Innovative technologies for city air pollution control—challenges and opportunities for scaling up and adoption

Keynote Lecture

Expert Group Meeting on Innovative Technologies and Applications for Urban Air Pollution Control in Asia & the Pacific

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Concerns over FINE PARTICLES (PM$_{2.5}$)

Human Health

- Lungs
- Brain
- Blood
- Heart
- Nervous system
- Cardiovascular system
- Respiratory function
- Inflammation
- Oxidative stress
- Acute effects
- Chronic effects
- Effects on pregnancy

PM$_{2.5}$ penetrates into the respiratory tract and can travel into the bloodstream.

7 MILLION deaths a year are linked to exposure to PM$_{2.5}$
(Source: WHO, 2018)

Urban Air Quality

More than 9 out of 10 people breathe in polluted air daily
(Source: WHO, 2018)

Climate Change

(Global climate forcing)

(Source: European Geosciences Union, 2016)
Airborne Particulate Matter (PM)

Chemical compositions
- Toxics
- Metals
- Secondary Sulfate & Nitrate
- Organic Carbon Compounds
- Elemental Carbon Core

Sizes
- \( \text{PM}_{10} \)
- \( \text{PM}_{2.5} \)
- UFP

Mass concentrations

Concentration-Response Functions

- Cause-specific mortality \((10^{-3} \text{ y}^{-1})\)
- Total attributable mortality \((10^{-3} \text{ y}^{-1})\)

- Ambient \( \text{PM}_{2.5} \) \((\mu\text{g m}^{-3})\)

- Ischemic Heart Disease
- Total (right axis)
- COPD
- Respiratory Infections
- Lung Cancer

Locations:
- Nasopharynx
- Mouth
- Trachea
- Lungs
- Bronchial Tree
- Diaphragm
Conventional Exposure assessment

Fixed PM monitoring stations (FMS)

- Lack of spatial results of PM data
- PM levels in various MEs are different from ambient levels
- Does not account for indoor air pollutants

ME: microenvironment

Offices/School

Transport

Home

Recreation locations

- People are mobile, visiting multiple indoor & outdoor MEs daily, influenced by different PM generating processes
Transport microenvironments (TMEs)

People spend ≈ 7-10% of their time in TMEs

TMEs contribute up 30% of daily integrated exposure to PM

- Lack of comprehensive investigations of exposure to PM in TMEs in Asian cities, especially during **active modes of transport** while motorized traffic is still in existence.

- Studies dealing with the estimation of the **actual amount** of PM intake (inhaled dose of PM) are relatively sparse.

*(Kumar et al., 2018); (Dons et al., 2012); (Dons et al., 2019)*
How can we make a realistic assessment of human exposure to inhaled PM and their associated health effects?
Personal exposure (PE) assessment

- Accounts for the actual exposure to PM experienced by individuals.
- Provide spatiotemporal variations of PM; brings indoor and outdoor air quality assessments together, linking the extent, place, duration, and frequency of human exposure to PM in diverse MEs.
### Case cities

<table>
<thead>
<tr>
<th>Metric</th>
<th>Singapore</th>
<th>Danang</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual PM$_{2.5}$ ($\mu$g m$^{-3}$)</td>
<td>14.2-24.3</td>
<td>15.7-21.8</td>
</tr>
<tr>
<td>Population density (pp km$^{-2}$)</td>
<td>7796</td>
<td>818</td>
</tr>
<tr>
<td>Weather</td>
<td>Tropical monsoon</td>
<td>Tropical monsoon</td>
</tr>
<tr>
<td>Ownership of motorized vehicles</td>
<td>29% (car + motorcycle)</td>
<td>1% (car)</td>
</tr>
<tr>
<td>Public transport</td>
<td>53% (bus + MRT)</td>
<td>1% (bus)</td>
</tr>
<tr>
<td>Walking, cycling</td>
<td>14%</td>
<td>--</td>
</tr>
<tr>
<td>Taxi/private hire car</td>
<td>4%</td>
<td>--</td>
</tr>
<tr>
<td>Motorcycle</td>
<td>--</td>
<td>98%</td>
</tr>
</tbody>
</table>
Data Collection

1. Multi-modal transport from Singapore to Danang and back
   *Taxi, aeroplane, walking, and apron bus*

2. On-road modes of transport in each city
   *Cycling, e-scooter, motorcycle, taxi*

3. Traffic counting at traffic intersections

Sidepak AM520  Micro-aethalometer AE51

Realtime PM$_{2.5}$  Realtime BC
Multimodal transport from SG to DN

Time-series

Integrated inhaled dose

PM$_{2.5}$ (µg m$^{-3}$)

WHO 24-hour PM$_{2.5}$ Guideline

PM$_{2.5}$ (µg m$^{-3}$)

SG Home

Taxi (AC)

SG Airport

Inflight: SG-HCM

Inflight: HCM-DN

Transit (by walking)

Transit (by apron bus)

Airport (HCM international)

Airport (HCM domestic)

DN Airport

Taxi (non-AC)

DN Home

Inhaled Dose (µg) = Intake Volume (m$^3$) × PM concentration (µg m$^{-3}$) × Deposition Fraction

Integrated inhaled dose of PM$_{2.5}$ and BC (µg)

