Traffic and emissions modelling and data in Australia

Hugh I. Forehead, SMART Infrastructure Facility, University of Wollongong, Wollongong, NSW, Australia

Contents

Introduction

The report was written to fulfil an objective of sub-project 7.1 of the Clean Air and Urban Landscapes hub of the Australian Government's National Environmental Science Programme. Sub-project 7.1 contributes to an initiative to upgrade the estimation of traffic emissions in the National Air Pollutant Inventory (NAPI). The report examines the availability of relevant data and capacity for traffic modelling in the different states and Territories of Australia.

The Australian Motor Vehicle Emissions Inventory for the National Pollutant Inventory (Smit, 2014) was a. state by state analysis for the base year 2010. It was the first time that Australia had adopted a uniform national approach to the inventory of pollution by on-road vehicles. The inventory was calculated using the software COmputer Programme to calculate Emissions from Road Transport Australia (COPERT

Australia, Emisia SA, Thessaloniki, Greece) a version of the European designed COPERT. Modifications for Australia include data from local vehicle registration databases, activity data, vehicle specifications and emissions tests (Smit, 2014). Using software that is designed for other countries can lead to substantial errors (Smit & Ntziachristos, 2013), COPERT Australia has detailed information of the local fleet composition (226 vehicle classes) for each state and average annual travel distances (km per year). Other, open source, options for modelling the inventory may become available soon.

There are situations where a more detailed inventory is required, such as targeted risk analyses, or environmental impact studies. The scale may be a suburb, or the roads surrounding a building or facility of interest. Depending on the level of detail and accuracy that is required, the quantity of data needed for such efforts can be considerable and acquiring the data expensive. This generally means that the only places where the modelling can be done (without additional measurements) are the busiest urban settings, where the local traffic authorities are funded to make the measurements. This means that it should not be expected that micro-scale simulation will be possible for many areas of one of the smaller capital cities without additional measurements or surveys For a review of what can be achieved with traffic emissions modelling and of its limitations, see Forehead and Huynh (2018).

The report comprises three main sections: the first is concerned with national resources, the second with Australia's states and territories and the final with private organisations.

National data

The Australian Bureau of Statistics (ABS) releases an annual national census of registered vehicles. Vehicles are listed by class in nine categories: passenger vehicles, campervans, light commercial vehicles, light rigid trucks, heavy rigid trucks, articulated trucks, non-freight carrying vehicles, buses and motor cycles (Australian Bureau of Statistics, 2016).

ABS also publishes the survey of motor vehicle use (SMVU). It was released annually between 1999 and 2007, biennially since 2010, the last version was published for the year ending 30th June 2016. The sample size (16,000 vehicles) was chosen as being large enough to allow reliable estimates of vehicle kilometres and tonne kilometres travelled for each state and territory (Australian Bureau of Statistics, 2017).

The second federal National In-Service Emission study (NISE 2) developed the composite urban emissions drive cycle (CUEDC) and a 4 minute test of emissions performance, for light petrol vehicles (Department of the Enviroment and Heritage, 2005)

Correctly representing heavy vehicles in Australian models can be challenging, freight modelling in Australia is limited by the availability of data, there is considerable variability between states and territories. Valuable improvements could include compiling lists of freight companies and databases of GPS data (Camargo & Walker, 2017)

Journey to work (JTW) data is taken from the Australian census, therefore available for every 5 years; last issued for 2016. That year was the first where the ABS compiled and published the data (Australian Bureau of Statistics, 2016).

Household travel surveys for different states & territories have often been carried out at different intervals and used different methods (Table 1). A nationwide emissions inventory would require a uniform approach across the country.

Table 1. Household Travel Survey in each capital city in Australia. CAPI stands for computer assisted personal interview (Shen, Fields, Stopher, & Zhang, 2016)

metropolitan region	**survey name**	**year last conducted**	**current data collection method**	**sample size**	**area covered**
Sydney	Sydney Household Travel Survey (HTS)	Continuous since 1997	CAPI	3,500 households per year	Sydney Greater Metropolitan Area
Melbourne	Victorian Integrated Survey of Travel and Activity (VISTA)	2012-2016	Self completion questionnaire (delivered/picked up)	10,000 households in Melbourne, 1,000 households elsewhere	Greater Melbourne, Geelong and, periodically, in selected regional centres
Brisbane	South East Queensland Travel Survey (SEQTS)	2011-2012	Self completion questionnaire (delivered/picked up)	10,000 households	Brisbane, Sunshine Coast, and Gold Coast
Adelaide	Metropolitan Adelaide Household Travel Survey (MAHTS)	1999	Face to face, using Memory Joggers	5,886 households	Adelaide Statistical Division
Perth	Perth And Regions Travel Survey (PARTS)	2002-2006	Interviewer drop-off and pick-up of a self-administered diary	10,947 households	Perth Metropolitan Region and the Shires of Mandurah and Murray
Hobart	Greater Hobart Household Travel Survey	2008-9	Self completion questionnaire (delivered/picked up)	2,400 households	Greater Hobart Area
Canberra	Canberra Household Travel Survey	1997	Self-administered diary	3,054 households	Canberra and Queanbeyan
Darwin	2003 Darwin Household Travel Survey	2004	Telephone	1,000 households	Darwin, Litchfield, and Palmerston LGAs

The 6 most populous capital cities all have their own strategic transport models, which are used to generate predictions for planning and management purposes (Table 2).

