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A tunnel study to validate motor vehicle emission prediction software in Australia

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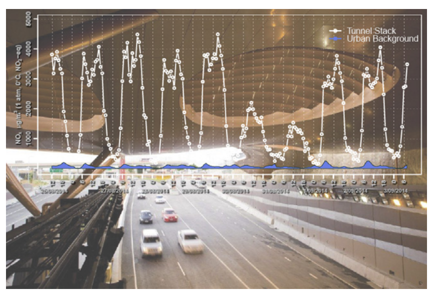
HIGHLIGHTS

- Tunnel studies are useful to partially validate vehicle emissions software.
- Air flow in tunnels can compensate the impacts of road gradients on vehicle emissions.
- Local fleet mix is an essential factor in validation studies.

GRAPHICAL ABSTRACT



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ABSTRACT

A tunnel emissions study was conducted to (partially) validate the Australian vehicle emissions software COPERT Australia and PIARC emission factors. The in-tunnel fleet mix differs substantially from the average on-road fleet, leading to lower emissions by a factor of about 2. Simulation with the PΔP software found that in-tunnel air-flow compensates to a large extent for road gradient impacts on NO_x emissions. PIARC emission factors are conservative and exhibit the largest prediction errors, except for one very good agreement for LDV NO_x. COPERT Australia is generally accurate at fleet level for CO, NO_x, $PM_{2.5}$ and PM_{10}, when compared with other international studies, and consistently underestimates emissions by 7% −37%, depending on the pollutant. Possible contributing factors are under-representation of high/excessive emitting vehicles, inaccurate mileage correction factors, and lack of empirical emissions data for Australian diesel cars. The study results demonstrate a large uncertainty in speciated VOC and PAH emission factors.

1. Introduction

Motor vehicles are a major source of air pollution and greenhouse gas (GHG) emissions in urban areas around the world. The close proximity of motor vehicles to the general population makes this a particularly relevant source from an exposure and health perspective. This is illustrated by Caiazzo et al. (2013) who estimated that total combustion emissions (particulates, ozone) in the U.S. account for about 210,000 premature deaths per year, with motor vehicles being the largest contributor, contributing to around 58,000 premature deaths per year, despite the fact that road transport only contributes about 7% to total $PM_{2.5}$ emissions.

Comprehensive measurement of vehicle emissions in urban networks is cost prohibitive due to the large number of vehicles

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that operate on roads with different emission profiles, large spatial and temporal variability in vehicle activity and many real-world factors that influence emission levels (Smit et al., 2008). The environmental impacts of road traffic are therefore commonly evaluated at different scales using transport and emission models and, in the case of air pollution, dispersion and exposure models. Models are also required to make projections into the future.

Vehicle-emission prediction software is well-established in Europe and the US. However, these models have been found to not adequately represent Australian conditions in terms of fleet mix, vehicle technology, fuel quality and climate. Large errors of up to a factor of 20 have been reported when overseas models were directly applied to Australian conditions without calibration (Smit and McBroom, 2009). Therefore, two software packages have been developed specifically for Australian conditions, using comprehensive empirical data from major Australian laboratory emission testing programs. COPERT Australia has been developed to estimate motor vehicle emissions at a regional and national level, while a power-based model (PΔP) was developed for local assessments, as will be discussed in Section 2.2.

As models are simplifications of reality, their limitations and accuracy should be clearly established. This paper presents results of a tunnel emissions study that was conducted in Brisbane, Australia.

2. Method

2.1. Tunnel studies

There are several methods used to (partially) validate vehicle emission models, such as on-board emission measurements (PEMS), remote sensing, near-road air quality measurements and tunnel studies (Smit et al., 2010). Like all validation methods, tunnel studies have specific strengths and weaknesses. A strength is that emissions are derived from a large sample of the on-road fleet under relatively controlled conditions, thereby adequately capturing inter-vehicle variability in emissions. The spatial resolution aligns better with distance-based emission factors (g/km) commonly 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 challenges with tunnel studies. They represent only a limited range of operating conditions (typically 'smooth', uncongested, high-speed driving). As a consequence, validation results cannot be directly translated, for example, to commonly occurring urban driving conditions at lower speeds. Tunnels may also have significant uphill and downhill gradients, and in-tunnel air-flows affecting emissions. Furthermore, assumptions relating to the unknown proportion of vehicles in cold-start mode and actual vehicle loads are required to make a comparison with model predictions. Nevertheless, tunnel studies provide a useful approach to (partially) validate vehicle emission models for specific traffic situations.

Tunnel studies have been extensively used around the world to compare model predictions with observed values (e.g. De Fré et al., 1994; Hausberger et al., 2003; Geller et al., 2005). In these studies, emission factors, expressed as grams of pollutant per vehicle kilometre (g/veh.km, subsequently denoted as g/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. SF_6). Regression analysis is often used to develop mean emission factors (g/km) by time of day for basic vehicle classes (e.g. light-duty vehicle, LDV and heavy-duty vehicle, 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), separate emission factors can be produced. Tunnel lengths vary from a few hundred metres 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 (Smit et al., 2010).

2.2. Australian vehicle emissions software

COPERT (COmputer Program to calculate Emissions from Road Transport) 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 (COPERT Australia) was developed to reflect local fleet composition and driving characteristics and provide vehicle emission estimates for the Australian situation (Mellios et al., 2013; Smit and Ntziachristos, 2013a). The software has been adopted by the National Pollutant Inventory as the recommended model for motor vehicle emission inventories and has been used to estimate motor vehicle emissions for all states and territories in Australia (UQ, 2014).

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. 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 (equivalent to Euro standards since 2003). The software accounts for various other factors such as driving conditions (average speed), fuel quality, impacts of ageing on emissions and meteorology (ambient temperature and humidity).

The PΔP software uses engine power (P, kW) and the change in engine power (ΔP, kW) to simulate fuel consumption and CO_2 and NO_x (hot-running) emissions for 73 Australian vehicle classes for each second of driving (Smit, 2013). PΔP has adopted the vehicle classification used in COPERT Australia, but with a focus on the most important vehicle classes. Similar to COPERT Australia, the software was developed using empirical data from a verified Australian emissions database with about 2500 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. The purpose was to estimate the impacts of a safety intervention programs on vehicle emissions using on-road GPS measurements and to assess the impacts of dynamic speed limits on emissions (Smit, 2014). 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).

PIARC (Permanent International Association of Road Congresses) publishes country-specific emission factor tables that are widely used around the world to estimate emission levels