Australasian Transport Research Forum 2013 Proceedings
2 - 4 October 2013, Brisbane, Australia
Publication website: http://www.patrec.org/atrf.aspx

COPERT Australia: a new software to estimate vehicle emissions in Australia

Robin Smit[1], Leonidas Ntziachristos[2]

[1]Department of Science, Information Technology, Innovation and the Arts, Air Quality Sciences, Inventory, Modelling and Assessment Unit, Brisbane, Australia

[2] Laboratory of Applied Thermodynamics, Aristotle University, PO Box 458, GR 54124, Thessaloniki, Greece

Email for correspondence: robin.smit@qld.gov.au

Abstract

COPERT is a globally used software tool used to calculate air pollutant and greenhouse gas emissions produced by road transport, and its scientific development is managed by the European Commission. The software estimates all types of emissions including hot running, start, evaporative and non-exhaust (tire wear, brake wear). Previous studies showed that a similar software used in Australia needs to reflect local fleet composition and driving characteristics in order to provide adequate vehicle emission predictions for the Australian situation. Therefore, a dedicated Australian version of COPERT was developed in cooperation with an EU partner. This software has been calibrated with thousands of vehicle emission tests that were conducted in Australia. This paper discusses the methods and data used for the development of COPERT Australia. The model is then used to estimate road transport emissions for South East Queensland and the results are discussed.

1. Introduction

Clean air is considered to be a basic requirement of human health and well-being. According to the World Health Organization, air pollution is responsible for approximately 2 million premature deaths annually (WHO, 2006), with vehicle emissions representing a major source of air pollution in urban areas. Greenhouse gas emissions from transport have increased by 50% in the period 1990-2010 and they made up about 15% of total Australian CO_2-equivalent emissions in 2010 (DCCEE, 2012), the majority of which is due to road transport.

Emissions from on-road vehicles are a function of often interacting variables. First, air pollutant emissions and fuel consumption vary substantially with vehicle design characteristics, which include (but are not limited to) vehicle size and weight, engine type, type of fuel, transmission type, presence and type of emission control technology, presence of auxiliary equipment such as air conditioning and aerodynamic characteristics.

In addition to these vehicle-related factors, the way a vehicle is driven (driving behaviour) affects vehicle emissions and fuel consumption. Driving behaviour itself is the result of factors such as the interaction with road characteristics (speed limits, intersections, road width, road condition, gradient, and so forth), level of congestion, road grade, personal driving style (aggressive, defensive, etc.), gear shift behaviour, use of auxiliary equipment and weather related conditions (ambient temperature, humidity, rain, fog, etc.).

Finally, other factors impact on emission levels, such as “driving mode” (cold, hot running, parked), deterioration of engine and emission control components (ageing effects), engine tuning and maintenance, fuel quality (composition and characteristics), and geographic location (e.g. air density and altitude). All these factors are often interrelated and may influence different “types of emissions”, namely:

- Hot running emissions (moving vehicles): exhaust emissions that occur under "hot stabilized" conditions, which means that the engine and the emission control system (e.g. catalytic converter) have reached their typical operating temperatures.
- (Cold) Start emissions (moving vehicles): exhaust emissions that occur in addition to hot running emissions because engines and catalysts are not (fully) warmed up and operate in a non-optimal manner.
- Non-exhaust particulate emissions (moving vehicles): particulate (PM) emissions due to wear of tires, brakes, roads and re-suspended road dust.
- Evaporative emissions (parked vehicles): non-exhaust hydrocarbon losses through the vehicle's fuel system.

Due to the continued growth in vehicle use and the ongoing deterioration in driving conditions (congestion), the prediction of traffic emissions has become increasingly relevant to air quality problems, climate change and mitigation policies. The development of reliable emission inventories is therefore needed to ensure that the use of this information results in sound policy decisions.

A review of road traffic emission modelling practice around the world found that models have become more complex and more comprehensive over time (Smit et al., 2009). This is reflected in the increasing numbers of vehicles types, fuel types, pollutants and types of emission (e.g. hot running, start, evaporative) considered in the models. For instance, models developed in the 1970s and 1980s generally only predicted hot running emissions of a small number of pollutants from petrol cars, based solely upon test data over certification driving cycles. In contrast, current models tend to include all relevant vehicle types, fuels, regulated and unregulated pollutants, greenhouse gases and fuel consumption, and are (at least partly) based on emission tests which reflect real-world driving behaviour. Similarly, the size of the emission test databases has generally increased with time. Pre-1990 models were typically based on less than 100 vehicles, whereas more recent models are typically based on thousands of vehicles.

2. Vehicle Emission Modelling in Australia

Although individual State Departments (e.g. QLD EPA, 2003; NSW EPA, 2012) and Federal Departments (BITRE, 2010) develop and maintain motor vehicle emission inventories, there is no Australian vehicle emissions software available that is actively developed and maintained, as is done overseas. In countries such as Australia it would be convenient to use well-known and established vehicle emission software tools such as COPERT, MOBILE, and MOVES. However, previous investigations showed that a vehicle emission inventory model used in Australia needs to reflect local fleet composition and driving characteristics in order to provide adequate vehicle emission predictions for the Australian situation.

