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A Brisbane Tunnel Study to Validate Australian Motor Vehicle Emission Models

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Abstract

Reliable motor vehicle emission predictions are needed to ensure sound policy decisions. This study reports on a comparison between measured in-tunnel fleet emissions and predictions made with two new Australian vehicle emission software programs (COPERT Australia and PΔP) for one air pollutant: nitrogen oxides (NO_x). Measurements were taken from a 6.8 km tolled motorway tunnel that links several major roads in Brisbane, Australia. The validation study suggests that modelled vehicle emissions of NO_x are similar to those measured in the tunnel with a prediction error less than ±25% for both light-duty and heavy-duty vehicles. A possible reason for the difference is a suspected younger and cleaner fleet in the tunnel as compared with the Queensland average fleet. Further analysis of license plate information is anticipated to verify this.

Introduction

Road transport is a major source of air pollution and greenhouse gas emissions around the world. Comprehensive measurement of transport emissions in urban networks is not feasible due to the large number of vehicles that operate on our roads, large spatial and temporal variability and the many factors that influence emission levels. Modelling tools are therefore commonly used to estimate fuel consumption and air emissions. Models are also required to make projections into the future.

A hierarchy of vehicle emission models exists reflecting different levels of complexity and different types of application. These include ‘average-speed’ models (e.g. COPERT, MOBILE), where emission rates (g/veh.km) are a function of mean travelling speed, ‘traffic-situation’ models (e.g. HBEFA, ARTEMIS), where emission factors (g/veh.km) correspond to particular traffic situations (e.g. ‘stop-and-go-driving’, ‘freeflow’) and ‘modal’ models (e.g. PHEM, CMEM, MOVES, PΔP), where emission factors (g/s or g/ driving mode) correspond to specific engine or vehicle operating conditions. Whereas average speed and traffic situation models are designed to operate at the national or city network level, modal models are designed for local assessments.

Vehicle emission prediction software is well-developed in Europe and the US. However, they do not adequately reflect Australian conditions in terms of fleet mix, vehicle technology, fuel quality and climate. Large errors of up to a factor of 20 [1], have been reported when overseas models are directly applied to Australian conditions without calibration. Therefore two software packages were recently developed for Australian conditions using comprehensive empirical data from major Australian emission testing programs. COPERT Australia has been designed to estimate motor vehicle emissions at regional and national level [2], whereas a power based model (PΔP) was developed for more localised assessments [3]. The environmental impacts of road traffic are commonly evaluated at different scales using transport and emission models and, in the case of air pollution, dispersion and exposure models. As models are simplifications of reality, their limitations and accuracy should be clearly established. The development of reliable motor vehicle emission inventories is needed to ensure sound policy decisions. Similarly, local-scale traffic management measures (e.g. intelligent traffic light control, dynamic speed limits) often have relatively small effects on traffic emissions, so sensitive and accurate models are needed to predict the extent of their environmental impacts.

Tunnel Studies

There are several methods used to (partially) validate vehicle emission models, such as on-board emission measurements, remote sensing, near road-air quality measurements and tunnel studies [12]. Tunnel studies have been extensively used around the world to compare model predictions with observed values [4, 5, 6].

In these studies, emission factors, expressed as grams of pollutant per vehicle kilometer (g/veh.km), are determined using the differences between the concentration levels at the tunnel entrance and exit, combined with tunnel features (e.g. road length), traffic flow and traffic conditions, as well as either measured tunnel air flow or a dilution factor based on a tracer gas (e.g. SF6). Regression analysis is often used to develop mean emission factors (g/veh.km) by time of day for basic vehicle classes (e.g. LDV, HDV).

License plate information is typically recorded to obtain a detailed breakdown of the on-road fleet. In tunnels with distinct traffic flow patterns (e.g. separate bores for trucks [7]), separate emission factors can be produced. Tunnel lengths vary from a few hundred meters to 10 km. Several studies are done in tunnels with significant road gradients up to 4.2%. The averaging time of measurement is typically one hour and total sampling times vary from 10 hours to a month [12].

