Measurement and Modeling of Fuel Use and Exhaust Emissions from Idling Long-Haul Truck Engines and Auxiliary Power Units

H. Christopher Frey, Ph.D.a, Po-Yao Kuoa and Charles Villab

Objectives

- Collect real-world activity data from long-haul sleeper cab trucks
- Categorize stop scenarios
- Analyze stop activity patterns
- Develop detailed characterizations of base engine and auxiliary power unit (APU) usage patterns
- Estimate fuel use rates and emission factors for trucks and APUs
- Quantify real-world fuel use and emissions from base engines and APUs

NC STATE UNIVERSITY

Long-Haul Sleeper Cab Trucks in the US

- Approximately 680,000 long-haul sleeper cab trucks
- Rest stops required by Federal Hours of Service (HOS) regulations
- Base engine idling to provide "hotel" services
- Long-haul truck idle hours are estimated to range from 1,460 to 1,800 hours annually
- Freight truck idling is estimated to consume 7% of freight truck fuel

Study Methodology

10 Fleet-A Trucks
With APU-A
With APU-B
Average in-service time: 11,300 hours (as of 2/29/07)

10 Fleet-B Trucks
With APU-A
With APU-B
Average in-service time: 8,500 hours (as of 2/29/07)

Data Acquisition System

Study Methodology (Continued)

(1) Categorize Stop Scenarios
- Different types of stop activities are sorted based on the use of:
  - Base engine
  - APU
  - Shore-power
  - Base engine and APU
  - Base engine and shore-power
  - Nothing (No power is used)

(2) Data Analysis
- Quality assurance
- Estimate stop activity
- Quantify number of stops and the time for different stop scenarios within specific stop duration ranges

Study Methodology (Continued)

(3) Fuel Use Rates and Emission Factors
- Fuel Use Rates
  - Base engine: ECU data
    (Field truck data vary depending on ambient temperature)
  - APU: function of electrical load
- Emission Factors
  - NO, CO, HC and CO2 emissions measured using a portable emission measurement system (PEMS)
  - Fuel-based emission factors
  - PM emission factors were estimated by averaging data from the literature
  - Mass per time emission factors: the product of fuel use rates and fuel-based emission factors
Study Methodology (Continued)

(4) Quantify Avoided Fuel Use and Emissions

Base Engine Scenario versus Actual Scenario

![Graph showing annualized fuel consumption (gal/yr) for Base Engine Scenario and Actual Scenario.]

*The Base Engine Scenario assumes that the base engine is used for all power needs during each stop.

*The Actual Scenario is based on the observed field data during each stop.

Combined Multi-Monthly Route Map for 20 Field Trucks

![Map showing routes for different trucks.]

Location and Duration of a Stop for an Example Truck

Example Truck: Truck No. 2

The driver of Truck No. 2 turned off the base engine and used the APU for 12 hours at a specific location.

Detailed Activity Patterns from An Example Truck

Number of Stops versus Stop Duration (Truck No. 1: 9/6/06-2/29/08)

Percentage of Stop Time for Scenarios for Field Trucks

![Bar chart showing percentage of time for different scenarios.]

Results of Portable Emission Measurement System Tests of Base and APU Engines

Fuel Use Rate and Emission Factors for the Base and APU Engines

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Fuel Use (g/hr)</th>
<th>NO (g/hr)</th>
<th>HC (g/hr)</th>
<th>CO (g/hr)</th>
<th>CO2 (kg/hr)</th>
<th>PM (g/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>0.45</td>
<td>0.52</td>
<td>2.7</td>
<td>12.8</td>
<td>4.6</td>
<td>1.4</td>
</tr>
<tr>
<td>APU-A</td>
<td>0.22</td>
<td>0.49</td>
<td>1.4</td>
<td>7.6</td>
<td>2.2</td>
<td>1.3</td>
</tr>
<tr>
<td>APU-B</td>
<td>0.45</td>
<td>0.61</td>
<td>1.0</td>
<td>7.3</td>
<td>2.3</td>
<td>0.7</td>
</tr>
</tbody>
</table>
**Conclusions and Recommendations**

- New methods have been developed for analyzing field data and quantifying avoided fuel use and emissions
- Trucks with single drivers have significantly more and longer stops than trucks with team drivers
- The total idling time for rest stops is less than typically estimated
- Driver preference for APU versus base engine varies
- APUs are used for both short and long duration stops
- Six trucks have 25 hours or more of activity in which the base engine and APU are operating simultaneously, which increases fuel use and emissions

**Conclusions and Recommendations (Continued)**

- Fuel use rates and emission rates of NO\textsubscript{x}, HC and CO\textsubscript{2} for the APUs are generally lower than those for the base engine, but the comparison of CO and PM emission rates is situation-specific
- Avoided annual average fuel use and CO\textsubscript{2} emissions for all stops are 24 and 6 percent for Fleets A and B, respectively, which are significantly lower than literature estimates of 50 to 80 percent
- Avoided annual average NO emissions for all stops are 46 and 14 percent for Fleets A and B, respectively, which are significantly lower than literature estimates of 70 to 90 percent

