Introducing PIMS: The Pollution In-Cabin Measurement System

Douglas Booker, NAQTS
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Who We Are and What We Do

National Air Quality Testing Services (NAQTS) is a social business that is passionate about improving the quality of life.

We seek to **improve awareness of indoor air quality** through widespread public and commercial monitoring using our holistic, high-quality, air pollution monitoring technology.

Based in UK (Lancaster University Environment Centre and Cardiff), and in Ann Arbor, Michigan, USA

**INDOOR AIR QUALITY & ENERGY EFFICIENCY**
Developing models for assisting building design and modification whilst ensuring energy efficiency and good indoor air quality.

**CITIZEN SCIENCE - INDOOR:OUTDOOR AIR QUALITY**
Air quality toolkit for citizen science measurements. Capturing real-time pollution levels during school drop off/pick up times, as well as levels of student exposure in the classroom

**OCCUPATIONAL HEALTH AND SAFETY**
Evaluation of exposure to nanomaterials

**AIR QUALITY MAPPING**
Routine mobile monitoring for measuring time-integrated concentrations at high spatial resolution

**BENCHMARKING VEHICLES “COMFORT”**
Air Quality, Noise, and Vibration
Data on in-cabin comfort from 100s of vehicles per year
What do we call a measurement device for in-cabin?

PEMS

PAMS

SEMS

456,976 combinations!
Introducing PIMS

• PN - CPC with 20:1 pre-dilution (IPA, d_{50} 15nm)
• CO, NO₂, NO – Electrochemical
• CO, NO₂, VOCs – Metal Oxide
• VOCs – Real-time and thermal desorption tubes for GC-MS Analysis
• CO₂ – NDIR
• T, P, RH – BME280
• Vibration – 3D accelerometer and 3D Gyro
• Noise – dBA
• Location – GPS
• OBD – Bluetooth
• Vibration – 3D accelerometer and 3D Gyro
• Web GUI with SQL Database
• GSM

The Pollution In-cabin Measurement System (PIMS)

Integrated measurement device for a “holistic” understanding of air quality
Introducing PIMS

- Installed into a mannequin, “Arnie”, to simulate human exposure, and for easy installation
- Outside unit can either be mounted on a suction cup, or inside with a sample line out
- Simultaneous inside and outside measurements to understand how much ambient air pollution is coming into the vehicle
Geofencing

- Geofenced triggered thermal desorption tubes for integrated full speciation VOCs
- Automatic reporting with averaged concentrations in geofenced areas
- Understand air quality and exposure in non-attainment areas
• PN: Regulatory grade PN: ISO 27891
• CO₂: Auto Baseline algorithm used for long-term sampling
• Calibration - easy, low cost calibration using typical automotive gas bottles, e.g. 16% CO₂ Quad Blend (CO, HC, NO), and NO₂ through the integrated diluter
Metrology - Colocation

- Extensive colocation activities at Chinese Academy of Sciences Supersite to improve low-cost sensor accuracy
- More than 3 months colocation work
Metrology - Colocation

- CO & NO$_2$
- Low-cost sensors a challenge and a great opportunity
- Low-cost sensor ≠ low cost device!
Vehicle Interior Air Quality (VIAQ)

• 101 minutes per day in vehicles (Dong et al. 2004)

• Immediate proximity to significant pollutant sources (other vehicles), plus in urban areas, high outdoor concentrations

NHAPS - Nation, Percentage Time Spent
Total n = 9,196

- TOTAL TIME SPENT
  - INDOORS (86.9%)
  - OUTDOORS (7.6%)
  - IN A VEHICLE (5.5%)
  - OFFICE-FACTORY (5.4%)
  - BAR-RESTAURANT (1.8%)
  - OTHER INDOOR LOCATION (11%)

What causes good/bad VIAQ?

- What are the effects on VIAQ of:
  - Fan Setting
  - Vehicle selection
  - Window open/closed
  - Location
  - Air conditioning


Effect of Occupant Behaviour

- **Ingress Ratio** – How much outside air pollution is getting into the cabin?

- **Stuffiness Factor** – How well is the vehicle ventilating CO$_2$?