Tunnel validation studies have specific strengths and weaknesses. A strength is that emissions are derived from a large sample of the on-road fleet, thereby adequately capturing inter-vehicle variability in emissions, including 'high emitters', which will be discussed later. Moreover, measurements are carried out under relatively controlled conditions. For instance, the air dilution conditions are better known in tunnels than in open road experiments, and the influence of meteorological parameters is usually negligible. Also, the spatial resolution aligns better with distance-based emission factors used in vehicle emission models as compared with localised validation methods such as remote sensing and near-road air quality measurements.

However, there are also some disadvantages of tunnel studies. They rely on indirect measurements rather than direct exhaust measurements, and this can introduce errors. Second, they represent only a limited range of operating conditions (typically 'smooth', uncongested, high-speed driving). Tunnels may also have significant uphill and downhill gradients. Third, the so-called 'piston effect' - which occurs with one-way traffic flow - and any forced ventilation in the direction of the traffic flow combine to produce an effective tail wind that reduces aerodynamic drag on the vehicles in the tunnel. The effects on vehicle emissions can be substantial, with reported reductions in fleet emissions up to 45% for CO [13]. Furthermore, assumptions relating to the proportion of vehicles in cold-start mode, unrecognised vehicles, vehicle loading, etc. are required to make a comparison with model predictions, as is the case for other ambient air quality measurements. For particulate matter, an additional problem originates from the contribution of both exhaust and non-exhaust (due to tyre and brake wear and particle re-suspension, sometimes possibly even direct emissions from gravel trucks as reported [14]) sources to total concentrations.

Nevertheless, tunnel studies provide an excellent approach to (partially) validate vehicle emission models for specific traffic situations (high speed free-flow drive conditions).

COPERT Australia

COPERT is a globally used software tool used to calculate air pollutant and GHG emissions produced by road transport, and its scientific development is managed by the European Commission. A dedicated Australian version of COPERT was recently developed in cooperation with an EU partner to reflect local fleet composition and driving characteristics and provide adequate vehicle emission estimates for the Australian situation [15]. The software has been adopted by the National Pollutant Inventory as the recommended model for motor vehicle emission inventories and has been used a few months ago to estimate motor vehicle emissions for all states and territories in Australia [16].

COPERT Australia estimates emissions for 122 air pollutants and greenhouse gases. The software estimates emissions of both cold start and hot running exhaust and non-exhaust pollutants. Exhaust pollutants are produced during engine operation and they include carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_x) and particulate matter (PM). Several of these pollutants are further divided into subgroups. For example, NO_x emissions are split into NO and NO_2, PM is split into different size fractions (PM_{10}, $PM_{2.5}$, $PM_{0.1}$) and carbonaceous species, and VOCs are split into several individual groups and species, including saturated, aromatic and polyaromatic hydrocarbons. Greenhouse gas emissions include CO_2, methane (CH_4) and nitrous oxide (N_2O). The model can also estimate sulphur dioxide (SO_2) and several heavy metal emissions, provided that fuel properties are known.

Non-exhaust emissions calculated by the software include hydrocarbon emissions resulting from fuel evaporation of spark-ignition vehicles. Evaporation losses can occur through the fuel canister, which is used to capture fuel vapours from the fuel tank, through non-metallic fuel lines or plastic fuel tank walls, or through losses in fuel line connectors and fittings. In Australia, evaporative emissions are estimated to contribute 23% to total VOC emissions [16]. Another source of non -exhaust emissions is wear of vehicle components, primarily brakes and tyres. The wear contributes to the total PM generation by the vehicle. Studies have shown that for a typical petrol passenger car, the amount of wear contributing to airborne PM is larger than the contribution from vehicle exhaust [16]. Hence non-exhaust emissions should not be ignored in air emission inventories.

The software also provides functions to calculate the fuel consumption of individual vehicle types. The total calculated fuel consumption per fuel is then compared with fuel sales data in the region of interest as a calibration step.