For instance, a vehicle emission model based on Australian measurements predicted total urban network emission levels of CO, THC and NO_x for an Australian city of up to a factor of 2 higher as compared with COPERT III predictions (Smit, 2006). Similarly, mean NO_x prediction errors as compared with observed values for freeway conditions were a factor of 1.6 to 2.0 higher for COPERT 4 and MOBILE 6, respectively, when compared to an Australian average speed model (Smit and McBroom, 2009a).

Another study (Smit and McBroom, 2009b) compared the default (European) emission algorithms in a commonly used microscopic traffic simulation package to measured modal emission rates for 60 typical Australian petrol vehicles. Observed average emission rates (g/km) for 15 stop-go-stop segments were compared with predicted values based on the European algorithms (Panis et al. 2006). A large underestimation of emissions was found, up to more than two orders of magnitude for individual micro-trips. On average an underestimation of a factor of about 20 (NO_x), 1.5 (THC), 4.0 (CO_2, freeway) and an overestimation of a factor of about 1.3 (CO_2, non-freeway) was reported. These investigations indicate that direct use of overseas vehicle emission models in Australia can lead to substantially biased results.

The main reason for these differences is that overseas models are based on overseas vehicle emissions datasets, which do not reflect Australian vehicles, fuels, climate, fleet composition and driving conditions. The Australian fleet, for instance, varies substantially from European fleets, despite the fact that Euro standards have been adopted in Australia since about 2003 (before 2003 US standards were used). One of the main differences with European fleets is the lower penetration of diesel light-duty vehicles in the Australian fleet, i.e. 17% in the Australian fleet (ABS, 2012) compared with approximately 33% in the European countries (ANFAC, 2010). The Australian light-duty fleet is mainly fuelled with petrol and the heavy-duty fleet with diesel, although there is also significant use of E10, LPG and CNG. Other important differences relate to vehicle technology. For instance, the Australian passenger car fleet has a large proportion of large passenger cars and (4WD) SUVs. The majority (about 75%) of the Australian car fleet has an engine capacity of more than 2 litres. This contrasts with e.g. the UK and Dutch car fleets where these vehicles only make up about 10% of the fleet because smaller engines are dominant (Smit, Rose and Symmons, 2010). Another difference in the Australian car fleet is the large share of cars with automatic transmissions – about 70%, which is substantially higher compared to what is known in European countries.

3. COPERT

Instead of developing a new motor vehicle emission prediction system, it is more cost-effective to calibrate a user-friendly, commonly used and well-tested overseas model with Australian data. As Australian vehicle emission standards are now aligned with European standards, it was preferred to adopt and calibrate a European model. The COPERT software was identified as a suitable candidate and a cooperative research agreement between EMISIA and DSITIA was signed in October 2011 to develop a dedicated Australian software (‘COPERT Australia’). A free beta version was released in February 2013 and a commercial version is expected by the end of 2013.

COPERT stands for COmputer Programme to calculate Emissions from Road Transport (http://www.emisia.com/copert/) and the first version was released in 1989 (Eggleston et al., 1993) as a result of a European initiative to develop emission inventory methodologies beyond local initiatives. The European Environment Agency (EEA) coordinates COPERT’s development, whereas the European Commission manages the scientific developments. COPERT 4 is the latest version and it is used world-wide to calculate air pollutant and greenhouse gas emissions from road transport, e.g. for submission of national road transport inventories to satisfy the requirements of the Convention on Long Range Trans-boundary Air Pollution (CLRTAP) and the UN Framework Convention on Climate Change (UNFCCC).

COPERT is designed to estimate tank-to-wheel vehicle fleet emissions at country or State level. The methodology aims to balance the need for detailed emission calculations to achieve an acceptable level of accuracy with limitations regarding the availability of the input data. COPERT 4 simulates emissions and fuel consumption for 241 vehicle types and covers a wide range of pollutants, and includes all ‘types of emissions’ (hot running, cold start, non-exhaust, evaporative) that were discussed before.

Different calculation methods are included for (engine) exhaust emissions and non-exhaust emissions (Ntziachristos et al., 2009). Exhaust emissions are simulated separately for hot and cold conditions and two types of non-exhaust emissions are simulated:

1. particulate matter (PM) from the wear of tires and brakes (‘non-exhaust PM emissions’); and
2. hydrocarbon emissions (THC) arising from fuel that evaporates via the fuel system (‘evaporative THC emissions’).

The software outputs total emissions by pollutant and type of emission and so-called emission factors, which represent normalized vehicle emissions expressed as grams per km for different driving conditions (‘urban’, ‘rural’, ‘freeway’).

