Insights into air quality from large-scale tailpipe emissions measurement of passenger cars

Nick Molden
2 July 2015
Agenda

• Background and credentials
• Intensive PEMS testing in practice
• Performance tracking database
• Insights on NO\textsubscript{x}
• Fuel economy context
• Comparison to Real Driving Emissions legislation
• Future trends and issues
Emissions Analytics’ credentials

- Founded in 2011
- Headquartered in Winchester, with operations in London and Los Angeles
- 10 employees, currently expanding in EU
- Specialist in PEMS testing and data analysis
- Almost 1000 vehicles tested
- RDE-compatible testing conducted since 2011
- Expert in cycle design and testing strategies to meet multiple and complex objectives
- Works with OEMs, Tier 1 suppliers, fuel and chemical companies, regulators, consultancies, consumer media
Benefits of PEMS

• Real on-road testing using PEMS is a powerful research method
• Authentic and cost effective
• Works on all vehicle types
• No permanent vehicle modification required
• Flexible location
• High rate of data acquisition – 1 Hertz
• Precision approaching laboratory levels
Equipment (1)

- SEMTECH-DS and Ecostar-FEM
- Portable Emissions Measurement System connects to tailpipe
  - Captures emissions for CO$_2$, CO, NO, NO$_2$, total hydrocarbons
  - At 1 Hertz
- Air temperature, pressure, humidity
- GPS for speed and altitude
- Engine data via CANBUS
- Fuel economy derived via carbon balance
- Ecostar weighs approximately 50kg including auxiliary batteries
Equipment (2)

- Pegasor Mi2
- Real-time tailpipe concentrations
- No filter papers
- Particle mass and number
- Sub-23nm particles

- Flexible, economic, real-world data collection
- Challenges around calibration and repeatability
INTENSIVE PEMS TESTING
Objectives

- On-going, real-time performance monitoring programme
- Air quality, greenhouse gases, fuel economy
- Independent
- Authentic: production vehicles, public highway
- Create feedback loop into better engineering, regulation and purchase decisions
- To ensure beneficial outcomes are achieved
Activity

- 200-250 passenger cars tested per year in EU
  - Similar in US
- Testing primarily in London, but flexible location
- New, commercially available vehicles
- Typically 2,000km+ on odometer
- Fixed weight addition
- Proprietary route based on typical driving
- 2.5-3 hour test

- New programme for light commercial underway
PERFORMANCE TRACKING DATABASE
By manufacturer

639 tests in Europe
# Engine, powertrain, Euro stage

## Euro Stage

<table>
<thead>
<tr>
<th>Euro Stage</th>
<th>Diesel</th>
<th>Petrol</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Euro 5</td>
<td>311</td>
<td>217</td>
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<td>Euro 6</td>
<td>66</td>
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<td>Total</td>
<td>377</td>
<td>262</td>
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## Model Year

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## Engine size (litres)

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<tr>
<td>1-2</td>
<td>136</td>
<td>172</td>
<td>308</td>
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<tr>
<td>2-3</td>
<td>189</td>
<td>50</td>
<td>239</td>
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<td>3-4</td>
<td>46</td>
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Real-time benchmarking
Drill-down to individual datasets
INSIGHTS ON NO$_x$
ICCT report

On-road emission results, by vehicle

- Above type-approval
- Below or equal to type-approval
- Above Euro 5 limit
- Above Euro 6, below Euro 5 limit
- Below Euro 6 limit
- Euro 5 limit
- Euro 6 limit

15 test vehicles in total (6 manufacturers), with different NOx control technologies:
- 10 selective catalytic reduction (SCR)
- 4 exhaust gas recirculation (EGR)
- 1 lean NOx trap (LNT)

Average Euro 6 NOx conformity factors (ratio of on-road emissions to legal limits):
- all cars: 7.1
- best performer (Vehicle C, SCR): 1.0
- bad performer (Vehicle H, LNT): 24.3
- worst performer (Vehicle L, SCR): 25.4
Euro 6 latest trends

