NREL Research and Thoughts on Connected and Automated Vehicle Energy Impacts

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Connected/Automated Vehicle (CAV) Topics

• Comprehensive energy impact assessment (positive and negative)

• Data collection and analysis

• Enabled energy efficiency opportunities

• Synergy with vehicle electrification
“Bookending” CAV Energy Impact Analysis

• **Identified dramatic potential energy impacts** (across automation levels)
  - Informed by related NREL work and literature review
  - Significant uncertainties remain; further research is warranted

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Positive Energy Outcomes

- Enabling electrification
- Lightweighting & powertrain/vehicle size optimization
- Full cycle smoothing
- Efficient driving
- Platooning

Negative Energy Outcomes

- Implications for advanced powertrains and vehicle design
- Travel demand impacts
- More travel
- Faster travel
- Travel by underserved

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Some Further Research Recommendations/Plans

• **Refine energy impacts analysis**
  o Reduce input uncertainties—including potential behavior changes (inform from surveys and present-day approximations such as car sharing, managed lanes, etc.)
  o Adjust calculation framework to better capture system interactions

• **Fully define multiple specific scenarios**
  o Identify corresponding energy outcome sensitivities/tipping points

• **Further energy-focused data collection, analysis and partnering on early CAV development, demonstration and deployment programs**
  o Feed best available data into refined analysis for informing stakeholders
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Evaluating Truck Platooning Efficiency Benefits

- Also potential safety and comfort benefits
- Many factors can influence
  - Vehicle spacing
  - Cruising speed
  - Speed variation
  - Baseline aerodynamics
  - Vehicle loading
  - Engine loading

Results from SAE Type II track testing of Peloton Technology system over a variety of conditions

Lammert and Gonder poster: [www.nrel.gov/docs/fy14osti/62494.pdf](http://www.nrel.gov/docs/fy14osti/62494.pdf)
Real-World Data for Transportation Decision-Making

Secure Access Paired with Expert Analysis and Validation

Alternative Fuels Data Center (AFDC)
*Public clearinghouse of information on the full range of advanced vehicles and fuels*

National Fuel Cell Technology Evaluation Center (NFCTEC)
*Industry data and reports on hydrogen fuel cell technology status, progress, and challenges*

Transportation Secure Data Center (TSDC): *Detailed fleet data, including GPS travel profiles*

Fleet DNA Data Collection
*MEDIUM- and heavy-duty drive-cycle and powertrain data from advanced commercial fleets*

FleetDASH: *Business intelligence to manage Federal fleet petroleum/alternative fuel consumption*

<table>
<thead>
<tr>
<th>Features</th>
<th>AFDC</th>
<th>NFCTEC</th>
<th>TSDC</th>
<th>Fleet DNA</th>
<th>Fleet DASH</th>
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<tbody>
<tr>
<td>Securely Archived Sensitive Data</td>
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<td>Y</td>
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<td>Publicly Available Cleansed Composite Data</td>
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<tr>
<td>Spatial Mapping/GIS Analysis</td>
<td>Y</td>
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<td>Y</td>
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<td>Custom Reports</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td>Controlled Access via Application Process</td>
<td></td>
<td></td>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td>Detailed GPS Drive-Cycle Analysis</td>
<td></td>
<td></td>
<td>Y</td>
<td>Y</td>
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</tbody>
</table>
Merging Datasets to Support Real-World Analyses

Vehicle use conditions from disparate datasets can be merged in a common environment to investigate the interplay of conditions (thermal, drive cycle/routing, grade, etc.).

<table>
<thead>
<tr>
<th>Data Element</th>
<th>Source</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive Cycles/Trip Distributions</td>
<td>NREL Transportation Secure Data Center</td>
<td>The TSDC houses hundreds of thousands of real-world drive cycles from vehicles across the country.</td>
</tr>
<tr>
<td>Climate Data</td>
<td>NREL National Solar Radiation Database</td>
<td>Home to TMYs from hundreds of U.S. locations, each containing hourly climate data.</td>
</tr>
<tr>
<td>Elevation/Road Grade</td>
<td>USGS National Elevation Dataset</td>
<td>Raw USGS elevations are filtered to remove anomalous data and produce smooth road grade curves.</td>
</tr>
</tbody>
</table>

USGS = United States Geological Survey
TDSC = Transportation Secure Data Center
TMY = Typical Meteorological Year
FASTSim = Future Automotive Systems Technology Simulator
Discussion Point: Many CAV technologies may require such a real-world/off-cycle assessment approach