COPERT can be classified as an ‘average speed model’. Average speed emission algorithms are commonly used around the world to estimate emissions from road traffic at a national or regional level. In essence, these models combine emission factors (grams/veh.km) with traffic activity data (VKT) using a detailed breakdown by vehicle class. The emission factors are a function of traffic performance (‘average travel speed’), as well as several other factors such as fuel quality, ambient temperature, ageing, etc. Average speed models are well suited to be interfaced with, or use output from macroscopic transport models. For its intended purposes, i.e. urban network and State level modelling, the average speed approach is considered to be a satisfactory compromise between model accuracy and the availability of input data.

4. COPERT (Europe) and COPERT Australia

The main differences between COPERT 4 and COPERT Australia relate to the vehicle classification and the methods used to develop average speed (hot running) emission algorithms and cold start emission factors. These are briefly discussed here.

4.1 Vehicle classification

COPERT Australia uses a different vehicle classification as compared with COPERT 4 to adequately reflect the Australian fleet characteristics and the structure of the Australian empirical database. COPERT Australia considers 223 vehicle classes. The classification is based on the combination of main vehicle type, fuel type (petrol, E10, diesel, LPG, CNG) and ADR category (‘technology level’). ADRs refer to “Australian Design Rules”, which are the emission standards adopted in Australia and COPERT Australia considers 18 ADR categories, including future ones. The main vehicle types in COPERT Australia are small passenger car (PC-S, engine capacity < 2 litres), medium passenger car (PC-M, 2-3 litres), large passenger car (PC-L, > 3 litres), compact SUV (SUV-C, 4WD, ≤ 4 litres), large SUV (SUV-L, 4WD, ≤ 6 litres), light-commercial vehicle (LCV, GVM ≤ 3.5 t), medium commercial vehicle (MCV, GVM 3.5-12.0 t), heavy commercial vehicle (HCV, GVM 12.0-25.0 t), articulated truck (AT, GVM > 25 t), light bus (GVM ≤ 8.5 t) and heavy bus (GVM > 8.5 t), and mopeds and motorcycles. This classification differs from COPERT 4. For instance, COPERT 4 does not include large passenger cars with an engine capacity larger than 3 litres and SUVs, which are both important vehicle classes in Australia.

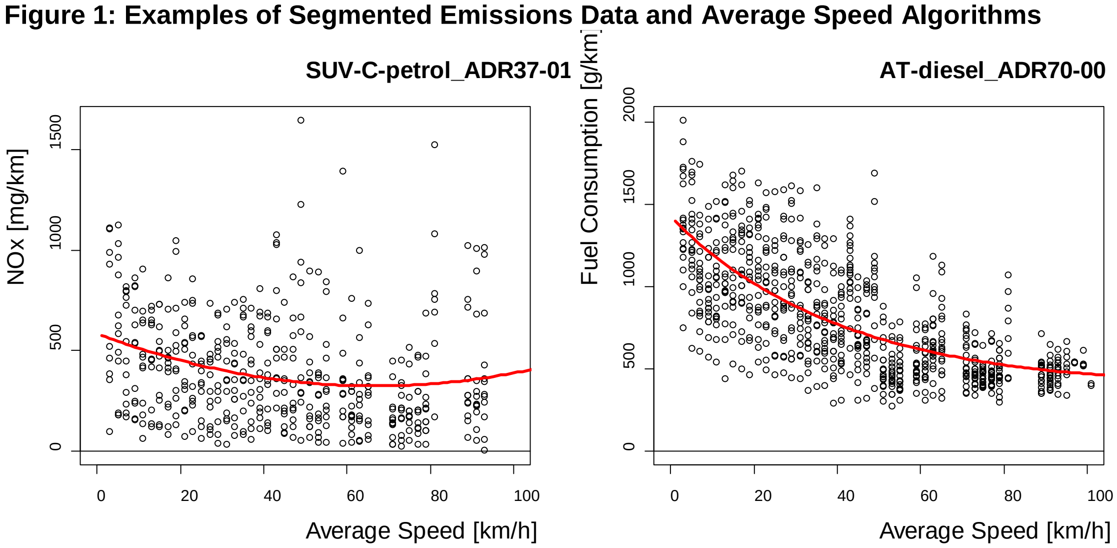
4.2 Average speed algorithms (hot running)

A large amount of vehicle emissions test data have been made available from various Australian test programs that were conducted over time. These emissions data have been collated in a verified emissions database with about 2,500 second-by-second modal emission tests and about 12,500 aggregated bag measurements. The modal data files typically contain 30 minutes of 1 Hz laboratory-grade emissions data over real-world Australian driving cycles that were developed from on-road driving pattern data in Australian cities.

A fundamental change with respect to COPERT 4 is explicit consideration of the required spatial resolution of the average speed algorithms in COPERT Australia. It was considered that macroscopic transport models are the most likely source of input data for emission predictions. A driving distance of 100 m was therefore selected as an appropriate scale for emission factor development. A procedure was developed to derive hot running emission algorithms at this spatial resolution using second-by-second emissions test data (Smit and Ntziachristos, 2012). All test data were subjected to a verification and correction protocol which included filtering of speed-time data with a T4253H smoothing algorithm, time realignment and computation of verification statistics. An automated procedure was created to extract 100 m driving pattern segments and their associated emissions data from the verified database (766 Australian vehicles) for each vehicle to create a segmented emissions database for regression modelling.