COPERT Australia predicts emissions for 226 individual vehicle classes, which are defined in terms of vehicle type (e.g. small passenger car, large SUV, heavy bus, rigid truck, articulated truck), fuel type (petrol, E10, diesel, LPG) and 'emission control technology level' or ADRs (Australian Design Rules), which are the vehicle emission standards adopted in Australia. The software accounts for various other factors such as driving conditions, fuel quality, impacts of ageing on emissions and meteorology (ambient temperature and humidity).

PΔP

The PΔP model uses engine power (P, kW) and the change in engine power (DP, kW) to simulate fuel consumption and CO_2 and NOx (hot running) emissions for 73 Australian vehicle classes for each second of driving, following the vehicle classification used in COPERT Australia, but with a focus on the most important vehicle classes [3].

Similar to COPERT Australia, the software was developed using empirical data from a verified Australian emissions database with about 2,500 second-by-second emission tests (1 Hz) and about 12,500 individual aggregated 'bag' measurements using real-world Australian drive cycles. Multivariate time-series regression models have been fitted to these data using P and ΔP as predictor variables.

The input to the model is speed-time data (1 Hz) and information on road gradient, wind speed, vehicle loading and use of air conditioning (on/off). This information is used to compute the required (change in) engine power for each second of driving, and subsequently predict second-by-second fuel consumption and emissions.

The software has been used to estimate vehicle emissions in small urban networks using output from a microscopic transport model [18], to estimate the impacts of a safety intervention programs on vehicle emissions using on-road GPS measurements [19] and to assess the impacts of dynamic speed limits on emissions [20]. The software is ideally suited to examine the combined impacts of vehicle speed, road gradient and piston air flow in tunnels on emissions for all major on-road vehicle types (cars, SUVs, LCVs, rigid trucks, buses, articulated trucks).

Tunnel Measurements in Brisbane, Australia

The Department of Science, Information Technology, Innovation and the Arts (DSITIA) conducted a measurement campaign in the Northbound ventilation stack of the CLEM7 tunnel over a one week period for a number of key air pollutants.

Brisbane's Clem Jones Tunnel (CLEM7) is one of the largest infrastructure projects ever completed in Queensland. It has 6.8km of tollway and 4.8km of twin 2-lane tunnels (or tubes), with a cross-sectional area of about 60m^2, linking major Brisbane roads, including the Pacific Motorway, Ipswich Road, Lutwyche Road, Inner City Bypass, Airportlink M7 and Shafston Avenue at Kangaroo Point. The tunnels are interconnected with 41 cross-passages every 120 metres, which provide safe passage/emergency egress for personnel in the event of an emergency incident. Its lowest point runs at 60 metres under the Brisbane River. Construction of the $3 billion tollway commenced in September 2006 and was completed March 2010. The CLEM7 opened to traffic in the evening of Monday 15 March 2010, with over 1 million trips recorded in the first 3 weeks of toll-free operation.

A database with hourly averaged data was created, combining all relevant measurement information that was collected for the period 25 August to 3 September 2014:

1. date and time stamps
2. background concentration data for the key air pollutants
3. tunnel vent concentration data for the key air pollutants
4. tunnel vent air quality sensor concentration data
5. in-tunnel meteorological parameters
6. in-tunnel air flow, air speed and air travel time
7. in-tunnel traffic counts derived from tolling statistics

The following hourly information was computed and added to the database:

8. in-tunnel vehicle kilometres travelled by vehicle class
9. average vehicle speed
10. total hourly vent emissions for each pollutant
11. average fleet emission factor for each pollutant (g/veh.km)

There were various verification and computation steps involved for most of these parameters. They are briefly discussed in this section.

Urban Background Concentrations

Pollutant emissions from the tunnel vent are a function of accumulated vehicle emissions in the tunnel and ambient concentrations at the tunnel entrance. Ideally, the 'background' concentrations are measured at the tunnel entrance. This was, however, not feasible for this study. Ambient concentration data from DSITIA's South Brisbane monitoring station was used as a conservative estimate of concentrations at the tunnel entrance point. The station is located on the southern side of the Brisbane River, adjacent to the South East Freeway. It provides air monitoring data at a location that is close to several heavily trafficked roads.