**Conclusions and Recommendations (Continued)**

- The differences in real world versus previously estimated avoided fuel use and emissions is because of differences in fuel use rates and emissions factors, and lower idle reduction activity
- Assess the cost effectiveness of idle reduction using APUs
- Apply similar methodology to assess other idle reduction scenarios, such as shore power
- More detailed analysis of avoided emissions as a function of stop duration, location, and ambient condition

**Acknowledgement/Disclaimer**

- This project is sponsored by the U.S. Environmental Protection Agency’s SmartWay\textsuperscript{TM} Mobile Idle Reduction Technology (MIRT) program
- The project partners include Volvo Technology of America, Volvo Trucks North America, the Department of Civil, Construction, and Environmental Engineering of North Carolina State University and the North Carolina Solar Center
- Anne Tazewell of the NC Solar Center is the overall project director. The authors are grateful to Skip Yeakel, George Bitar, Mike Siebert, Randy Peck, and Bill Kordaski of Volvo for their contributions to the APU prep kit and data acquisition tasks
- The authors are responsible for the facts and accuracy of the data presented herein
- The contents do not necessarily reflect the official views or policies of U.S. Environmental Protection Agency
Backup Slides

**Auxiliary Power Units**

- Auxiliary power units (APUs):
  - Small diesel engine-generator
  - Power for electrical air conditioning, heating, and auxiliary loads

*Source: Mechtron Power Systems*

http://www.ccslightning.com/

**Categorization of Stop Scenarios**

<table>
<thead>
<tr>
<th>Start</th>
<th>[\text{Read the Original Data}]</th>
</tr>
</thead>
</table>
| No | \[\text{Scenario 1:} \text{Base Engine on?} \text{Yes} \]
| Yes | \[\text{Scenario 2:} \text{APU & Base Engine on?} \text{Yes} \] |
| \[\text{Scenario 3:} \text{APU on?} \text{Yes} \] | \[\text{Scenario 4:} \text{SP on?} \text{Yes} \] |
| \[\text{Scenario 5:} \text{SP & Base Engine on?} \text{Yes} \] | \[\text{Scenario 6:} \text{Off-Board IdleAire Use?} \text{Yes} \] |
| \[\text{Scenario 7:} \text{No Power} \text{Yes} \] | \[\text{Scenario 8:} \text{No Engine IdleAire Location?} \text{Yes} \] |

**Note:**
- APU = Auxiliary power units
- SP = On-board truck stop electrification system
- Off-board = Off-board truck stop electrification system
- IdleAire = An example of an off-board system
- No Power = Truck ignition key off, no anti-idling system

**Analyze Truck Stop Activity Patterns**

**Multi-Monthly Route Map for an Example Truck**

**Example Truck:** Truck No. 11

**Per-Stop Location for an Example Truck**

**Example Truck:** Truck No. 1
Avoided Fuel Use and Emissions from the Base and APU Engines (Continued)

<table>
<thead>
<tr>
<th></th>
<th>Avoided Fuel Use (%)</th>
<th>Avoided NO Emission (%)</th>
<th>Avoided HC Emission (%)</th>
<th>Avoided CO Emission (%)</th>
<th>Avoided CO2 Emission (%)</th>
<th>Avoided PM Emission (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Fleet A</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>24</td>
<td>46</td>
<td>31</td>
<td>6</td>
<td>24</td>
<td>12</td>
</tr>
<tr>
<td>Range</td>
<td>6.5-37.8</td>
<td>10.2-64.5</td>
<td>7.3-46.0</td>
<td>-20.0-38.9</td>
<td>6.5-37.8</td>
<td>3.7-21.2</td>
</tr>
<tr>
<td><strong>Fleet B</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average</td>
<td>6</td>
<td>14</td>
<td>8</td>
<td>2</td>
<td>6</td>
<td>2</td>
</tr>
<tr>
<td>Range</td>
<td>-0.4-27.3</td>
<td>0.3-51.9</td>
<td>-0.33.5</td>
<td>-12.1-16.1</td>
<td>-0.4-27.1</td>
<td>-11.3-16</td>
</tr>
</tbody>
</table>

Note: All estimates are in the annualized basis
1 kWh of end-use electricity = 0.0779 gallon of diesel equivalent

- 1 kWh of end-use electricity = 10,806 BTU of primary energy consumed to generate electricity
  - 1 kWh = 3,412 BTU
  - Primary energy consumed to generate electricity is 3.167 times of end-use electricity in 2006 in the US (EIA, 2007)
- 1 gallon of diesel fuel = 138,690 BTU