The final emissions database contains the following information for 100 m driving segments: relevant vehicle information (vehicle class, fuel type, model year, mileage), distance (m), travel time (s), emission rates (g/km), and average speed (km/h). Non-linear least-squares regression was then used to create average speed algorithms. Figure 1 shows two examples of the segmented data for two vehicle classes, as well as the fitted regression lines.

Figure 1: Examples of Segmented Emissions Data and Average Speed Algorithms



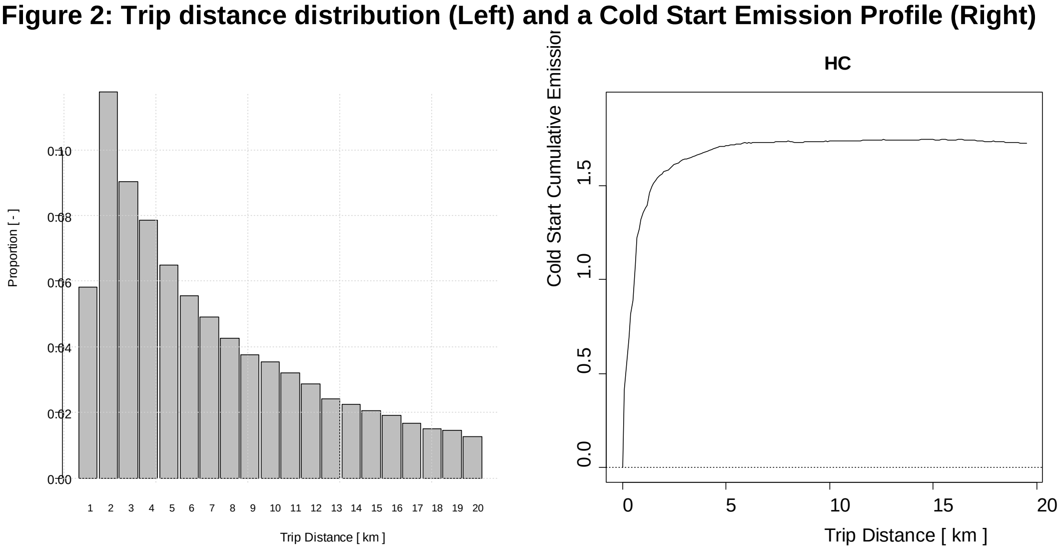
Note that the large scatter is mainly caused by differences between individual vehicle emissions. So the regression line represents a fleet average emission rate value for that particular vehicle class (e.g. compact petrol SUVs ADR37/01).

4.3 Cold start emission rates

Cold start vehicle emissions are defined as additional emissions (expressed as grams per vehicle start) due to fuel-rich combustion in the engine, increased friction, and reduced emission control efficiency, as compared with hot running emissions. Cold start emissions can make a substantial contribution to total emissions from motor vehicles. Emissions test data for 170 Australian petrol light-duty vehicles were used to develop cold start emission rates (grams/start) for inclusion in COPERT Australia. Cold start emission rates for each vehicle class were computed in 2 steps. Figure 2 visualizes the two main inputs to this process.

First, trip matrices from the South East Queensland (SEQ) Strategic Transport Model (Department of Transport and Main Roads; DTMR, 2012a) were used to create a daily trip length distribution with 100 m bins, as is shown in Figure 2. Note that for the purpose of readability the trip distribution has been aggregated to 1 km bins and truncated at 20 km. Second, for each vehicle class (e.g. large Petrol PC ADR79/00) a cold start emission profile was computed. This profile is the mean cumulative difference between cold start and hot running emission profiles as a function of trip distance (100 m bins). The hot and cold emission profiles are obtained by running the same vehicle over the same test and driving schedule, but with a cold or hot engine. An example of a mean cumulative cold start profile is shown in Figure 2.

Figure 2: Trip distance distribution (Left) and a Cold Start Emission Profile (Right)