Tunnel Vent Concentration Data

Air monitoring equipment was installed in the north tunnel ventilation stack on 25 August 2014. Air monitoring data (5 minute average) was collected by DSITIA in the north tunnel ventilation stack for a number of key air pollutants (CO, NO, NO_2, NO_x, $PM_{2.5}$, PM_{10}, SO_2, speciated VOCs and PAHs) and CO_2, as well as variables quantifying conditions in the tunnel vent (temperature, relative humidity, atmospheric pressure). Nitrogen oxides (NO, NO_2, NO_x) were determined using a technique known as 'chemiluminescence'. This requires the sample to react with ozone to convert NO to NO_2, releasing energy as light when the molecules return from the activated to normal state. To measure the NO_2 component, the sample is also passed through a molybdenum converter to convert NO_2 to NO, which is then reacted with ozone as described. The difference between NO levels in the two alternating gas streams quantifies the amount of NO_2. The pollutant monitoring data was checked by pre-and post-test calibration, because daily calibration for zero and span values could not be carried out during the test period. Examination of five minute data was performed to check the quality and validity of the raw concentration measurements, before hourly averaged values were computed.

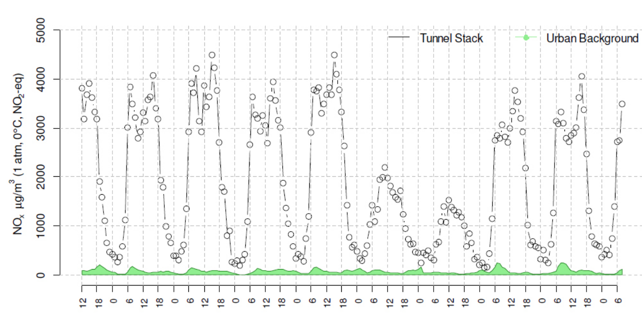

Figure 1. Hourly averaged tunnel vent NO_x concentrations (NO_2-equivalents) and urban background concentrations.

Figure 1 shows a time-series plot of measured NO_x concentration levels (µg/m^3) in the north ventilation stack, including the urban background concentration levels measured at South Brisbane station. Note that the concentration levels are normalised to 0 °C and an atmospheric pressure of 101.3 kPa. The daily variation in traffic flows is clearly visible in the concentration data, as is the difference between weekdays and weekend (30 and 31 August).

Estimation of Tunnel VKT

Emissions from the tunnel vent are a function of total vehicle travel in the tunnel, which is quantified with a variable called 'vehicle kilometres travelled' (VKT). Hourly VKT is computed by multiplication of total traffic volume (veh/h) with total distance (km).

Tolling statistics are collected at the exit of the northbound tunnel using camera imaging technology. License plate numbers (LPNs) are collected and date-time stamped for each vehicle that passes the cameras. Each vehicle is then classified as a motorcycle, car, light commercial vehicle (LCV) or heavy commercial vehicle (HCV) using height, length and width of each vehicle, which are determined when the vehicle travel through a specific zone on the road. The tolling data have been used to compute hourly total traffic counts for each of these four vehicle classes. The data were verified, corrected and time-aligned.

A time adjustment is required to better align the emission measurements with the traffic count data. A constant time offset of 8 minutes was used for the traffic count data. It is noted that the tunnel itself will smooth and delay motor vehicle emissions over time, which, given the changes in air speeds and vehicle speeds, is a dynamic process. As a result, the use of a constant time offset of 8 minutes is a first order estimate that could potentially be improved. The alignment errors in the 5 minute traffic volume data are expected to be significantly reduced after aggregation to hourly traffic count values.

The northbound tunnel has two main entry points and a vehicle will travel a different distance, depending on its entry point. The tolling statistics are believed to provide accurate information on the number and types of vehicles exiting the tunnel, but they do not provide information on the number of vehicles entering the tunnel at the two entry points. Therefore, additional data were collected from CCTV cameras at the entry points, which are not used for tolling purposes. The CCTV system cameras scan across one or two lanes of traffic and two closely spaced vehicles can be counted as a single 'large' vehicle (e.g. articulated truck), leading to significant vehicle detection and classification errors. The CCTV data were therefore only used to determine the proportion of vehicles entering the tunnel through Shafston Avenue (typically 15-25%) and Main Entrance for each hour of data. These proportions were then multiplied with the hourly traffic count data obtained from the tolling statistics and corresponding travel distances to compute total hourly VKT.

