Improved Emission Estimation at Intersections – A Roundabout Study

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Background

- Transportation related emissions as one of the intersection performance measures.

- **Urban intersections** are a major emission source, as complex vehicle activities including stop-and-go, deceleration, idling, and acceleration lead to a large amount of pollutant emissions.

- **Research Need**: Method that can monitor vehicle emission at intersection level in real time.
Existing Methods of Emission Monitoring

• Traditional environmental sensor based method
  • Point-based data.
  • Measured emission may include pollutants from non-transportation source.

• Probe GPS data + MOVES model based method
  • Inaccurate: using one vehicle’s trajectory to represent the entire traffic.
  • Cannot fulfill real-time surveillance.
Advanced Radar Detection as A Solution

• **Solution**: Radar sensor + MOVES operating mode method
  - Accurate; all vehicles’ trajectories included in computing the operating mode distribution.
  - Real-time surveillance.

• **Radar sensor**: tracks all vehicles’ trajectories from up to 600 ft away at a refreshing rate of 0.2 seconds/refresh.
Proof-of-Concept at A Signalized Intersection
Trajectory Data Collected
Vehicle Trajectory Data for A Platoon of Vehicles
Comparison between Traditional and Radar-based Methods

- Speed and Acceleration Rate Distributions

(a) Speed Distribution

(b) Acceleration Distribution
Improved Emission Estimation: Radar-based Trajectory Data + MOVES

- Operating mode distribution method of EPA’s MOVES Model
- MOVES’ most accurate approach to estimate vehicle emission.
- Requires trajectory data at every second as input.
- Operating mode is based on VSP (vehicle specific power), vehicle speed.

\[ VSP = v \times [1.1a + 9.81 \times \text{grade}(\%) + 0.132] + 0.000302 \times v^3 \]

<table>
<thead>
<tr>
<th>Operating Mode</th>
<th>Operating Mode Description</th>
<th>Vehicle-Specific Power (VSP, kW/metric ton)</th>
<th>Vehicle Speed ( (v, \text{mi/hr}) )</th>
<th>Vehicle Acceleration ( (a, \text{mi/hr-sec}) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Deceleration/Braking</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Idle</td>
<td>VSP &lt; 0</td>
<td>(-1.0 \leq v_i \leq 1.0)</td>
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<tr>
<td>11</td>
<td>Coast</td>
<td>VSP &lt; 0</td>
<td>1 \leq v_i &lt; 25</td>
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<tr>
<td>12</td>
<td>Cruise/Acceleration</td>
<td>0 \leq VSP &lt; 3</td>
<td>1 \leq v_i &lt; 25</td>
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<tr>
<td>14</td>
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<td>1 \leq v_i &lt; 25</td>
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<tr>
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<td>16</td>
<td>Cruise/Acceleration</td>
<td>12 \leq VSP</td>
<td>1 \leq v_i &lt; 25</td>
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</tr>
</tbody>
</table>

Figure 12: CO emission rates [g/hr] by operating mode for model year 2002 and age group 0.5.
Comparison between Traditional and Improved Methods

- Operating Mode Distribution

[Graphs showing distribution of operating modes for different links (Link 1, Link 2, Link 3, Link 4).]
A Roundabout Case Study
Trajectory Data Collected at A Roundabout

• Study site: 2-lane roundabout located in Oshkosh, WI

• Vehicle trajectories collected and traced by radar sensors
  • Speed and acceleration rates are derived from the trajectories.
Speed vs. Distance (non-stopped vehicles)
Acceleration Rate vs. Distance (non-stopped vehicles)
MOVES Links Breakdown

- Link 0 - Circulating Link = 85 feet
- Link 1 = 150 feet
- Link 2 = 150 feet
- Link 3 = 150 feet
Analysis

• MOVES operating model distribution based modeling was used in analyzing the emission from roundabout.

• Trajectory data input into MOVES calculation is aggregated for every five minutes.

• Emission rate of the PM 2.5 pollutant were modeled for the roundabout entrance approach.
Result

PM2.5 Emission Rate vs. Sum of Entering and Circulating Volume

Sum of Entering and Circulating Volume (veh/hr)

PM2.5 Emission Rate (g/veh-mile)

- Link 1 Emission Rate
- Link 2 Emission Rate
- Link 3 Emission Rate
Result

PM2.5 Emission Rate vs. Sum of Entering and Circulating Volume

- **Link 1 Emission Rate**:
  - $y = 0.0072e^{0.0004x}$
  - $R^2 = 0.7539$

- **Link 2 Emission Rate**:
  - $y = 6E^{-0.09}x^2 - 3E^{-0.05}x + 0.052$
  - $R^2 = 0.3914$

PM2.5 Emission Rate (g/veh-mile) vs. Sum of Entering and Circulating Volume (veh/hr)

- **Link 1 Emission Rate**: Diamond symbols
- **Link 2 Emission Rate**: Square symbols
Conclusions

• The improved radar sensor-based method benefits from the high-frequency radar-based trajectory data that cover all approaching vehicles in the traffic flow, which addresses the "failure to describe traffic dynamics" issue pertaining to the GPS probe method (significant difference between individual vehicles).

• The roundabout case study reveals:
  • Emission rate of PM2.5 for the entrance approach section located 150 feet from the yield line increases, as the sum of entering and circulating volumes increases. The pattern follows exponential distribution.
  • Emission rate of PM2.5 for the entrance approach section located 150-300 feet from the yield line increases and then decreases, as the sum of entering and circulating volumes increases. The pattern follows polynomial distribution.
Future Research

• Issues that need to be addressed in future research
  • Detection rate of radar detectors becomes lower as the distance from the center of intersection increases.
    • A low detection rate can underestimate the vehicle volume on certain links. Secondly, vehicle length information collected by radar detectors is sometime inaccurate.
  • Vehicle length information collected by radar detectors is sometime inaccurate.

• Possible future solution
  • Solution to the above issues can be simply switching to other radar detector product with more reliable detection, or adding a video detector into system to collect more reliable volume and vehicle classification data.
Thank you!

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Questions?

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