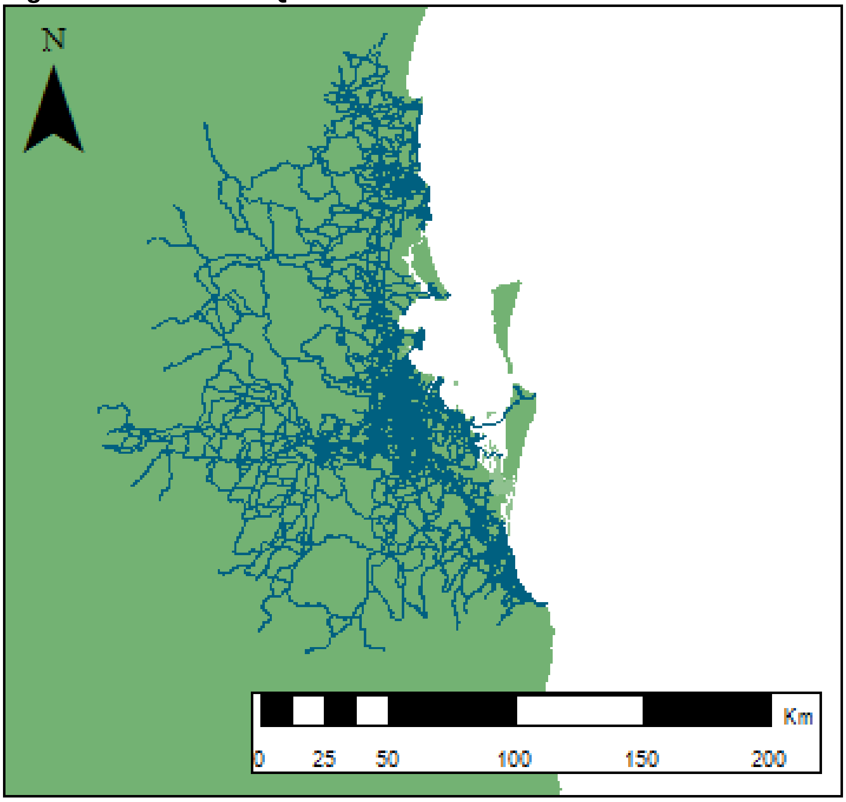
Finally combination of these trip distance based emission profiles (one for each vehicle class) with the trip length distribution allows for the computation of a (travel distance weighted) cold start emission rate for each vehicle class, expressed as grams per start.

5. Application – a case-study

Modelling of the air quality impacts from motor vehicles requires traffic input data for all relevant roads in the road network. Output from transport models is commonly used for this purpose as they provide reasonable road network coverage as compared with more limited availability of measured traffic information (e.g. traffic volumes, average speeds). In addition, transport models are needed to make predictions for future situations.

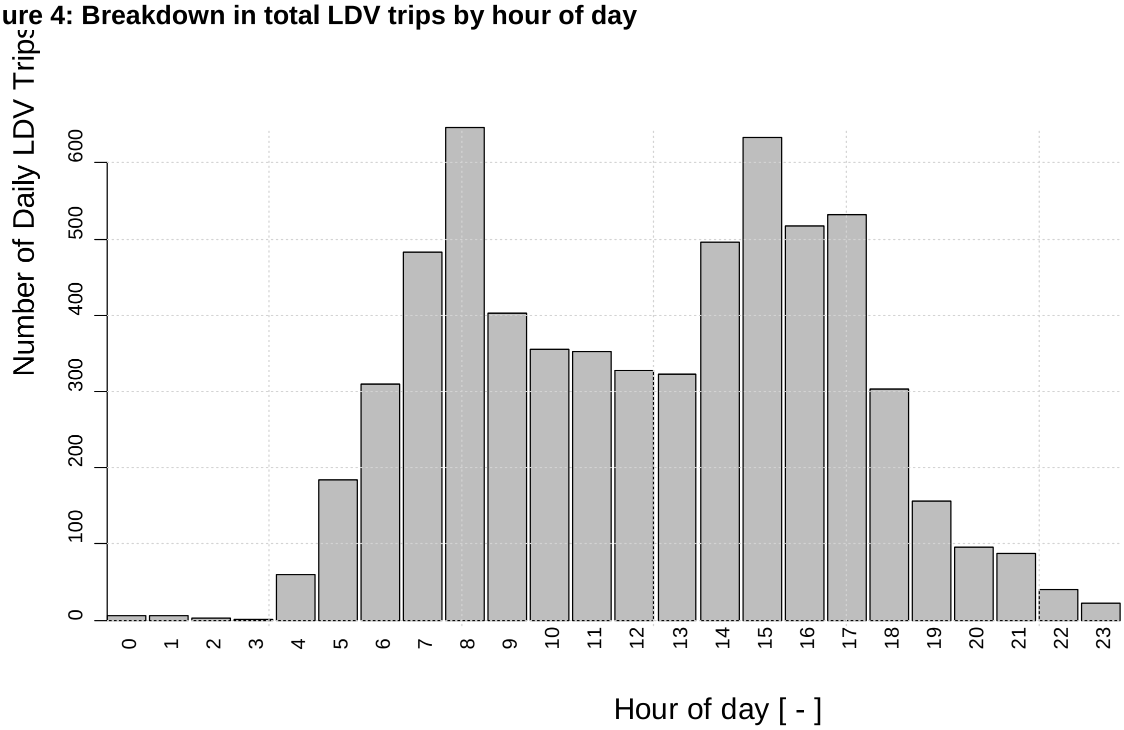
In this study output from a macroscopic transport model was used. The (Queensland) Department of Transport and Main Roads (TMR) provided transport data for 2011 from the ‘South East Queensland Strategic Transport Model’ or SEQSTM (DTMR, 2012a). Network link data for almost 46,000 road links for South East Queensland (SEQ) were used to estimate speed-dependent hot running emissions (and non-exhaust PM emissions) and trip matrices were used to compute cold start emissions. The link data provides detailed information on the spatial location of roads (represented by links, A and B nodes) and traffic volumes (vehicles per time period), link length (km) and average speed (km/h) for each link by main vehicle type (LDV, HDV) and time of day (AM peak, PM peak, off-peak and night time). The TMR network includes all higher order roads (e.g. arterial, sub-arterial and distributors), and most of the local access streets have been excluded. This means that all major traffic carrying roads are included, whereas roads that tend to serve an access function (and carry much less traffic) are excluded (Smit, 2006). The road network is shown in Figure 3.