Table 2: Current government strategic transport models in Australia

Model name	Abbrevation	Area
Sydney Strategic Travel Model	STM	Sydney NSW
Victorian Integrated Transport Model	VITM	Melbourne Vic
Canberra Strategic Transport Model	CSTM	Canberra ACT
Greater Brisbane Transport Demand Model	BNE Model	Brisbane Qld

Metropolitan Adelaide Strategic Transport Evaluation Model	MASTEM	Adelaide SA
Strategic Transport Evaluation Model	STEM	Perth WA

Bluetooth radio technology is used to collect traffic data (speeds, travel times and tracing routes) in all jurisdictions (Austraffic, 2018). It is a cost-effective way to acquire travel information and more convenient than number plate surveys, previously the method most commonly used to capture travel data.

The Sydney Coordinated Adaptive Traffic System (SCATS) is used nationwide. Its main purpose is to optimise the operation of traffic signals across a network; but it also collects detailed traffic volume data at controlled intersections.

National agencies with data/modelling capacity

Austroads: report of traffic microsimulation (Austroads, 2006), national harmonisation of road asset data (Austroads, 2018)

The health costs of transport emissions, Bureau of Transport and Regional Economics (BTRE, 2005), (BTRE) with ABS: analysis of the survey of motor vehicle use (SMVU). Disparity between petrol sales data and petrol use statistics in Australia were identified as being due to significant usage by unregistered vehicles, boats, lawnmowers and machinery. Some surveys do not include newer vehicles, which tend to be driven further, so consume more petrol. (Skutenko, Cosgrove, & Mitchell, 2006). Greenhouse gas emissions from Australian transport from Bureau of Infrastructure, Transport and Regional Economics (formerly BTRE) (BITRE, 2009).

CSIRO Manufacturing and Infrastructure Technology: urban freight emissions (Marquez & Salim, 2007)

Australian Nuclear Science and Technology Organisation (ANSTO), Commonwealth Scientific and Industrial Research Organisation (CSIRO), NSW Office of Environment and Heritage (OEH), Queensland University of Technology (QUT): Sydney Particle study, measurement and modelling of particulate matter ($PM_{2.5}$ and PM_{10}) in Sydney, to predict sources, sinks and health effects (Cope et al., 2014).

Australian Road Research Board (ARRB): Guidance on traffic studies, speed & travel times, surveys

States and Territories

This section presents the modelling and data resources found for each state and territory. Publications and reports from associated agencies and universities are listed.

Australian Capital Territory

Canberra Strategic Transport Model is updated and maintained by the Snowy Mountains Engineering Corporation (SMEC).

Data from the National Pollutant Inventory (NPI) indicates that motor vehicles are the largest source of pollution in the ACT, accounting for approximately one quarter of all air emissions in the territory (ACT Planning and Land Authority, 2011)

New South Wales

Traffic data is collected from 1,783 counters, 600 are permanent installations and 874 are classifiers.

Household travel surveys are published every year, based upon 5,000 samples

The Strategic Travel Model (STM) is operated by the Bureau of Transport Statistics (BTS) and used for projecting travel patterns in Sydney, Newcastle and Wollongong under different scenarios of land use, transport and pricing. It is validated against the household travel survey (HTS) and the survey of motor vehicle use (SMVU). It can be used to calculate trips and generate vehicle kilometres travelled (VKT) for each hour of a day for an average school day. Other uses include testing scenarios for alternative settlement, employment and transport policies. Also for predicting future limits to the capacity of the network, or evaluating usage of proposed upgrades to infrastructure or services (BTS, 2011) (BTS, 2012). It has 5 road types and 7 vehicle classes: passenger vehicles, motor cycles, taxis, light commercial, rigid trucks, articulated trucks and public transport buses.

In 2012, the NSW EPA published an emissions inventory of 15 priority pollutants from on-road mobile sources for 2008 base year. Results were calculated for 4 zones: Sydney, Newcastle, Wollongong and non-urban NSW. The distances travelled by vehicles in the inventory were calculated with the STM (EPA, 2012)

Heavy vehicle forecasts are produced from the Sydney Freight Movement Model (FMM). The FMM produces base year and forecast estimates of heavy commercial travel movements for the Sydney Greater Metropolitan Area (GMA) at travel zone level. Data includes traffic counts, employment, production by industry, consumption for ports, industry & regional areas (TDC, 2010a).

The Transport Data Centre (TDC) produces light commercial vehicle forecasts from the Light Commercial Vehicle Model (LCVM). The LCVM produces base year and forecast estimates of LCV travel movements for the Sydney Greater Metropolitan Area (GMA) at travel zone level (TDC, 2010b)

A range of useful information can be extracted from the Household Travel Survey database, for example the data from the Transport Performance and Analytics (TPA) centre in Transport for NSW. Previously, BTS provided a breakdown of the distribution of parking times prior to each trip start by hour of the day, which was used for adjusting cold start emission estimation. They also supplied a distribution of parking times subsequent to the end of a trip (Gareth Jones, EPA, pers. comm).

The Office of Environment and Heritage publish an air quality map from sensor data. Sydney has 9 stations and there are 31 across the remainder of the state.

