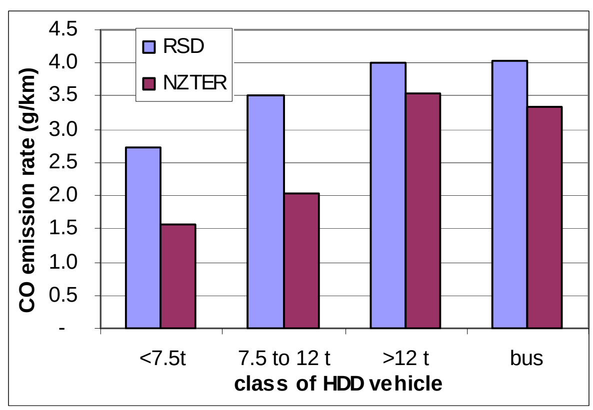

Figure 5. Modelled and measured CO emission rates for heavy-duty diesel vehicles (2002 fleet).

Figure 5 suggests that the NZTER underestimates the CO emissions from all classes of HCV and buses. Measured emissions from small and medium HDD are larger than the modelled emissions by a factor of approximately 1.7. The measured emissions from large HDD and buses are higher than the modelled emissions by a factor of approximately 1.2. The data displayed in Figure 5 suggest that the NZTER may underestimate CO emission rates for heavy-duty diesel vehicles and buses.

4. Composite Emission Factor

The emission factors for the different types of vehicles were used for calculating a composite emission factor for the vehicle fleet being modelled in the case study. Table 1 shows the calculation of the fleet composite emission factor from NZTER and RSD data for the year 2001.

Table 1. Fleet composite emission factor.

Vehicle Type	NZTER emission factor (g/km)	RSD emission factor (g/km)	% of fleet	NZTER contrib. to fleet (g/km)	RSD contrib. to fleet (g/km)
Petrol	8.98	7.37	78	7.00	5.75
LDD	1.25	0.83	16	0.20	0.13
HDD small	1.58	2.74	2	0.03	0.05
HDD medium	2.03	3.51	2	0.04	0.07
HDD large	3.55	4.0	2	0.07	0.08
Fleet (g/km)				**7.34**	**6.08**

5. Effect of Emission Factors on Dispersion Model Results

Figure 6 compares the monitored 1-hour average CO concentrations with the CO concentrations predicted by CALINE-4 using both modelled (NZTER) or monitored (RSD) emission factors.

Figure 6 shows that low concentrations of CO are measured during the early hours of the morning. From 0500 there is a rapid increase in observed concentrations and a daytime maximum is reached at about 0800. CO concentrations decline from the morning peak over the period 0800 to 1200 and then remain relatively constant until around 1500. A smaller evening peak is reached at approximately 1800 after which concentrations steadily decline toward the lower night-time levels. The observed data clearly shows a diurnal pattern of CO concentrations that is consistent with the combined effect commuter traffic emissions (higher vehicle numbers during the day and a morning and afternoon “rush hour”) and the higher more dispersive wind speeds during daylight hours.

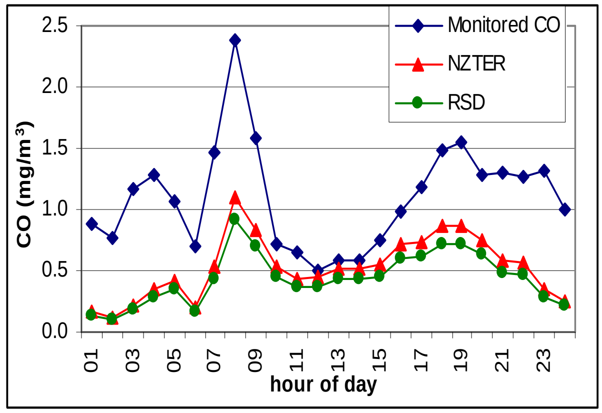

Figure 6. Diurnal variation of monitored and modelled CO concentrations.

Figure 6 shows that the diurnal pattern of CO concentrations is matched fairly well by the model predictions. The timing of the morning and evening peaks is captured well by the model.

While the model captures the diurnal pattern of 1-hour average CO concentrations reasonably well, the magnitude of the CO concentrations is underestimated on average by a factor of 1.9 and 2.3 for the NZTER and RSD emission factors respectively. Figure 6 shows that roadside concentrations of CO are underestimated to a greater extent when using the RSD emission factors.

Previous analyses have increased the NZTER emission factors to account for the proportion of vehicles (approximately 10%) running under cold-start conditions. (e.g. Bluett and Kuschel, 2002). Figure 7 compares the monitored 1-hour average CO concentrations with the CO concentrations predicted by CALINE-4 using the NZTER emission factors increased to account for the emissions from vehicles operating under cold-start conditions.

Figure 7 shows that the diurnal pattern and magnitudes of peak CO concentrations is matched fairly well by the model predictions when NZTER emission factors have been increased to account for 10% of vehicles operating under cold-start conditions. This set of modelling results is encouraging in terms of the quality of the emission data and the ability of the model to predict concentrations.

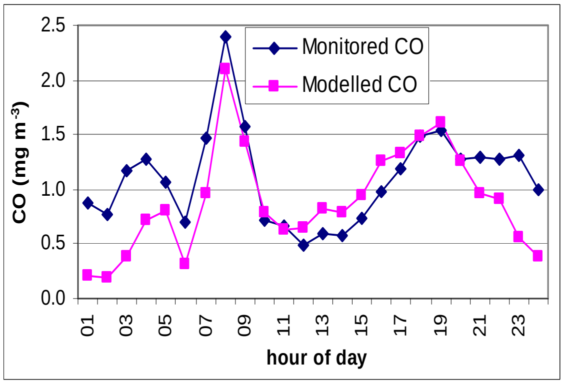

Figure 7. Diurnal variation of monitored and NZTER cold-start modelled CO concentrations.

However, the comparison of the results suggests that the NZTER produces higher estimates of the CO emission rates of vehicles in the New Zealand fleet than observed from RSD measurements. This occurs to a greater extent when the NZTER is adjusted to include the 10% of cold start vehicles (10.1 g CO/km).

If indeed the NZTER does overestimate the CO emission factors then, for the Auckland case study, it appears that the dispersion model, CALINE4, is underestimating the roadside concentrations. This could be due to other input data such as vehicle numbers, or fleet composition which itself is obtained from transport models, poor representation of local meteorological conditions by the input data used, or some other aspect of the model formulation.

5. Discussion and Conclusion

This project has been one of the first attempts carried out in New Zealand to validate the performance of vehicle emissions estimation methods.

This has been done firstly by comparing an emissions model (NZTER) with on-road emissions measurements (RSD). The results for CO show reasonably good agreement for petrol vehicles (the main source of vehicle CO), but tend to suggest that the NZTER overestimates CO from light duty and underestimates CO from heavy duty diesel vehicles.

Secondly, both emissions estimates have been compared with road-side monitoring data using a dispersion model. The results show that whilst the general diurnal pattern of the effects is reasonably easy to replicate, getting agreement on peak concentrations is difficult. The agreement improves if modelled emissions are increased to account for 10% of the vehicles in the fleet operating under cold start conditions. The dispersion model performance has yet to be fully investigated, but may be sensitive to other factors, such as meteorological input or very site-specific features associated with the monitoring location.

Nevertheless, the results presented here build on the confidence of the various techniques being used, and with some further work, promise to improve substantially the accuracy and reliability of both the emissions estimation techniques, as well as the effects of modelling.

Acknowledgments

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