Figure 3: South East Queensland road network



Trip matrices provide data on the number of trips that are made between traffic analysis zones (TAZs) by main vehicle type (LDV, HDV) and time period of day. Another data source is the Brisbane Household Travel Survey (DTMR, 2012a). These data were used in combination with the trip matrices to obtain a higher resolution (i.e. hourly) in the number of trip starts and trip ends. The results are shown in Figure 4.

Figure 4: Breakdown in total LDV trips by hour of day



One particular issue is that the vehicle classification in COPERT Australia (223 vehicle classes) is much more detailed than the vehicle breakdown in the transport model output (2 vehicle classes). As a consequence, a fleet composition model is needed to generate information on the proportion of total travel (VKT) for each individual COPERT vehicle class. Fleet composition models are developed from vehicle registration and vehicle sales data, and they use algorithms for (age-dependent) vehicle use and scrappage rates, as well as base year dependent growth rates. The relative proportions for each COPERT vehicle class are then used to compute composite emission factors that match the classification in the transport model. An in depth analysis of Australian fleet data and vehicle use data (e.g. ABS, 2010; ABS, 2012; BITRE, 2010) provided these weighting factors to compute composite emission factors for LDVs and HDVs.

Total annual network hot running and start emissions were computed using link based and trip based data, respectively. The results are shown in Table 1. It can be seen that cold start emissions can make a significant contribution to total emissions but that this depends on the pollutant, varying from 1% (PM) to 45% (THC)

Table 1: Total hot running and cold start emissions for SEQ (Tonnes/Annum)

Pollutant	Hot Running	Cold Start	Total
CO	59,720	31,889	91,609
THC [1)]	3,941	3,272	7,213
NO_x	29,919	2,383	32,302
PM_{10}	1,371	12	1,383
$PM_{2.5}$	1,012	12	1,024
SO_2	324	33	357

[1)] Evaporative emissions not included.

PM emission estimates include exhaust and non-exhaust emissions. It is noted that evaporative (THC) emissions are not included in Table 1, as their estimation requires an analysis of the number of parked vehicles and parking behaviour, which is currently ongoing. Evaporative emissions can make a substantial contribution to total THC emissions. For instance, the latest NSW motor vehicle emissions inventory (NSW EPA, 2012) estimates that 50% of total THC emissions is due to evaporative emissions. It is also noted that parking time and temperature corrections are not yet included in the cold start simulation, and they are expected to reduce cold start emission predictions. So the cold start predictions in table 1 should be regarded as conservative estimates.

The benefit of using transport model data as input to the emission modelling process lies not only in the convenience of using a consistent and (partly) validated and calibrated input database, but also in the possibility of resolving emissions at a higher spatial and temporal scale, i.e. at road link level and hour of day.

This information can be visually presented in emission maps. An example is shown for NO_x emissions in figure 5 for the entire SEQ network and in Figure 6 for the Brisbane CBD and surrounding suburbs. The maps show the emission intensities (g/day) of each modelled road link. Large emission levels occur on links with high traffic volumes and/or high levels of congestion (low speeds).

Improved spatial and temporal attribution of vehicle emissions is of increased importance because of a new international (and Australian) focus on the reduction of population exposure to air pollution and (health) risk (NEPC, 2011). So the time and space resolved traffic emissions information can be fed into air quality models, which simulate dispersion and chemical conversion processes to predict air pollution concentration levels, exposure and health risks in urban areas. This type of analysis can be used to identify air pollution 'hot spots', or even greenhouse gas emission hot spots, in urban areas like SEQ. A population density overlay can then be added to assess if hot spots coincide with areas where people live. This information can then be used for policy development and focus assessment of specific traffic management measures.