Published expertise

NSW Dep. of Environment and Conservation:

health costs of air pollution (NSW Department of Environment and Conservation, 2018)

Roads and Maritime Services, Roads and Traffic Authority:

managing congestion with SCATS (Chong-White, Millar, & Carlos Aydos, 2014), SCATS and the environment, simulation model with SCATSIM (V. N. Nguyen, 1997)

Transport for NSW:

review of nationwide HTS methods (Shen et al., 2016)

University of New South Wales:

satellite land use regression models for NO_2 (Knibbs et al., 2016), dynamic traffic assignment model for Melbourne (Shafiei, Gu, & Saberi, 2018), effect of transit signal prioritisation on emissions (Wijayaratna, Dixit, Mao, & Waller, 2013), link transmission model for nework design (Chakraborty, Rey, Moylan, & Waller, 2018)

University of Sydney:

probabilistic approach to travel time estimation (Moylan & Rashidi, 2017), variability of pedestrian exposure to PM2.5 (Greaves, Issarayangyun, & Liu, 2008) NO2 exposure (Hanigan et al., 2017), rules for trip identification using GPS, the optimal resolution and analysis of GPS travel records to classify events such as vehicle stops (Shen & Stopher, 2013), macroscopic node models (Smits, Bliemer, Pel, & van Arem, 2015), processing routines for GPS traces (Stopher, Greaves, & Shen, 2013), a comparison of existing commercial software to interpret GPS data into trips (Stopher, Moutou, & Liu, 2013), traffic pollution and health benefits of alternative transport (Xia et al., 2015)

University of Wollongong:

agent-based mesoscopic traffic simulation (Barthélemy & Carletti, 2017), synthetic population (Huynh et al., 2013)

Northern Territory

A total of 283 locations for traffic counts: 62 temporary urban volume-only (111 rural), 42 permanent volume-only urban sites (40 rural), 10 permanent classifiers (18 rural)

Annual traffic report, 2016 was the most recent year published
(Department of infrastructure planning and logistics, 2016)

The NT Environment Protection Authority conduct full ambient air quality monitoring at 3 locations in the Darwin region: Palmerston, Winnellie and Stokes Hill.

Queensland

Annual traffic census collects counts of vehicles at 2,207 locations, the majority distinguish heavy vehicles, 158 are traffic cameras

Greater Brisbane Transport Demand Model (BNE MODEL) is an EMME based model, for travel demand and assignment (discrete choice demand model)

Gold Coast strategic transport demand model, simulates 24 hours typical weekday traffic counts for 3 vehicle classes. 67 sites were chosen to validate the model, with data collected between March and May 2012.

Queensland has its own traffic management system: 1,700 signalised intersections controlled by SCATS, coordinated by STREAMS integrated transport system.

Website has annual reports concerning roads and traffic. The website has a webpage that provides access to traffic and travel information (Hazards, Crashes, Congestion, Flooding, Roadworks, Special Events and Web Camera details) via their interface and RSS feeds. Brisbane uses a Bluetooth traffic monitoring system.

Air quality data is produced from 17 stations in south east Queensland, including 8 stations for Brisbane and 22 over the remainder of the state.

Published expertise:

Department of Science, Information Technology Innovation and the Arts:

> Co-authored software for traffic emissions inventory: COPERT Australia, adaptation of European COPERT 4 (Smit & Ntziachristos, 2013)

Deptartment of Transport and Main Roads:

> New Brisbane Strategic Transport Model (BNE) Model Improvement Program. Improvements included changes to Generation, Distribution and Mode Choice modules in a nested logit methodology. BNE (Brisbane) and Brisbane Strategic Transport Model elements have been modified for compatibility, also public transport refinement (Pool & Van Den Berg, 2018).

Griffith University:

> Chemicals in PM aerosols in Brisbane (Chan et al., 1997), source apportionment of PM in Brisbane (Chan et al., 1999), composition of PM (Denison, Wong, Chan, Simpson, & Williams,

2004), congestion in traffic emission models (Smit, 2006). TRansport Add-on Environmental Modelling System (TRAEMS). Designed for planners; it used traffic information, mostly from travel-forecasting models, added to land use information, then commonly used models to estimate pollution and fuel consumption from road traffic systems. The system was demonstrated at local-area and metropolitan scales (Affum, Brown, & Chan, 2003).

Queensland University of Technology:

Evaluation of Bluetooth and WiFi for monitoring traffic; explored the usefulness of scanning Bluetooth and WiFi transmissions from vehicles, mobile phones, car navigation systems and headphones for tracking vehicle travel (Abbott-Jard, Shah, & Bhaskar, 2013). Model travel time estimation that allows for increased detector spacing (Bhaskar, Qu, & Chung, 2013) and using freeway loop detectors, with methods for correcting missing data QUT (Abedi, Bhaskar, & Chung, 2013). Work integrating Bluetooth, loop detector and GPS data from Brisbane road authorities was to model traffic state (Nantes, Ngoduy, Bhaskar, Miska, & Chung, 2016) Demonstration of the need for Australian data in emissions modelling (Bover, Zhu, & Ferreira, 2013), sources and composition of fine particles (Crilley et al., 2014), emissions factors (Keogh et al., 2010). Travel time prediction with Bluetooth (Khoei, Bhaskar, & Chung, 2013), OD matrices from Bluetooth (Michau, Nantes, & Chung, 2013). Effects of eco-driving on fuel consumption and emissions (Qian & Chung, 2014). Short term traffic forecasts: a review of combining models (Tselentis, Vlahogianni, & Karlaftis, 2015). Airborne particles and factors affecting them (Wang, Morawska, Jayaratne, Mengersen, & Heuff, 2011). Needs for improving data inputs to Australian emissions models to better reflect local vehicles and conditions. Example given, using AIMSUN. (Bover et al., 2013). Brisbane case study found errors from micro-scale emission model with poor representation of congestion due to aggregation (Zhu & Ferreira, 2013). Pre-crash traffic analysis (Hamzehei, Chung, & Miska, 2013). Review of combinations of different types of traffic models: statistical, Bayesian and classical single time series (Tselentis et al., 2015)

University of Queensland:

Satellite LUR models for NO_2 (Knibbs et al., 2016), Australian motor vehicle emission inventory for the NPI (Smit, 2014), method to compare remote sensing & laboratory measurements of vehicle emissions (Smit & Bluett, 2011), simulation of fuel consumption and vehicle emissions (Smit, Casas, & Torday, 2013), tunnel study to validate motor vehicle emissions software (Smit, Kingston, Wainwright, & Tooker, 2017), vehicle emissions models for Australian conditions (Zhu, 2015). Smit etal used Aimsun microscopic traffic simulation with new Australian vehicle emission software, PΔP (engine power, and change in engine power) The model used a database of Australian emissions with about 2,500 emission tests (1 Hz) and about 12,500 individual bag measurements. Validation gave average R^2 values of 0.65 for NOx and 0.93 for CO_2/Fuel Consumption (Smit et al., 2013). The model was to be extended to deal with other pollutants. (Smit, 2013). Developing emissions models for Australian conditions; thesis (Zhu, 2015). Quantifying errors in microscopic emissions models (Zhu & Ferreira, 2013)

South Australia

Traffic volume data, total of 2,523 measurement locations; 1,233 volume only, not classified; instruments included 752 Bluetooth receivers. Lane counts at SCATS controlled signalised intersections and pedestrian crossings (3,208 locations), heavy vehicles at intersections (Department of Planning, 2018).

Travel speed on metropolitan Adelaide arterial routes is assessed with floating cars. Annual measurements cover 13 routes, most in both directions, at 3 times of day, annually from 1998 (Department of Planning, 2016)

South Australia's EPA publishes air quality data from 8 sensors for Adelaide, 5 for Port Augusta, Whyalla and Port Pirie. Updates are hourly

The Department of Planning, Transport and Infrastructure developed an extensive Bluetooth traffic monitoring system, widely distributed, including integration with the SCATS network. The system is cheap and easy to deploy, mainly installed in the SCATS communications boxes (Southern, 2015). The system was also deployed in Brisbane, Melbourne and the UK. The Bluetooth system achieves a sample rate of about 15% of vehicles, better on arterial roads, mostly due to the presence of freight vehicles. For privacy, the primary data is truncated and then purged at the end of each day. The system is good enough that the Department do not buy any external traffic data (such as from Google, INRIX etc.). Mr Southern suggested that accuracy and coverage is sufficient that the existing programme of traffic surveys may become unnecessary. It has been used for a number of functions, including automated incident detection (AID) and for monitoring compliance with permits for traffic controls for roadworks, the department can see if traffic is being slowed down outside the times stipulated by a permit.

Published expertise:

Department of Planning, Transport and Infrastructure:

> integrating traffic models for planning: a microscopic traffic modelling of a busy arterial corridor in Adelaide used the analytical model SIDRA and empirical model LINSIG to analyse traffic flow and signalling, Aimsun was used for dynamic modelling. The combination was used to increase confidence in the modelling process (Zhang, 2013).

Flinders University:

> effects of tram replacing traffic (H. A. Nguyen, Soltani, & Allan, 2018), traffic emissions inventory for Dhaka (Iqbal, Allan, & Zito, 2016)

University of Adelaide:

> traffic pollution and health benefits of alternative transport (Xia et al., 2015)

University of South Australia:

> mean speed distributions for emissions (Schultz, Shah, Giandomenico, & Chiera, 2015),
>
> adding detailed speed data improved estimates of vehicle emissions of CO, non-methane VOCs and PM2.5 in Adelaide (Schultz et al., 2015),
>
> emissions and population exposure (Schulz, Chiera, Shah, & Boland, 2013), GPS for intelligent vehicle-highway systems (Zito, D'Este, & Taylor, 1995)

Tasmania

There were 543 locations where traffic was counted over the years from 2002 to 2017. The length of the segments counted ranges from 40 m up to 74 km with an average length of 7 km.
(Department of State Growth, 2016b).

Hobart's traffic signal system has had various upgrades over the years and much of the physical infrastructure associated with SCATS is aging. This has resulted in some incompatibility with new software and failures of loop detectors (Department of State Growth, 2016a). In an effort to better understand road use, number plate cameras were used in a study of the major traffic flows into and out of the city (Department of State Growth, 2017)

Victoria

Vic Roads publish the state's traffic counts, accessible via an interactive map interface. Volume on freeways and arterial roads (excluding toll roads), contains 14,541 rows; Bluetooth travel time on links: 3,849 rows; total of 57,947 locations (Vic Roads, 2018) Data is collected for main roads 15 minutely, every 20 sec on highways.

The Victorian Integrated Survey of Travel and Activity is an ongoing state-wide survey of travel. It contains data about household travel, between 2012 and 2016, the survey included 18,152 households and 46, 562 people (Transport for Victoria, 2018).

The Victorian EPA publishes hourly air quality data from 18 sites in the state, 11 for Melbourne. All measure $PM_{2.5}$, other parameters at some stations include PM_{10} ozone, NO_2, CO and SO_2.

Freight Movement Model FMM predicts freight traffic in the metropolitan area

Published expertise:

Monash University:

> Calibration of Vissim traffic simulation with an evolutionary algorithm (Aghabayk, Sarvi, Young, & Kautzsch, 2013), Study of lane changing behaviour, that treats passenger cars and heavy vehicles separately. Examines interactions with surrounding vehicles (Cao, Young, & Sarvi, 2013). Dynamic traffic assignment model for Melbourne (Shafiei et al., 2018). Lane changing behaviour for microscopic models Monash (Blainey & Mulley, 2013). Melbourne, Australia bus transit time and reliability modelling progressed from use of trip timing with land use, section length and other route variables(Mazloumi, Currie, & Rose, 2008), to GPS (Mazloumi, Currie, & Rose, 2010) and trials of using artificial neural networks, which resulted in small improvement (Mazloumi, Moridpour, Currie, & Rose, 2012). Evolutionary algorithm for the calibration of VISSIM Monash (Aghabayk et al., 2013)

RMIT University:

O-D estimation using TFlowFuzzy (Yousefikia, Mamdoohi, Moridpour, Noruzoliaee, & Mahpour, 2013)

Swinburne University

emissions models using neural networks and regression with Australian fleet data (Dia & Boongrapue, 2015)

University of Melbourne:

Freight priority in Melbourne, using EMME4 and VISUM (Bagloee & Sarvi, 2017). Australian Integrated Multimodal Ecosystem test bed (Sarvi, 2017). Freight movement, model; CBD distribution; transport & logistics supply chain (Thompson, 2017)

Western Australia

Traffic count data is available via an easy to use map-based format. Measurements from 4,461 locations, some classified volume, some only total volume. Average number of vehicles for a typical weekday in metropolitan areas; for any weekday for other areas. Last updated 6/5/2018
(Main Roads Western Australia, 2018)

The state has 25 traffic cameras, mainly along N-S hwy through city (Mitchell Highway in the north, Kwinana Highway in south)

Published expertise:

University of Western Australia, Edith Cowan University:

exposure assessment in Perth, using land use regression models for NO_2 and NO_x (Dirgawati et al., 2015)

Curtin University:

trip distribution using neural networks (Rasouli & Nikraz, 2013)

Main Roads Department:

Perth freeway modelling (Johnstone & Carvajal, 2017), Neural network for trip distribution (Curtin) (Rasouli & Nikraz, 2013)

State Emergency Management Committee:

uses Paramics to predict traffic movements in emergencies

Private agencies

Enterprises in Australia involved in collecting data and modelling (activity description extracted from company websites) include:

> ARUP, traffic modelling; Aurecon, Freight Movement Models for Sydney, Adelaide, Brisbane and Perth; Austraffic, traffic and transport studies; Cardno, traffic, transport and parking; Flyt, transport modelling, traffic management planning; GHD, traffic and transport modelling, planning; GTA consultants, traffic and transport modelling, planning; High Range Analytics, traffic and transport modelling, planning; Hyder Consulting, transport infrastructure planning; SMEC, traffic and transport studies, modelling, planning; , TCS for Surveys, road monitoring and surveys; Traffic Data and Control, traffic and transport surveys; Transport Modellers Alliance, transport and traffic modelling; Veitch Lister Consulting, transport and freight modelling

Details of studies from Australian Institute of Traffic Planning and Management Ltd. (AITPM), Australasian Transport Research Forum Inc. (ATRF) conferences

> AECOM: saturation flow calibration of Aimsun for hybrid simulation
>
> Jacobs International: transition from Strategic to Mesoscopic Models - Matrix Estimation Approaches and Learnings. Recent projects have needed mesoscopic level matrices (some for dynamic models) derived from strategic demand matrices. Moving to tour-based models in QLD: "tours" as more complex versions of trips as inputs for planning models.
>
> Metrocount: traffic sensing equipment, including vehicle classifiers for detailed axle data. Inductive loop classifier uses paired inductive loops to give time, highly accurate speed and length-based classification. Piezo-electric classifiers, are usually permanently installed, embedded in the roadway to give timed speed, class and axle count data.
>
> Survey Tech Australia: measure traffic via video on masts, automatic traffic counts (Metrocount brand classifiers for volume, speed and class), journey times via GPS or manual recording, public transport surveys, queue length surveys and number plate surveys for origin & destination analysis.
>
> TSS: quasi-dynamic model in Aimsun compared to static and dynamic models, comparing all models for time estimation, using real networks and data.
>
> Urbsol: microsimulation traffic modelling

References

Abbott-Jard, M., Shah, H., & Bhaskar, A. (2013). *Empirical evaluation of Bluetooth and Wifi scanning for road transport.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

Abedi, N., Bhaskar, A., & Chung, E. (2013). *Bluetooth and Wi-Fi MAC address based crowd data collection and monitoring: Benefits, challenges and enhancement.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

ACT Planning and Land Authority. (2011). *Molonglo Valley air quality assessment*. Retrieved from

Affum, J. K., Brown, A. L., & Chan, Y. C. (2003). Integrating air pollution modelling with scenario testing in road transport planning: the TRAEMS approach. *Science of the Total Environment, 312*(1–3), 1-14. doi:http://dx.doi.org/10.1016/S0048-9697(03)00192-X

Aghabayk, K., Sarvi, M., Young, W., & Kautzsch, L. (2013). *A novel methodology for evolutionary calibration of vissim by multi-threading.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

Austraffic. (2018). Bluetooth based technology. Retrieved from https://austraffic.com.au/projects/bluetooth-based-technology

Australian Bureau of Statistics, A. (Producer). (2016, 13/7/2017). Motor Vehicle Census. Retrieved from http://www.abs.gov.au/ausstats/abs@.nsf/mf/9309.0

Australian Bureau of Statistics, A. (2016). Census of population and housing: commuting to work. Retrieved from http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/2071.0.55.001Main+Features102016?OpenDocument

Australian Bureau of Statistics, A. (2017). Survey of motor vehicle use, Australia, 12 months ended 30 June 2016, explanatory notes. Retrieved from http://www.abs.gov.au/AUSSTATS/abs@.nsf/Lookup/9208.0Explanatory%20Notes112%20months%20ended%2030%20June%202016?OpenDocument

Austroads. (2006). *The use and application of microsimulation traffic models*. Retrieved from Sydney, Australia:

Austroads. (2018). Road data harmonisation project. Retrieved from http://www.austroads.com.au/road-operations/asset-management/road-data-harmonisation-project

Bagloee, S. A., & Sarvi, M. (2017). *Freight priority for the city of Melbourne.* Paper presented at the AITPM.

Barthélemy, J., & Carletti, T. (2017). *An adaptive agent-based approach to traffic simulation.* Paper presented at the Transportation Research Procedia.