Computation of Tunnel Vent Emissions

Concentration levels measured in the ventilation stack are governed by ambient concentration levels near the tunnel entrance ('background levels'), traffic volumes in the tunnel, air flow in the tunnel and the fleet mix (e.g. proportion of heavy trucks). Concentration data are used to calculate hourly emissions from the tunnel vent. Emissions of pollutant p at hourly time step t ($E_{t,p}$, g/h) are computed as follows:

$$E_{t,p} = \left(C_{t,p,v} - C_{t,p,b}\right) F_t \, 10^{-6} \tag{1}$$

where $C_{t,p,v}$ represents the measured average hourly concentration of pollutant p at time step t in the tunnel vent (µg/m^3), $C_{t,p,b}$ represents the average hourly urban background concentration of pollutant p at time step t (µg/m^3), Ft represents the total tunnel air flow at time step t (m^3/h) and 10^{-6} is a unit conversion factor.

Computation of Fleet Average Emission Factors

A fleet-averaged emission factor ($e_{t,p}$, g/veh.km) is computed when total tunnel emissions (g/h) are divided by total travel (veh.km/h) for each hour of measurement. These normalised hourly emissions can then be plotted against the percentage of heavy-duty vehicles (P_{HDV}) and a simple linear ordinary least-squares (OLS) regression model can be fitted:

$$e_{t,p} = (a + b\, P_{HDV}) + h + \varepsilon \tag{2}$$

In this model, a and b are fitted regression coefficients (intercept and slope, respectively), h is a high-emitter emission factor offset, which is discussed later, and ε is the error term. This model is useful as it can be used to estimate the mean emission factors (including 95% confidence intervals) for light-duty vehicles (LDV) and heavy-duty vehicles (HDV) by setting P_{HDV} to zero and 100%, respectively.

Hours with reduced average speeds less than 75 km/h (due to e.g. maintenance) were removed to ensure homogeneous and comparable traffic conditions. In addition, data points with less than 20 vehicles going through the tunnel per hour were removed. Data points with a small number of vehicles can be significantly influenced by errors in urban background concentrations.

It has long been known that fleet emissions are dominated by a small percentage (< 10%) of high-emitters, and the impact of high emitters is increasing [21, 22]. It has been reported that 1% of on-road vehicles in the USA contributed less than 10% to total vehicle emissions in the late 1980s, and that this contribution of 1% of on-road vehicles now has increased to about 30% [23]. So total fleet emissions are becoming increasingly sensitive to a small number of high emitting vehicles. In line with international studies, the CLEM7 data suggests that the distributions of emissions from vehicles in the tunnel are highly skewed where the majority of the vehicles have low emissions, but some vehicles exhibit (very) high emission levels and have a disproportionate impact on total vehicle emissions. These vehicles are commonly referred to as 'high emitters'. Studies have shown that vehicle emissions of these vehicles can be up to 50 times higher, respectively, than a properly functioning catalyst car [24]. This vehicle emissions behaviour reflects two main trends:

- The penetration of cleaner vehicles into the fleet over time due to increasingly strict emission standards and improved control technologies.
- The presence of vehicles that are badly tuned or have been tampered with, have engine issues and/or have malfunctioning or partly functioning emission control systems (catalysts, lambda sensor, faulty fuel caps, etc.).

It is however, important to include these valid measurements in the determination of fleet averaged emission factors from the in-tunnel measurements, so the data points are retained and used in model fitting. A robust weighted linear modelling (RWLM) approach is used to identify outliers in the hourly emissions data for each pollutant. This regression is weighted with the total number of vehicles for each hour (sample size), and thus accounts for the higher accuracy of data points with more vehicles. This approach is not sensitive to outliers, which is preferred from a model fitting perspective, but at the same time does not properly reflect high hourly emissions in the model.