Figure 5: Emission maps for the South East Queensland Road Network

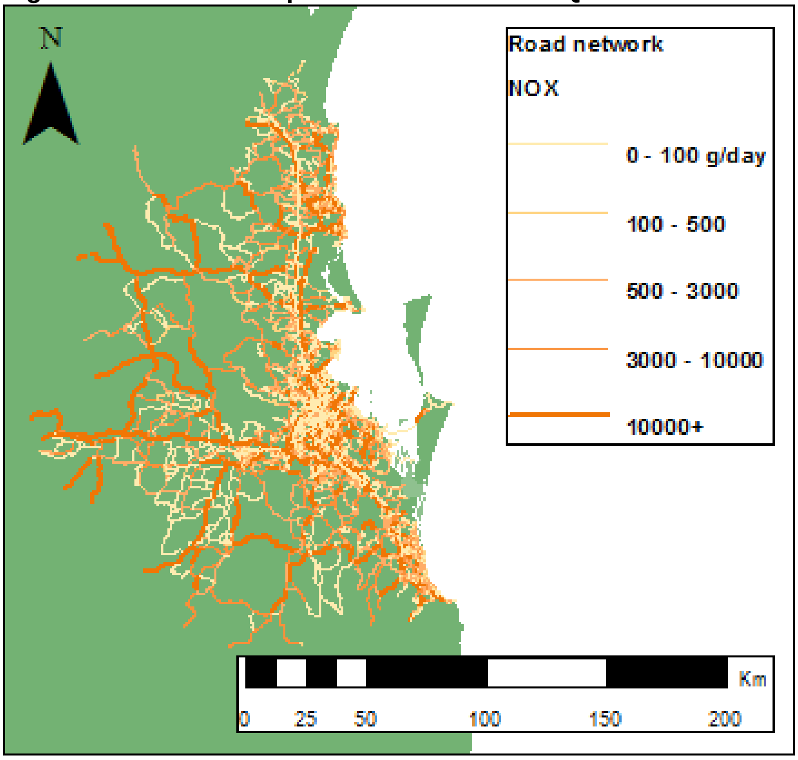
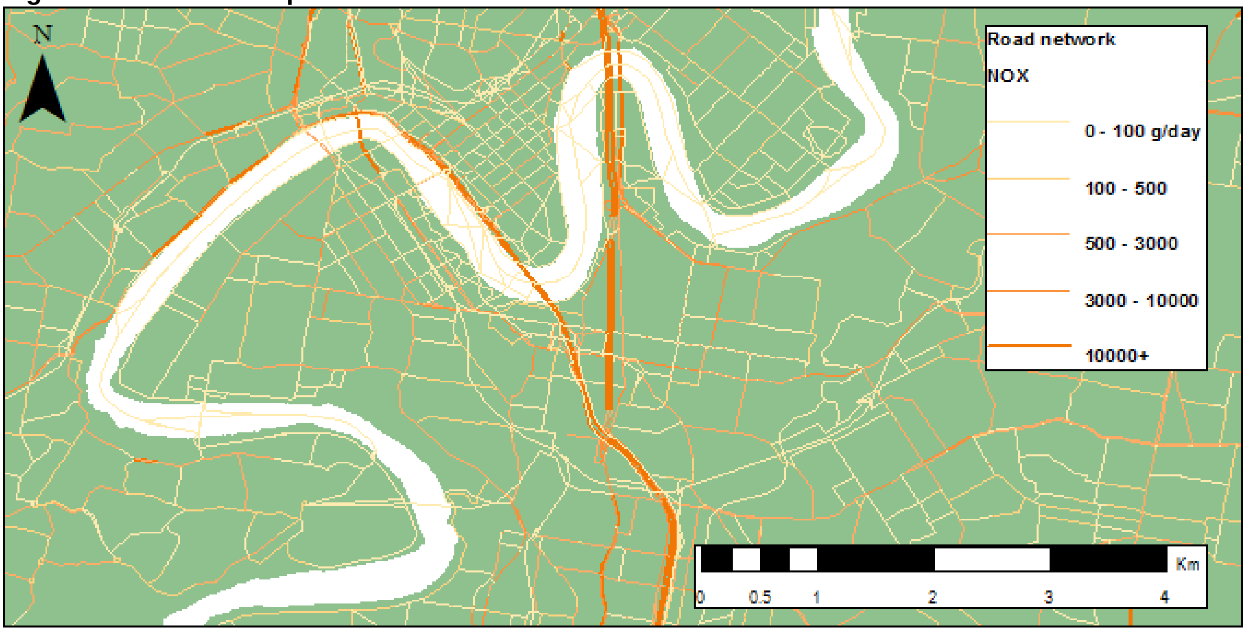


Figure 6: Emission map for the Brisbane CBD



6. Discussion and conclusions

This paper discussed the development of a new Australian vehicle emissions software: COPERT Australia. The software has been adopted from the well-tested, comprehensive and user-friendly COPERT software that is used internationally, and has been calibrated with data from a large Australian emissions database. It includes a number of new and innovative aspects that were developed specifically for the Australian spin-off software. Examples are explicit consideration of spatial modelling resolution for hot running average speed functions and inclusion of trip matrices in the computation of cold start emission factors.