Bhaskar, A., Qu, M., & Chung, E. (2013). *Motorway travel time estimation: A hybrid model, considering increased detector spacing.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

BITRE. (2009). *Greenhouse gas emissions from Australian transport: projections to 2020*. Retrieved from Canberra, Australia:

Blainey, S., & Mulley, C. (2013). *Using geographically weighted regression to forecast rail demand in the sydney region.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

Bover, P., Zhu, S., & Ferreira, L. (2013). Modelling vehicle emissions for Australian conditions. *Road and Transport Research, 22*(4), 15-29.

BTRE. (2005). *Health impacts of transport emissions in Australia: economic costs*. Department of Transport and Regional Services.

BTS. (2011). *Sydney strategic travel model (STM): modelling future travel patterns*. Retrieved from Sydney, NSW:

BTS. (2012). Bureau of Transport Statistics InfoSheet, Strategic Travel Model standard outputs. In. Sydney.

Camargo, P., & Walker, L. (2017). *Freight modelling in Australia: what we've got, what do we need and how are we getting there?* Paper presented at the AITPM National Traffic & Transport Conference 2017, Melbourne, Australia.

Cao, X., Young, W., & Sarvi, M. (2013). *Exploring duration of lane change execution.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

Chakraborty, S., Rey, D., Moylan, E., & Waller, S. T. (2018) Link Transmission Model-Based Linear Programming Formulation for Network Design. In. *Transportation Research Record*: SAGE Publications Ltd.

Chan, Y. C., Simpson, R. W., McTainsh, G. H., Vowles, P. D., Cohen, D. D., & Bailey, G. M. (1997). Characterisation of chemical species in PM2.5 and PM10 aerosols in Brisbane, Australia. *Atmospheric Environment, 31*(22), 3773-3785. doi:http://dx.doi.org/10.1016/S1352-2310(97)00213-6

Chan, Y. C., Simpson, R. W., McTainsh, G. H., Vowles, P. D., Cohen, D. D., & Bailey, G. M. (1999). Source apportionment of PM2.5 and PM10 in Brisbane (Australia) by receptor modelling. *Atmospheric Environment, 33*(19), 3251-3268. doi:10.1016/S1352-2310(99)00090-4

Chong-White, C., Millar, G., & Carlos Aydos, J. (2014). *Scenarios demonstrating congestion management policies using SCATS: stage 2*. Paper presented at the 26th ARRB conference- Research driving efficiency, Sydney, Australia.
Cope, M., Keywood, M., Emmerson, K., Galbally, I., Boast, K., Chambers, S., . . . Zeng, J. (2014). *Sydney particle study- stage II*. Retrieved from
Crilley, L. R., Ayoko, G. A., Stelcer, E., Cohen, D. D., Mazaheri, M., & Morawska, L. (2014). Elemental composition of ambient fine particles in urban schools: Sources of children's exposure. *Aerosol and Air Quality Research, 14*(7), 1906-1916. doi:10.4209/aaqr.2014.04.0077
Denison, L., Wong, N., Chan, A., Simpson, R., & Williams, G. (2004). Composition of PM2.5 amd PM2.5-10 in four Australian cities. *Epidemiology, 15*(4), S209-S210.
Department of infrastructure planning and logistics. (2016). *Annual traffic report*. Retrieved from https://dipl.nt.gov.au/__data/assets/pdf_file/0009/447399/2016-atr-final-sept17.pdf
Department of Planning, Transport and I. (2016). Travel speed in metropolitan Adelaide.
Department of Planning, Transport and I. (2018). Traffic volumes.
Department of State Growth. (2016a). *Hobart congestion traffic analysis*. Retrieved from https://www.transport.tas.gov.au/__data/assets/pdf_file/0011/132986/Hobart_Traffic_Congestion_-_Traffic_Analysis.pdf
Department of State Growth. (2016b). Traffic statistics (AADT) for Tasmanian roads. http://datat.stategrowth.tas.gov.au/geoserver/ssg/wfs?version=1.1.0&request=GetFeature&typename=TSM_LATEST_UTS_VW&outputFormat=text/javascript&srsName=EPSG:28355&bbox=224000,5160000,616000,5640000
Department of State Growth. (2017). *Hobart traffic origin-destination report*. Retrieved from https://www.transport.tas.gov.au/__data/assets/pdf_file/0020/152138/Hobart_Traffic_Origin-Destination_Report_June_20172.pdf
Department of the Enviroment and Heritage. (2005). *NISE 2 - Drive cycle and short test development, final report*. Retrieved from
Dia, H., & Boongrapue, N. (2015). Vehicle emission models using Australian fleet data. *Road and Transport Research, 24*(1), 14-26.
Dirgawati, M., Barnes, R., Wheeler, A. J., Arnold, A. L., McCaul, K. A., Stuart, A. L., . . . Heyworth, J. S. (2015). Development of Land Use Regression models for predicting exposure to NO2 and NOx in Metropolitan Perth, Western Australia. *Environmental Modelling and Software, 74*, 258-267. doi:10.1016/j.envsoft.2015.07.008
EPA. (2012). *On-Road Mobile Emissions* (EPA 2012/0256). Retrieved from
Forehead, H., & Huynh, N. (2018). Review of modelling air pollution from traffic at street-level - The state of the science. *Environmental Pollution, 241*, 775-786. doi:https://doi.org/10.1016/j.envpol.2018.06.019
Greaves, S., Issarayangyun, T., & Liu, Q. (2008). Exploring variability in pedestrian exposure to fine particulates (PM2.5) along a busy road. *Atmospheric Environment, 42*(8), 1665-1676. doi:10.1016/j.atmosenv.2007.11.043
Hamzehei, A., Chung, E., & Miska, M. (2013). *Pre-crash and non-crash traffic flow trends analysis on motorways*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Hanigan, I. C., Williamson, G. J., Knibbs, L. D., Horsley, J., Rolfe, M. I., Cope, M., . . . Morgan, G. G. (2017). Blending Multiple Nitrogen Dioxide Data Sources for Neighborhood Estimates of Long-Term Exposure for Health Research. *Environmental Science & Technology, 51*(21), 12473-12480. doi:10.1021/acs.est.7b03035
Huynh, N., Namazi-Rad, M. R., Perez, P., Berryman, M. J., Chen, Q., & Barthelemy, J. (2013). *Generating a synthetic population in support of agent-based modeling of transportation in Sydney*. Paper presented at the 20th International Congress on Modelling and Simulation, Adelaide, Australia.
Iqbal, A., Allan, A., & Zito, R. (2016). Meso-scale on-road vehicle emission inventory approach: a study on Dhaka City of Bangladesh supporting the 'cause-effect' analysis of the transport system. *Environmental Monitoring and Assessment, 188*(3), 1-21. doi:10.1007/s10661-016-5151-4
Johnstone, A., & Carvajal, R. (2017). *Perth freeway modelling*. Paper presented at the AITPM, Melbourne.
Keogh, D. U., Kelly, J., Mengersen, K., Jayaratne, R., Ferreira, L., & Morawska, L. (2010). Derivation of motor vehicle tailpipe particle emission factors suitable for modelling urban fleet emissions and air quality assessments. *Environmental Science and Pollution Research, 17*(3), 724-739. doi:10.1007/s11356-009-0210-9

