Healthy Urban Atmospheres

Observing and modelling particle number concentrations inside vehicles in busy traffic

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Particle number concentration exposure diary

Measurements using TSI P-Trak in Manchester, UK

(Acknowledgements Anna Leavey, formerly of University of Manchester)
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Contribution to inhaled dose

Constant breathing rate

Variable breathing rate

Commuting duration 76 minutes, or 5% of day

Data from Manchester-based pilot study
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New Zealand, Auckland, cars and health

- 1/3 of estimated health costs due to air pollution in NZ is incurred in Auckland
- Auckland has 1.3m people and 1m vehicles
- 90% commuting trips in Auckland by car
- 125,000 children in Auckland travel to school by car

![Graph showing car ownership per 1,000 population for selected countries in 2005.](image)

Source: "Pocket World In Figures 2009", International Road Federation
*Or latest year available

Adapted from Massal et al. (60.)
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Auckland-based study approach (to date)

Long-term aim of systematic semi-empirical prediction of exposure of large population

1. Trials: exploratory in-car observations in Auckland traffic
2. Simple high-res air exchange modelling
3. Semi-controlled study of car-related variables
4. Intensive observations of commuting in Auckland rush-hour (PNC, PM, CO)
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Observations in “normal” conditions
Observations of in-vehicle PNC in ‘normal’ conditions

- TSI P-Trak in inter-peak studies
- TSI 3007 in peak traffic studies (Aug 2009)
- Honda Civic, Toyota Camry, Ford Falcon
- Total dataset: 15 hrs over 8 days
- “normal” ventilation

- Inter-peak traffic:
  - Mean of all motorway segments: 27,000 cm$^{-3}$
  - Mean of all CBD segments: 20,000 cm$^{-3}$
  - Mean of all non-CBD segments: 14,000 cm$^{-3}$
  - Typical background during campaign: 3,000 cm$^{-3}$

- Peak traffic:
  - Mean of all motorway segments: 63,000 cm$^{-3}$
  - Mean of all non-motorway segments: 26,000 cm$^{-3}$ (background ~4,000 cm$^{-3}$)
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Example study routes (from 2007 pilot study)
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Initial trial example, Honda Civic
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1. internal < external, as vehicle acts as band-pass filter for brief spikes
2. highest values in congested traffic at Central Motorway Junction (CMJ) and suburban high street (Avondale)
3. next highest concentrations on free-flowing motorways
4. $\Delta N$ much lower on non-motorway sections – external less spiky
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WAIVE (Waitakere to Auckland In-Vehicle Exposure) 2009
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- External concentrations elevated by order of magnitude for 18 seconds
- Internal concentrations elevated 7x (initially), and remain >external for 4 minutes/3.5 km

**Observational features #1: response to intersections**

![Graph showing PNC/cm³ over time elapsed in minutes](image)
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Observational features #2: encounters with gross emitters

- 3 minutes behind bus doubled journey mean external PNC
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Experimental determination of air exchange rate
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Experimental determination of AER

1st-order infiltration model:
\[ \lambda = AV + B = \frac{\partial N}{\partial t}/-\Delta N \]

\( V = \text{speed} \), and \( A \) and \( B \) are empirically derived constants describing “leakiness” of the vehicle

For typical conditions \( \lambda \sim 1 \text{ min}^{-1} \)
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Initial trial: effect of ventilation settings on journey means

- Reduction in AER has non-linear effect on exposure
- Effect depends on characteristics of the trip (traffic encounters/fresh particle injection events)
- Some evidence of I/O >1 for certain trip/ventilation profiles
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Air exchange modelling
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Air & Particles Exchange Model (APEX)

Model interior time series based on exterior and speed
Interior obs used as validation only (no feedback into model)

APEX v.1: 1st-order infiltration model: \( \frac{dN}{dt} = -\lambda \Delta N \), where \( \lambda = f(V) \)
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v.1 Model weaknesses

- Model missing lag in internal response
- Model under-representing initial rapid decay post-injection (when PNC:PM$_{10}$ ratio was elevated – not shown)
- Interpretation: increased removal of UFP during high concentrations (gross-emitter encounter?) or within first ~20 seconds after injection
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Terrace Tunnel model initialisation

- Trialled adding simple removal (deposition) and lag (mixing) terms
- Initialised on data from drive-throughs of Terrace Tunnel (Wellington)
- Lag based on CO data, removal based on PNC (Ptrak) data
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Remaining weaknesses of model (v.3)

\[ \frac{dN(t)}{dt} = (A\nu(t) + B)(N_{out}(t - t_{lag}) - N(t)) - kN(t) \]

- Lag term \((t_{lag} = 10 \text{ s})\) is arbitrary
- Particle deposition term \((k = 0.009 \text{ s}^{-1})\) should be particle size-dependent
- Currently based on data from Ptrak with uncertain response < 50 nm
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Where next for the modelling?

Air exchange modelling:
- Size-dependent processes (SMPS?)
- More complex process modelling
- Intercomparison with simpler “black box” (e.g. band-pass filter) modelling

Operational modelling:
- Relate statistical properties of external concentrations to traffic data and emissions modelling
- Developing probabilistic modelling for population in-transit exposure
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Proposed model integration

Ventilation variable model

Aerosol process sub-model

Air & Particles Exchange model

Probabilistic external profile model

Simplified in-car response model

Personal exposure assessment model

Land-use planning model

Trip assignment model

Traffic model

Emission model
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