A case-study was conducted using output from a macroscopic transport for South East Queensland (SEQ). One particular issue was that the vehicle classification in COPERT Australia (223 vehicle classes) is much more detailed than the vehicle breakdown in the transport model output. A fleet composition model was used to compute composite emission factors for LDVs and HDVs. Emissions were estimated for each individual road link and aggregated to compute total annual network emissions. Maps are then used to show the emission intensities (g/day) of each modelled road link in areas of interest (e.g. 'hot spots').

It is anticipated that the software will be applied to other States and cities in Australia. New information and emissions data for the Australian fleet (where available) and new scientific information from European programs will be incorporated into the model through regular updates.

The beta version of COPERT Australia is freely available and can be downloaded at http://www.emisia.com/copertaustralia/General.html.

Acknowledgement

The Australian Government and the SA Department of Transport Energy and Infrastructure are acknowledged for commissioning vehicle emission test programs that have collectively provided the (unverified) empirical emissions data used in this research. These include the following test programs: the First and Second National In-Service Vehicle Emissions studies (NISE1 and NISE2), the Diesel Vehicle Emissions National Environment Protection Measure Preparatory Work (DNEPM) and the South Australian Test and Repair Program (SATR).

References

ABS, 2012, Survey of Motor Vehicle Use, Australian Bureau of Statistics, Report 9208.0.

ABS, 2010. Motor Vehicle Census, 9309.0, 31 March 2010.

ANFAC, 2010. European Motor Vehicle Parc 2008, available online at www.acea.be.

BITRE, 2010. Long-Term projections of Australian Transport Emissions Base Case 2010, Australian Government, Department of Infrastructure and Transport, Bureau of Infrastructure, Transport and Regional Economics (BITRE), November 2010.

DCCEE, 2012. Australian National Greenhouse Accounts – National Inventory Report 2010, Volume 1, Australian Government, Department of Climate Change and Energy Efficiency (DCCEE), April 2012.

DTMR, 2012a. South East Queensland Strategic Transport Model (SEQSTM), Modelling Data and Analysis Centre, 2-2-2012.

DTMR, 2012b. South East Queensland Household Travel Survey 2009, The State of Queensland, Department of Transport and Main Roads, Modelling data and Analysis Centre, May 2012.

Eggleston, H.S., Gaudioso, D., Gorissen, N., Joumard, R., Rijkeboer, R.C., Samaras, Z. & Zierock, K.-H. (1993) CORINAIR Working Group on Emission Factors for Calculating 1990

Emissions from Road Traffic, Volume 1: Methodology and Emission Factors, Final Report, Commission of the European Communities, ECSC-EEC-EAEC, Brussels, Luxembourg, ISBN 92 826 5771 X.

NEPC, 2011. National Environment Protection (Ambient Air Quality) Measure Review, May 2011, National Environment Protection Council Service Corporation (NEPC).

NSW EPA, 2012. Air Emissions Inventory for the Greater Metropolitan Region in New South Wales, 2008 Calendar Year, On-Road Mobile Emissions: Results, NSW Environment Protection Authority (NSW EPA), Technical Report 7, August 2012.

Ntziachristos, L., Gkatzoflias, D., Kouridis, Ch., Samaras, Z. 2009. COPERT: A European Road Transport Emission Inventory Model, 4th International ICSC Symposium on Information Technologies in Environmental Engineering. May, 28-29, Thessaloniki, Greece.

Panis, L.I., S. Broekx, R. Liu, 2006. Modelling instantaneous traffic emission and the influence of traffic speed limits, Science of the Total Environment, 371, 270-285

QLD EPA, 2003. Air Emissions Inventory South East Queensland Region, Queensland Environment Protection Authority (QLD EPA).

Smit, R., 2006. An Examination of Congestion in Road Traffic Emission Models and Their Application to Urban Road Networks, Ph.D. Dissertation, Griffith University, Brisbane, Australia. 2006.

Smit, R., Poelman, M., Schrijver, J. 2008. Improved road traffic emission inventories by adding mean speed distributions, Atmospheric Environment, 42 (5), 916-926.

Smit, R., Dia, H., Morawska, L., 2009. Road Traffic Emission and Fuel Consumption Modelling: Trends, New Developments and Future Challenges, in "Traffic Related Air Pollution and Internal Combustion Engines", Nova Publishers, U.S.A., https://www.novapublishers.com/catalog/product_info.php?products_id=9546.

Smit, R., J. McBroom, 2009a. Use of overseas emission models to predict traffic emissions in urban areas, Road and Transport Research, 18 (3), 52-60.

Smit, R., J. McBroom, 2009b. Use of microscopic simulation models to predict traffic emissions, Road and Transport Research, 18 (2), 49-54.

Smit, R., G. Rose, M. Symmons, 2010. Assessing the impacts of ecodriving on fuel consumption and emissions for the Australian situation, 33rd Australasian Transport Research Forum (ATRF 2010), 29 Sep - 1 Oct 2010, Canberra, Australia.WHO, 2006. WHO Air Quality Guidelines for Particulate Matter, Ozone, Nitrogen Dioxide and Sulfur Dioxide – Global Update 2005, World Health Organisation.