Khoei, A. M., Bhaskar, A., & Chung, E. (2013). *Travel time prediction on signalised urban arterials by applying SARIMA modelling on Bluetooth data.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

Knibbs, L. D., Coorey, C. P., Bechle, M. J., Cowie, C. T., Dirgawati, M., Heyworth, J. S., . . . Hewson, M. G. (2016). Independent Validation of National Satellite-Based Land-Use Regression Models for Nitrogen Dioxide Using Passive Samplers. *Environmental Science and Technology, 50*(22), 12331-12338. doi:10.1021/acs.est.6b03428

Main Roads Western Australia. (2018). Traffic Digest. Retrieved from http://portal-mainroads.opendata.arcgis.com/datasets/traffic-digest/data?geometry=68.668%2C-38.627%2C185.915%2C-11.105

Marquez, L., & Salim, V. (2007). Assessing impacts of urban freight measures on air toxic emissions in Inner Sydney. *Environmental Modelling and Software, 22*(4), 515-525. doi:10.1016/j.envsoft.2006.02.007

Mazloumi, E., Currie, G., & Rose, G. (2008). *Causes of travel time unreliability - A Melbourne case study.* Paper presented at the 31st Australasian Transport Research Forum, ATRF 2008, Gold Coast, QLD.

Mazloumi, E., Currie, G., & Rose, G. (2010). Using GPS data to gain insight into public transport travel time variability. *Journal of Transportation Engineering, 136*(7), 623-631. doi:10.1061/(ASCE)TE.1943-5436.0000126

Mazloumi, E., Moridpour, S., Currie, G., & Rose, G. (2012). Exploring the value of traffic flow data in bus travel time prediction. *Journal of Transportation Engineering, 138*(4), 436-446. doi:10.1061/(ASCE)TE.1943-5436.0000329

Michau, G., Nantes, A., & Chung, E. (2013). *Towards the retrieval of accurate od matrices from bluetooth data: Lessons learned from 2 years of data.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

Moylan, E. K. M., & Rashidi, T. H. (2017). Latent-Segmentation, Hazard-Based Models of Travel Time. *IEEE Transactions on Intelligent Transportation Systems, 18*(8), 2174-2180. doi:10.1109/TITS.2016.2636321

Nantes, A., Ngoduy, D., Bhaskar, A., Miska, M., & Chung, E. (2016). Real-time traffic state estimation in urban corridors from heterogeneous data. *Transportation Research Part C: Emerging Technologies, 66*, 99-118. doi:10.1016/j.trc.2015.07.005

Nguyen, H. A., Soltani, A., & Allan, A. (2018). Adelaide's East End tramline: Effects on modal shift and carbon reduction. *Travel Behaviour and Society, 11*, 21-30. doi:10.1016/j.tbs.2017.12.002

Nguyen, V. N. (1997) Evaluation of SCATSIM-RTA adaptive traffic network simulation model. In. *Transportation Research Record* (pp. 8-19).

NSW Department of Environment and Conservation. (2018). *Air pollution economics: health costs of air pollution in the greater Sydney metropolitan region.* Retrieved from

Pool, B., & Van Den Berg, J. (2018). *Overview of the New Greater Brisbane Travel Demand Model.* Paper presented at the AITPM.

Qian, G., & Chung, E. (2014). *Evaluating effects of eco-driving at traffic intersections based on traffic micro-simulation.* Paper presented at the 34th Australasian Transport Research Forum, ATRF 2011.

Rasouli, M., & Nikraz, H. (2013). *Trip distribution modelling using neural network.* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.

Sarvi, M. (2017). *Melbourne's NCMT test bed.* Paper presented at the AITPM.