• Early Euro 6 passenger cars exceeded regulatory levels by 7.1 times – ICCT
• Early evidence of gap closing, especially towards end of 2014
• Further analysis required
• Best performers meet standard
• SCR dominant solution
• Spread reducing, but still wide
COPERT study

- Joint project with Imperial College London
- February 2015
- 5 Euro 5/6 passenger cars
- Detailed comparison with COPERT v4.10 and v4.11 models
- To assess effectiveness for policy and planning
- Euro 5 to Euro 6 performance compared to regulated levels
- Analysis of fraction of NO$_x$ and NO$_2$
CO$_2$ comparison

Car A, Urban

- **speed**
- **PEMS**
- **COPERT 4.10**
COPERT results – CO$_2$

- Only one vehicle met the 2015 limit (130g/km) on one cycle
- Some improvement suggested from Euro 5 to 6 in urban driving
- COPERT has tendency to underestimate CO$_2$

![Average CO$_2$ emissions (g/km), Motorway Cycle](image1)
![Average CO$_2$ emissions (g/km), Urban Cycle](image2)

Euro 6: A, B, C
Euro 5: D, E
$\text{NO}_x$ comparison

\begin{figure}
\centering
\includegraphics[width=\textwidth]{chart.png}
\caption{Car $A_5$, Urban}
\end{figure}

- Red: speed
- Green: PEMS
- Blue: COPERT 4.10
NO\textsubscript{x} comparison

Car A\textsubscript{e}, Motorway

- speed
- PEMS
- COPERT 4.10
COPERT results – NO$_x$

- COPERT better on average, but lacks resolution for road and model type
- Euro 6 significantly lower on average than Euro 5
- High inter-vehicle NO$_x$ variability
- All vehicles above regulated level in both urban and extra-urban

Euro 6: A, B, C
Euro 5: D, E
COPERT results – NO$_2$

- No consistent relationship between fNO$_2$ ratio and speed
- Variance between different models
- COPERT consistently underestimates primary NO$_2$ emissions in urban areas where public exposure is greatest
- Implies high primary fraction of NO$_2$ in urban areas, up to ~90%
- COPERT v4.11 assumes a ratio of 30% for Euro 6 diesel cars
- Danger of meeting NO$_x$ target but not solving air quality problem
NO$_x$ headline statistics

- From Emissions Analytics’ database, at OEM level
- Over 350 tests

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<th>Diesel Euro 6</th>
<th>Gasoline Euro 5/6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Real-world NOx (g/km)</td>
<td>0.718</td>
<td>0.405</td>
<td>0.049</td>
</tr>
<tr>
<td>Average Conformity Factor</td>
<td>4.0</td>
<td>5.1</td>
<td>0.8</td>
</tr>
<tr>
<td>fNOx – minimum</td>
<td>27</td>
<td>17</td>
<td>0</td>
</tr>
<tr>
<td>fNOx – mean</td>
<td>44</td>
<td>48</td>
<td>24</td>
</tr>
<tr>
<td>fNOx – maximum</td>
<td>71</td>
<td>80</td>
<td>72</td>
</tr>
</tbody>
</table>
COMPARISON TO RDE
Comparison with RDE

• Many similarities, some differences
  • RDE before RDE...
  • RDE-compatible
• Test ~50% longer in time
  • Economies of scale
• Town/rural/motorway defined by continuous route-segments
• Range of driving modes tested, but avoiding extended conditions
• Prescribed weight addition
• Separation of cold start and DPF regeneration
• Controlled use of air conditioning, no other auxiliary systems
• Maximum speed 110km/h
Future trends and issues

• Optimisation of dosing strategies
• Limitations of some deNO$_x$ systems
• Inclusion of cold start are more extreme ("extended") driving important
• Switch back to petrol to lower NO$_x$, but growing fuel economy and CO$_2$ penalty?
• Together with fuel economy and other technologies such as GDI – some 3 times over limit – need for mitigation
• In-use compliance will be critical
• Emissions Analytics are expanding tracking programme of fuel economy and NO$_x$, to measure progress and trade-offs
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