> 50 %

> 60 %
### On-road modes of transport in each city

<table>
<thead>
<tr>
<th>City</th>
<th>Mode of transport</th>
<th>Monitoring period</th>
<th>Average trip duration (min)</th>
<th>PM$_{2.5}$ Inhaled dose rate (µg km$^{-1}$)</th>
<th>BC Inhaled dose rate (µg km$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SG</strong></td>
<td>Cycling</td>
<td>Peak</td>
<td>41.2</td>
<td>19.5 ± 2.4</td>
<td>18.3</td>
</tr>
<tr>
<td></td>
<td>Non-peak</td>
<td>38.0</td>
<td>13.5 ± 1.3</td>
<td>11.7</td>
<td>2.39</td>
</tr>
<tr>
<td></td>
<td>E-scooter</td>
<td>Peak</td>
<td>41.8</td>
<td>19.0 ± 2.1</td>
<td>9.1</td>
</tr>
<tr>
<td></td>
<td>Non-peak</td>
<td>38.2</td>
<td>14.7 ± 1.3</td>
<td>6.4</td>
<td>1.31</td>
</tr>
<tr>
<td></td>
<td>Taxi</td>
<td>Peak</td>
<td>30.2</td>
<td>9.0 ± 1.1</td>
<td>1.1</td>
</tr>
<tr>
<td></td>
<td>Non-peak</td>
<td>30.0</td>
<td>21.9 ± 3.4</td>
<td>2.7</td>
<td>0.55</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>24.2</td>
<td>7.7 ± 1.2</td>
<td>0.8</td>
<td>0.16</td>
</tr>
<tr>
<td></td>
<td>Non-AC</td>
<td>23.3</td>
<td>20.7 ± 1.4</td>
<td>2.0</td>
<td>0.41</td>
</tr>
<tr>
<td><strong>DN</strong></td>
<td>Cycling</td>
<td>Peak</td>
<td>106.5</td>
<td>98.6 ± 3.7</td>
<td>239.2</td>
</tr>
<tr>
<td></td>
<td>Non-peak</td>
<td>101.3</td>
<td>50.4 ± 2.4</td>
<td>116.4</td>
<td>8.19</td>
</tr>
<tr>
<td></td>
<td>Motorcycle</td>
<td>Peak</td>
<td>59.3</td>
<td>100.8 ± 11.3</td>
<td>68.1</td>
</tr>
<tr>
<td></td>
<td>Non-peak</td>
<td>54.3</td>
<td>49.2 ± 6.4</td>
<td>30.4</td>
<td>2.14</td>
</tr>
<tr>
<td></td>
<td>Taxi</td>
<td>Peak</td>
<td>50.7</td>
<td>21.4 ± 1.9</td>
<td>4.5</td>
</tr>
<tr>
<td></td>
<td>Non-peak</td>
<td>49.5</td>
<td>112.6 ± 9.2</td>
<td>23.1</td>
<td>1.63</td>
</tr>
<tr>
<td></td>
<td>AC</td>
<td>48.0</td>
<td>14.8 ± 1.9</td>
<td>2.9</td>
<td>0.21</td>
</tr>
<tr>
<td></td>
<td>Non-AC</td>
<td>48.3</td>
<td>79.6 ± 8.3</td>
<td>15.9</td>
<td>1.12</td>
</tr>
</tbody>
</table>

Influence of traffic volume and composition

PM$_{2.5}$ and BC concentrations as functions of hourly traffic rates in (a) Singapore, (b) Danang. The BC-to-PM$_{2.5}$ ratios for each category are also shown.

LDVs: light-duty vehicles; HDDVs: heavy-duty diesel vehicles; P1-P6: traffic intersections
Effect on years of life expectancy (YLE)

Potential gains/losses in YLE in SG

<table>
<thead>
<tr>
<th>Age group (Years)</th>
<th>E-scooter</th>
<th>AC Taxi</th>
<th>Non-AC Taxi</th>
<th>E-scooter</th>
<th>AC Taxi</th>
<th>Non-AC Taxi</th>
<th>E-scooter</th>
<th>AC Taxi</th>
<th>Non-AC Taxi</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-39</td>
<td>-0.231</td>
<td>-0.251</td>
<td>-0.261</td>
<td>-0.224</td>
<td>-0.224</td>
<td>-0.234</td>
<td>-0.150</td>
<td>-0.169</td>
<td>-0.170</td>
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<td>40-64</td>
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<td>65+</td>
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</tbody>
</table>

Potential gains/losses in YLE in DN

<table>
<thead>
<tr>
<th>Age group (Years)</th>
<th>Motorcycle</th>
<th>AC Taxi</th>
<th>Non-AC Taxi</th>
<th>Motorcycle</th>
<th>AC Taxi</th>
<th>Non-AC Taxi</th>
<th>Motorcycle</th>
<th>AC Taxi</th>
<th>Non-AC Taxi</th>
</tr>
</thead>
<tbody>
<tr>
<td>20-39</td>
<td>0.025</td>
<td>0.017</td>
<td>0.015</td>
<td>0.030</td>
<td>0.022</td>
<td>0.020</td>
<td>0.014</td>
<td>0.005</td>
<td>0.004</td>
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<tr>
<td>40-64</td>
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<td>65+</td>
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</tbody>
</table>

Potential gains or losses in YLE due to PM$_{2.5}$ exposure and physical activity compared between any mode of transport and cycling in (a) Singapore and (b) Danang.
Conclusions

- **Airport concourses** and transit MEs to/from the aeroplane by **apron buses** made major contributions to the total integrated exposure to PM$_{2.5}$ and BC.

- The PE to PM$_{2.5}$ and BC in TMEs: an order of magnitude **higher** in Danang compared to Singapore while using various on-road modes of transport in each city.

- Elevated concentrations of PM in Singapore and Danang: significantly contributed by **heavy-duty diesel vehicles** and **motorcycles**, respectively.

- A reduction in YLE is likely to occur among urban commuters while using motorized transport compared to active mobility (**cycling**).
Personal exposure to airborne particles in transport micro-environments and potential health impacts: A tale of two cities

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National University of Singapore
Thank you!

Feel free to ask any questions