So a two-step approach was employed. First a RWLM was fitted to the data and the residuals were calculated. Any hourly emission values that exceeded the median value plus three times the standard deviation were tagged as outliers [25]. These values are not used in the OLS regression model fitted in the next step, but they are used separately to calculate a 'high emitter' emission offset (h), which is added to the intercept of the regression model (see equation 2).

Second, a weighted OLS linear regression is performed on the hourly emissions data without outliers to compute the regression coefficients and their standard errors. This regression is weighted with the total number of vehicles for each hour (sample size), and thus accounts for the higher accuracy of data points with more vehicles.

The 'high emitter' emission offset *h* is computed as the mean of the hourly emission values tagged as outliers multiplied with the proportion of outliers in the data. It is thus assumed that high emitters form a low portion of the fleet and occur randomly in time, they dominate normalised emissions (g/km) when they are in the tunnel and that they are not significantly affected by the proportion of HDVs.

Figure 2 shows the results for NO_x. The regression model predicts a fleet averaged light-duty vehicle (LDV) NO_x emission factor of 0.55 g/veh.km (95% confidence interval of 0.52 - 0.59 g/veh.km) and a fleet averaged heavy-duty vehicle (HDV) emission factor of 5.85 g/veh.km (95% confidence interval of 5.28 - 6.42 g/veh.km). The high emitter offset of 0.07 g/veh.km contributes 8% to the fleet averaged NOx emission factor at a PHDV value of 5%.

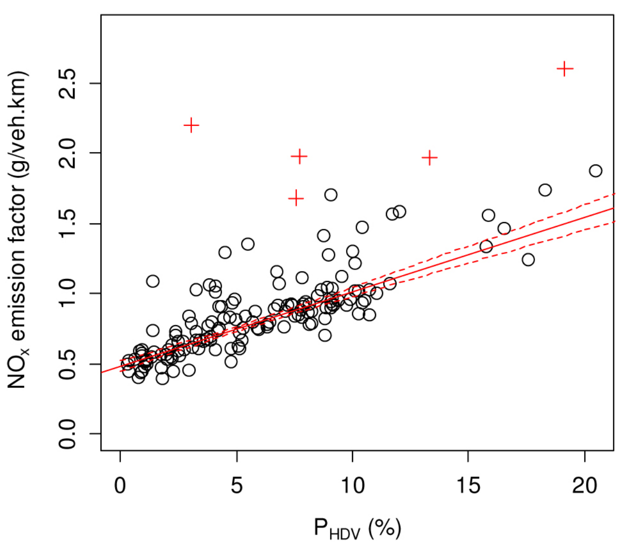

Figure 2. Fleet averaged NO_x emission factors (NO_2-equivalents) as a function of proportion of heavy-duty vehicles, outliers (+) and fitted regression model with 95% confidence interval.

A coefficient of determination (R^2) of 0.68 shows that the model explains 68% of the variation in fleet averaged emission factors. Residual analysis shows that model performance can be further improved to better account for measurements at higher P_{HDV} values. It is possible that these elevated values are caused by a higher portion of large articulated trucks. Further work is conducted using license plate information to determine hourly fleet composition at a higher level of detail and this information will be used to develop prediction models with an improved goodness-of-fit. The results of the initial model presented in Figure 2 are compared with emission factors predicted with Australian vehicle emission software as a first-order validation.

Model Validation

COPERT Australia was used to generate vehicle base emission factors for LDVs and HDVs for an average speed of 80 km/h and using a detailed breakdown of Queensland vehicle fleet [16].

Subsequently, the PΔP software was used to examine the impacts of road gradient, piston air flow and tunnel driving conditions on emission factors. As a first step, the range of measured air speeds in the tunnel was determined to 7 to 18 km/h. The average daily variation in air speed is shown in Figure 3.

Second, the road gradient of the tunnel with accumulated distance was determined from tunnel design maps. Third, recorded driving behaviour in free-flow freeway conditions with an 80 km/h speed limit was used to create a second-by-second input speed-time profile for driving in the tunnel. The driving profile accounts for small natural fluctuations in speed. The accumulated distance in the tunnel was then computed for each second of driving and a road gradient input profile was created.