Schultz, L., Shah, P., Giandomenico, E., & Chiera, B. (2015). Mean Vehicle Speed Distributions for the Spatiotemporal Estimation of Exhaust Emissions. *Environmental Modeling and Assessment*. doi:10.1007/s10666-015-9463-5

Schulz, L., Chiera, B., Shah, P., & Boland, J. (2013). *Modelling motor vehicle emissions and population exposure in South Australia.* Paper presented at the 20th International Congress on Modelling and Simulation, Adelaide, Australia. www.mssanz.org.au/modsim2013

Shafiei, S., Gu, Z., & Saberi, M. (2018). Calibration and validation of a simulation-based dynamic traffic assignment model for a large-scale congested network. *Simulation Modelling Practice and Theory, 86*, 169-186. doi:10.1016/j.simpat.2018.04.006

Shen, L., Fields, S., Stopher, P. R., & Zhang, Y. (2016). *The future direction of household travel surveys methods in Australia.* Paper presented at the Australasian Transport Research Forum 2016, Melbourne, Australia. http://www.atrf.info

Shen, L., & Stopher, P. R. (2013). *Should we change the rules for trip identification for GPS travel records?* Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Skutenko, D., Cosgrove, D., & Mitchell, D. (2006). *Survey of Motor Vehicle Use- An Investigation into Coherence*. Retrieved from
Smit, R. (2006). *An examination of congestion in road traffic emsision models and their application to urban road networks*. (PhD), Griffith University, Brisbane, Australia.
Smit, R. (2013). Development and performance of a new vehicle emissions and fuel consumption software (PΔP) with a high resolution in time and space. *Atmospheric Pollution Research, 4*(3), 336-345. doi:10.5094/APR.2013.038
Smit, R. (2014). *Australian Motor Vehicle Emission Inventory for the National Pollutant Inventory (NPI)*. Retrieved from St Lucia, Australia:
Smit, R., & Bluett, J. (2011). A new method to compare vehicle emissions measured by remote sensing and laboratory testing: High-emitters and potential implications for emission inventories. *Science of the Total Environment, 409*(13), 2626-2634. doi:10.1016/j.scitotenv.2011.03.026
Smit, R., Casas, J., & Torday, A. (2013). *Simulating fuel consumption and vehicle emissions in an Australian context*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Smit, R., Kingston, P., Wainwright, D. H., & Tooker, R. (2017). A tunnel study to validate motor vehicle emission prediction software in Australia. *Atmospheric Environment, 151*, 188-199. doi:10.1016/j.atmosenv.2016.12.014
Smit, R., & Ntziachristos, L. (2013). *COPERT Australia: A new software to estimate vehicle emissions in Australia*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Smits, E. S., Bliemer, M. C. J., Pel, A. J., & van Arem, B. (2015). A family of macroscopic node models. *Transportation Research Part B: Methodological, 74*, 20-39. doi:10.1016/j.trb.2015.01.002
Southern, M. (2015, 3/8/2015). [Traffic Mananagement Centre Supervisor at Department of Planning, Transport and Infrastructure (DPTI)].
Stopher, P. R., Greaves, S. P., & Shen, L. (2013). *Comparing two processing routines for GPS traces - Lessons learnt*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Stopher, P. R., Moutou, C. J., & Liu, W. (2013). *Sustainability of voluntary travel behaviour change initiatives - A 5-year Study*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
TDC. (2010a). *Heavy Vehicle Travel Zone Forecasts*. Retrieved from Sydney NSW, Australia:
TDC. (2010b). Light commercial vehicle travel zone forecasts. In T. D. Centre (Ed.): Transport Data Centre.
Thompson, R. G. (2017). *Transport & logistics supply chain analysis*. Paper presented at the AITPM, Melbourne.
Transport for Victoria. (2018). VISTA data and publications. Retrieved from https://transport.vic.gov.au/data-and-research/vista/vista-data-and-publications/
Tselentis, D. I., Vlahogianni, E. I., & Karlaftis, M. G. (2015). Improving short-term traffic forecasts: To combine models or not to combine? *IET Intelligent Transport Systems, 9*(2), 193-201. doi:10.1049/iet-its.2013.0191
Vic Roads. (2018). Traffic open data. Retrieved from http://vicroadsopendata-vicroadsmaps.opendata.arcgis.com/datasets?t=all(traffic%20open%20data%2Ctraffic)
Wang, L., Morawska, L., Jayaratne, E. R., Mengersen, K., & Heuff, D. (2011). Characteristics of airborne particles and the factors affecting them at bus stations. *Atmospheric Environment, 45*(3), 611-620. doi:10.1016/j.atmosenv.2010.10.036
Wijayaratna, K., Dixit, V., Mao, T., & Waller, S. T. (2013). *Emissions impacts of transit signal prioritisation*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Xia, T., Nitschke, M., Zhang, Y., Shah, P., Crabb, S., & Hansen, A. (2015). Traffic-related air pollution and health co-benefits of alternative transport in Adelaide, South Australia. *Environment International, 74*, 281-290. doi:10.1016/j.envint.2014.10.004
Yousefikia, M., Mamdoohi, A. R., Moridpour, S., Noruzoliaee, M. H., & Mahpour, A. (2013). *A study on the generalized TFlowFuzzy O-D estimation*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Zhang, D. R. K. (2013). *An integrated approach to traffic modelling - Linking SIDRA, LINSIG & AIMSUN*. Paper presented at the 36th Australasian Transport Research Forum, ATRF 2013.
Zhu, S. (2015). *Development of vehicle emissions models for Australian conditions*. (PhD), University of Queensland,

Zhu, S., & Ferreira, L. (2013). Quantifying errors in micro-scale emissions models using a case-study approach. *Transportation Research Part D: Transport and Environment, 21*, 19-25. doi:10.1016/j.trd.2013.01.010

Zito, R., D'Este, G., & Taylor, M. A. P. (1995). Global positioning systems in the time domain: How useful a tool for intelligent vehicle-highway systems? *Transportation Research Part C, 3*(4), 193-209. doi:10.1016/0968-090X(95)00006-5