- E.g., efficient routing, cycle smoothing and adaptive control technologies
- Assess energy benefit from potential real-world change, and frequency of occurrence
- Could utilize existing pathway for demonstrating off-cycle credit beyond pre-defined table of technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Adjustments for cars</th>
<th>Adjustments for trucks</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g/mi</td>
<td>gallons/mi</td>
</tr>
<tr>
<td></td>
<td>g/mi</td>
<td>gallons/mi</td>
</tr>
<tr>
<td>High Efficiency Exterior Lights (at 100 watt savings)</td>
<td>1.0</td>
<td>0.000113</td>
</tr>
<tr>
<td>Waste Heat Recovery (at 100W)</td>
<td>0.7</td>
<td>0.000079</td>
</tr>
<tr>
<td>Solar Panels (based on a 75 watt solar panel)</td>
<td>3.3</td>
<td>0.000372</td>
</tr>
<tr>
<td>Battery Charging Only</td>
<td>2.5</td>
<td>0.000282</td>
</tr>
<tr>
<td>Active Cab Ventilation and Battery Charging</td>
<td>0.6</td>
<td>0.000068</td>
</tr>
<tr>
<td>Active Aerodynamic Improvements (for a 3% aerodynamic drag or Cd reduction)</td>
<td>0.0000113</td>
<td></td>
</tr>
<tr>
<td>Engine Idle Start-Stop: w/ heater circulation system</td>
<td>2.5</td>
<td>0.000282</td>
</tr>
<tr>
<td>w/o heater circulation system</td>
<td>1.5</td>
<td>0.000169</td>
</tr>
<tr>
<td>Active Transmission Warm-Up</td>
<td>1.5</td>
<td>0.000169</td>
</tr>
<tr>
<td>Active Engine Warm-up</td>
<td>1.5</td>
<td>0.000169</td>
</tr>
<tr>
<td>Solar/Thermal Control</td>
<td>Up to 3.0</td>
<td>0.000338</td>
</tr>
</tbody>
</table>

*High efficiency exterior lighting credit is scalable based on lighting components selected from high efficiency exterior lighting list (see Joint TSD Section 5.2.3, Table 5–51).

**Solar Panel credit is scalable based on solar panel rated power, (see Joint TSD Section 5.2.4). This credit can be combined with active cab ventilation credits.

In order to receive the maximum engine idle start stop, the heater circulation system must be calibrated to keep the engine off for 1 minute or more when the ambient temperature is 30 deg F and when cabin heat is demanded (see Joint TSD Section 5.2.5.1).

+ This credit is scalable; however, only a minimum credit of 0.05 g/mi CO₂ can be granted.
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Notes from Driver Feedback Fuel Savings Project

Motivation

• “Your mileage will vary”
  o Based on driving conditions & style
• Improve efficiency of existing vehicles

Approach

• Quantify savings from cycle changes
  o Vehicle simulations & cycle analysis
  o On-road experiments over repeated routes
• Identify/understand behavior influences
  o Literature review & expert consultation
  o On-road observations
• Assess feedback methods
  o Survey existing examples
  o Evaluate based on project’s other findings

2010 Prius Fuel Economy Histogram for 133 Drivers

Midsize Conventional Vehicle Assumptions

Engine = 123 kW  CD = 0.30
Curb mass = 1473 kg  Crr = 0.009
FA = 2.27 m²
Driver Feedback Analysis Project: Key findings

• **Driving changes can save fuel**
  - 30%-40% outer bound for “ideal” cycles
  - 20% realistic for aggressive drivers
  - 5%–10% for majority of drivers

• **Existing methods may not change many people’s habits**
  - Other behavior influences dominate
  - Current approaches unlikely to have broad impact

**Developed several recommendations to maximize savings…**

Notes from Collaborative Project on Green Routing and Adaptive Control for the Chevy Volt

Green Routing Example

<table>
<thead>
<tr>
<th>Route</th>
<th>A</th>
<th>B</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Distance, mi</td>
<td>81.6</td>
<td>76.2</td>
<td>67.6</td>
</tr>
<tr>
<td>Duration, min</td>
<td>107</td>
<td>107</td>
<td>113</td>
</tr>
<tr>
<td>Avg Elec Rate, Wh/mi*</td>
<td>0.83</td>
<td>0.89</td>
<td>1.0</td>
</tr>
<tr>
<td>Avg MPG*</td>
<td>0.45</td>
<td>0.50</td>
<td>1.0</td>
</tr>
<tr>
<td>Cost, $*</td>
<td>1.0</td>
<td>0.89</td>
<td>0.59</td>
</tr>
</tbody>
</table>

*Normalized Values
Summary

- Demonstrated ability to model vehicle speed/accel profiles relative to road type
- Constructed high-level powertrain model employing cycle metrics and vehicle state as inputs
- Applied model using real-world distribution of O/D pairs, demonstrating:
  - Aggregate energy savings of up to 4.6% for green routing (relative to passenger value of time)
  - Average energy savings of 3.3% for mode scheduling

Modest aggregate savings, but may be cost-effective
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- **Synergy with vehicle electrification**
Thoughts on Automation/Electrification Synergy

- Automation **easier with electrified driveline**
- Information **connectivity** helps with **vehicle/grid integration**
- Automated alignment for wireless power transfer (WPT)
- Automated plug-in **electrified vehicle parking/charging**
  - Value from valet anywhere, maximized electrified miles and infrastructure utilization, minimized anxiety about range and finding chargers
- **Vehicle right-sizing for trip/range**

Acknowledging some caveats
- Can also automate conventional vehicle powertrains to obtain on-demand valet and taxi benefits
- **Shared-use automated taxis may have lengthy daily ranges**
  - But improvements in battery cost, fast charging, WPT could still enable electrification
  - Also note **operating cost/efficiency** may become more important for such vehicles
CAV Assessment Summary

- **Dramatic potential energy impacts** (positive and/or negative)
  - Significant uncertainties remain; further research is warranted
  - Thoughtful policy needed to encourage desired outcomes

![Graph showing energy outcomes](image)

Thanks! Questions?