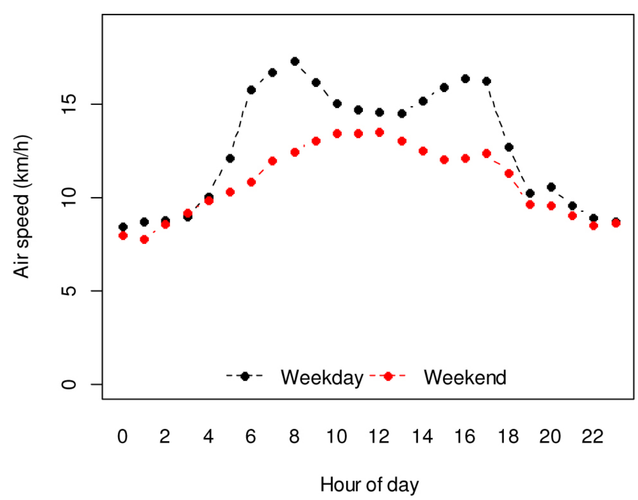

Figure 3. Measured air speed in the tunnel.

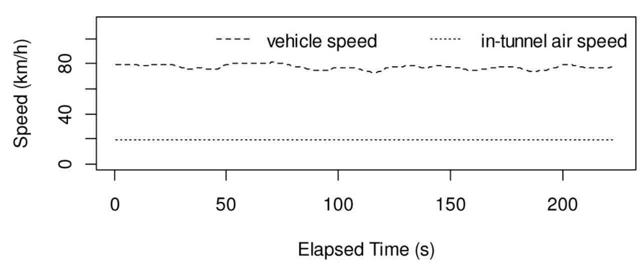

Figure 4. Example of second-by-second input data for PΔP software including in-tunnel air speed (maximum), road gradient and vehicle speed for the base-case and tunnel.

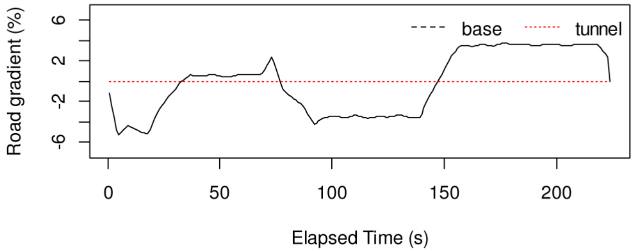

Figure 4. (cont.) Example of second-by-second input data for PΔP software including in-tunnel air speed (maximum), road gradient and vehicle speed for the base-case and tunnel.

Figure 4 shows the results for an in-tunnel air speed of 19 km/h. Note that a 'base-case' is also defined, which is the same speed-time profile but with zero gradient and zero air speed. The PΔP software was then run for the range of in-tunnel air speeds, producing second-by-second estimates of NO_x emissions for 73 vehicle classes in the tunnel. An example is shown in Figure 5.

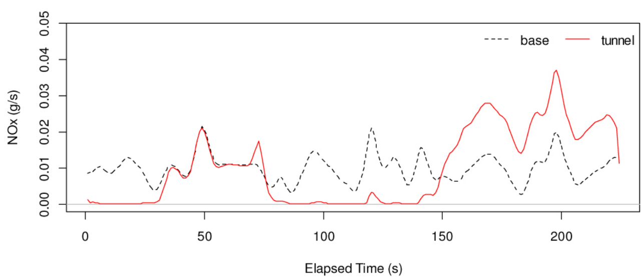

Figure 5. Example of second-by-second emission predictions with the PΔP software a large petrol passenger car for the base-case and tunnel.

Total emissions (grams of NO_x) were calculated for each case and divided by total distance to compute average emission factors (g/veh.km) for each of the 73 vehicle classes and range of in-tunnel wind speeds. Composite emission factors for LDVs and HDVs were then computed for each in-tunnel air speed using VKT weighting factors reflecting the average Queensland fleet. By dividing these composite emission factors with the base case, emission correction factors are computed as a function of in-tunnel air speed. The results are shown in Figure 6.