<table>
<thead>
<tr>
<th></th>
<th>INGRESS RATIO</th>
<th>STUFFINESS FACTOR</th>
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<tbody>
<tr>
<td><strong>German Sedan</strong></td>
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<tr>
<td>Recirculation Off</td>
<td>24%</td>
<td>1.4</td>
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<tr>
<td>Recirculation On</td>
<td>5%</td>
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<tr>
<td><strong>American Hatchback</strong></td>
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<tr>
<td>Recirculation Off</td>
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Effect of Occupant Behaviour

- **Ingress Ratio** – How much outside air pollution is getting into the cabin?
- **Stuffiness Factor** – How well is the vehicle ventilating CO₂?

### Japanese Crossover

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<tr>
<td>Recirculation Off</td>
<td>99%</td>
<td>1.3</td>
</tr>
<tr>
<td>Recirculation On</td>
<td>18%</td>
<td>3.4</td>
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### German MPV

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<td>Recirculation Off</td>
<td>41%</td>
<td>1.4</td>
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<tr>
<td>Recirculation On</td>
<td>17%</td>
<td>4.97</td>
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Effect of Occupant Behaviour - Summary

• These data show the heterogeneity of Ingress Ratios

• 24–99% with recirculation mode off, 5–17% with recirculation mode on

• An inherent tradeoff between protecting passengers from ambient ingress, and adequate ventilation

• Huge influence of passenger habit on dose. By driver education, and automation of HVAC controls, exposure can be reduced significantly
Effect of Occupant Behaviour

- Drive from Long Beach to Downtown LA
- ~ 2 hours in length
- A variety of HVAC settings
  - “Fresh Air” mode
  - Recirculation mode
- A variety of speeds
  - High
  - Low
  - Stop/start
- A variety of locations
  - Urban
  - Highway
Effect of Occupant Behaviour – "Fresh Air" Mode

- PN peaks at 100,900 #/cm³
- NO₂ peaks associated with following dirty diesels!
- Vehicle is well ventilated, with CO₂ concentrations <1000ppm
- VIAQ is susceptible to extremely localized air quality: dirty diesels!
Effect of Occupant Behaviour – Recirculation Mode

- PN exponential decay to low concentrations
- CO₂ peaks at >3500ppm
- Increased leakage of HVAC associated with higher speeds, results in some CO₂ ventilation, and some PN infiltration
- Obvious dichotomy between PN & CO₂, but it is not so clear for NO₂
Effect of Location - Mobile Air Quality Monitoring

- Routine mobile monitoring for measuring time-integrated concentrations at high spatial resolution

- **4-5 orders of magnitude improvements** in spatial resolution than current central site monitoring stations

- Where are vehicles causing poor air quality? And in what areas are drivers exposed to higher concentrations?
Mobile Air Quality Monitoring – Lancaster, UK

- Lancaster is a small city of 138,000 people in the North-West of England

- Over a period of 1 week, particle number concentrations were recorded every second over a 20-mile route during evening rush hour (5:30/7:00pm)
Mobile Air Quality Monitoring – Lancaster, UK

- Air Quality "hotspots" change in space and time!
Mobile Air Quality Monitoring – Lancaster, UK

- Air Quality "hotspots" change in space and time!
Air Quality Mapping

- 2 year project in Guangzhou (megacity)
- **Land-use regression model** combining: mobile air quality monitoring, fixed site stations, meteorological, land-use, traffic volume, POI data etc.
- Will map UFP and other pollutants
- Developing an **app to predict air pollution exposure**
- When combined with cellular GPS data, rich “personal exposure analytics” become possible
- Case study to demonstrate feasibility of a low-cost air quality monitoring network
Conclusions

• Measurements to reduce population level exposure must include measurements inside AND outside vehicles

• Vehicles are already being equipped with PEMS, PIMS air quality measurements can be “piggybacked” to provide valuable air quality and exposure data

• The general public can leverage PIMS data to have informed choice when purchasing a car, and to reduce their exposure

• OEMs can use this technology to refine HVAC systems to provide “clean air cabins”

• Unregulated space? - what are the implications for occupational health and safety?
Indoor Air Quality at UCR PEMS

- Average person spends ~90% of their time indoors.
- There is far less information / public knowledge on it!
- Particles reach 10x higher than background concentrations
Indoor Air Quality at UCR PEMS

- Average person spends ~90% of their time indoors.
- There is far less information / public knowledge on it!
- Very well ventilated conference, with levels not exceeding 1000ppm
Any questions?

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