The Non-Linear Relationship Between Road Traffic Emissions and Pollutant Concentrations

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Outline of talk

- Background
  - Vehicle-induced turbulence
  - Initial mixing height
  - Non-exhaust emissions
  - Conclusions
Background

Road traffic emissions can be modelled in a number of ways:

- **Basic linear models**
  - Quick, easy to use
  - X Not very accurate

- **Complex non-linear models**
  - X Less easy to use
  - ✓ More accurate

Background

**UK Design Manual for Roads and Bridges (DMRB)**

- Screening model
- Old version:
  - Concentrations given ‘per 1000 vehicles/hr at 100km/hr’ at distances from the road
  - Adjustments for:
    - Speed
    - Light/heavy vehicles
    - Year
Background
UK Design Manual for Roads and Bridges (DMRB)

What were the results like?

- Generally not good for motorways

<table>
<thead>
<tr>
<th>Measured NOx (µg/m³)</th>
<th>Predicted NOx (µg/m³)</th>
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- Introduced traffic flow-dependent adjustment factors based on the monitored data
What are the new results like? ✓ Good

But......

Issues with models based on monitored data:
- Correlations biased towards the chosen dataset
- Factors different for each pollutant - unphysical
- Adjustments have to be recalculated each time basic model updated (e.g., emissions datasets)

Better to include non-linear, near-field processes
Vehicle-induced turbulence

Proposed Formulation

- Extra lateral spread, $\sigma_{y_{\text{vehicle}}}$

$$
\sigma_{y_{\text{vehicle}}} = \sigma_{v_{\text{vehicle}}} \sqrt{1 + \left(\frac{t}{t_d}\right)^2}^{-1/2}
$$

Increased vertical turbulence from OSPM:

$$
\sigma_{v_{\text{vehicle}}} = b \left[ N_h U_h A_h + N_i U_i A_i \right]^{1/2}
$$

Number density of traffic, $\mathrm{veh/km}^2$

Road-receptor travel time

Turbulence decay time: $t_d = \frac{W}{\tau} / \sigma_{v_{\text{vehicle}}}$

Constant derived from monitor data

CERC
Vehicle-induced turbulence

Proposed Formulation

- Extra lateral spread, $\sigma_{y,\text{vehicle}}$, represents 2 regimes:
  - Near field: $t \ll 1 \quad \sigma_{y,\text{vehicle}} \rightarrow \sigma_{v,\text{vehicle}} t$
    
    i.e. plume spread dominated increased lateral turbulence from traffic
Vehicle-induced turbulence

Proposed Formulation

- Extra lateral spread, $\sigma_{\text{vehicle}}$, represents 2 regimes:
  - Near field: $t << 1 \Rightarrow \sigma_{\text{vehicle}} \rightarrow \sigma_{\text{vehicle}} t$
    - i.e. plume spread dominated increased lateral turbulence from traffic
  - Far field: $t \rightarrow \infty \Rightarrow \sigma_{\text{vehicle}} \rightarrow \frac{W}{\tau}$
    - i.e. plume spread independent of speed and number of vehicles

Note this formulation is for an OPEN ROAD

Vehicle-induced turbulence

Wind-direction dependence

<table>
<thead>
<tr>
<th>Wind direction</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Parallel to road</td>
<td></td>
</tr>
<tr>
<td>Perpendicular to road</td>
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</tr>
</tbody>
</table>

lateral plume spread

vehicle

road

wind

overlapping plumes
Vehicle-induced turbulence

Results

- Constant $\tau = 0.1$ (validation exercise)
- Cross-sectional areas of light and heavy vehicles:
  - $A_L = 4m^2$, $A_H = 16m^2$
- Investigate urban and rural areas (roughness $z_0 = 0.2$ and $0.75m$ respectively)

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Vehicle-induced turbulence

Results – ADMS-Urban: annual average concentrations

- High speed Urban area $Z_0 = 0.75m$
Vehicle-induced turbulence

Results – ADMS-Urban: annual average concentrations

High traffic flow

Urban area

$Z_0 = 0.75 \text{m}$

- Slow speed
- Medium speed
- Fast speed

Distance from road centre (m)

Normalised concentration

- Slow flow
- Medium flow
- High flow

Distance from road centre (m)
Vehicle-induced turbulence

Results

- Constant $\tau = 0.1$ (validation exercise)
- Cross-sectional areas of light and heavy vehicles: $A_L = 4\, m^2$, $A_H = 16\, m^2$
- Investigate urban and rural areas (roughness $z_0 = 0.2$ and 0.75m respectively)
- Most effect on high flow, high speed, thin roads in rural areas
Consider
- Height of line source that represents the road
- Initial vertical plume spread parameter

Initial mixing height parameter

Exit velocity 15 – 20 m/s
(54-72 km/hr)

Initial mixing height (m)

0 1 2 3 4

0 40 80 120

Speed (km/hr)

Low level exhausts
Vertical exhausts

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Initial mixing height

**Results** – ADMS-Urban: annual average concentrations

![Graph showing annual average concentrations vs distance from road centre](image)

Distance from road centre (m) vs Concentration (µg/m³) for 1m, 2m, and 3m from the road

Non-exhaust emissions

**Estimation of contribution to concentrations**

- Compare monitored and modelled (ADMS-Urban) concentrations:
  - NOₓ and NO₂ – good
  - PM₁₀ – generally modelled results low
- Analysis of ‘roadside’ and ‘urban background’ sites

HARMO-10 Crete 2005
Non-exhaust emissions
Estimation of contribution to concentrations

Raw data

- Compare monitored and modelled (ADMS-Urban) concentrations:
  - NO\textsubscript{x} and NO\textsubscript{2} – good
  - PM\textsubscript{10} – generally modelled results low
- Analysis of ‘roadside’ and ‘urban background’ sites
- Calculate average difference (Monitored – Modelled) for each site type
- Use this value to represent non-exhaust emissions
Non-exhaust emissions
Estimation of contribution to concentrations

Adjusted data

Monitored  Modelled
20  30  40
20  30  40
Roadside sites
Urban background sites

Raw data

Monitored  Modelled
20  30  40
20  30  40
Roadside sites
Urban background sites
Non-exhaust emissions
Required work

- Need to parameterise the non-exhaust emissions
- Likely that emissions related to nature of flow (e.g., stop/start), road surface type rather than linear with exhaust emissions

CERC involved in project with:
- TRL (UK)
- Environmental Health & Risk Management Division, University of Birmingham (UK)

Aim of project: Review, Development of new non-exhaust emissions model, Integration of new model into ADMS-Urban, Validation of emissions estimates, Validation of concentration estimates, Abatement options
Conclusions

- Relationship between vehicle flow rate and pollutant concentrations is non-linear
- Processes include:
  - Vehicle-induced turbulence
  - Initial mixing height
  - Non-exhaust emissions

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Thank-you for your attention

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