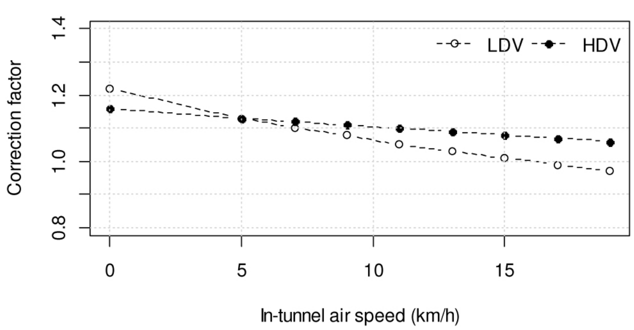

Figure 6. Combined road grade and in-tunnel air flow correction factors for LDVs and HDVs as computed with the PΔP software.

The road gradient effect on in-tunnel emissions is substantial with an approximately 20% increase in NOx emissions (air speed is zero km/h). It is interesting to see the significant impacts of in-tunnel air speed on emissions, which roughly compensates for the impacts of road gradient at high air speeds. The average correction factor for the entire measurement period is 1.01 and 1.08 for LDVs and HDVs respectively. COPERT Australia base emission factors were multiplied with these values.

Figure 7 compares the modified COPERT Australia emission factors with those determined from the CLEM7 measurements. The PΔP/COPERT Australia software predicts (Queensland) fleet average hot running emission factors of 0.68 and 6.63 g/veh.km for LDVs and HDVs respectively. These values are 23% higher and 13% higher than those measured in the tunnel.

The difference is statistically significant ($p < 0.05$) as the COPERT Australia emission factors falls outside the 95% confidence interval, but the magnitude of the difference appears small. For instance, a review of 50 international vehicle emission model validation studies showed that reported model prediction errors are generally within a factor of 2 for NO_x [12].

It is suspected that the in-tunnel fleet is younger than the Queensland fleet, which would explain the lower emissions in the tunnel. This will be further examined through more detailed analysis of vehicle information obtained through matching recorded license plates with vehicle registration information.

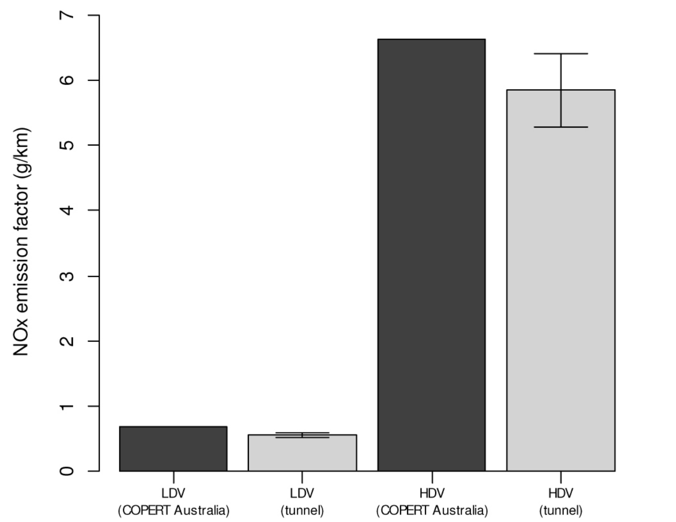

Figure 7. Comparison of average fleet emission factors from Australian vehicle emissions software with those determined from tunnel measurements, including 95% confidence intervals for tunnel measurements.

Conclusions

This study reports on a comparison between measured in-tunnel fleet emissions and predictions made with two new Australian vehicle emission software programs (COPERT Australia and PΔP). Measurements were taken from a 6.8 km tolled motorway tunnel that links several major roads in Brisbane, Australia. The validation study suggests that modelled vehicle NO_x emissions are within 25% of those measured in the tunnel.

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Definitions/Abbreviations

CMEM - Comprehensive Modal Emissions Model

COPERT - COmputer Programme to calculate Emissions from Road Transport

HDV - Heavy-Duty Vehicle

HBEFA - HandBook of Emission FActors

LDV - Light-Duty Vehicle

PΔP - Power-delta-power

PHEM - Passenger car and Heavy duty Emission Model

VKT - Vehicle Kilometres Travelled

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