Toward More Realistic Estimation of Energy Consumption with General Transit Feed Specification and National Elevation Dataset

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Introduction

• The Challenge
  – Adoption of Clean, Green Energy for Transit
  – Provide transit services with
    • Reducing greenhouse gas emissions
    • Reducing energy use
  – Difficulty in accurately measuring energy use and GHG emissions
• An energy use measure could be a surrogate for measuring GHG emissions
• Estimation of energy use in vehicle operations
Tractive Demand

- Tractive energy and power demand
  - To make a vehicle travelling
  - Independent from powertrain configurations

- A general form:

\[
P_t = (mgC_{RR} \cos \varphi + 0.5 \rho C_D A_F v^2 + mr \Delta v + mgsin\varphi)v
\]

where

- \(P_t\): average tractive power demand (watts);
- \(m\): vehicle mass (kg);
- \(g\): gravitational constant (9.81 m/s^2);
- \(v\): average speed (m/s);
- \(r\): rotational inertia compensation factor;
- \(C_{RR}\): tire rolling resistance coefficient;
- \(\rho\): density of air (kg/m^3);
- \(C_D\): drag coefficient;
- \(A_F\): projected front area (m^2);
- \(\varphi\): road gradient.
Example of the Impact

Difference in Tractive Demand Estimation due to Grade

\[ m: 16783 \, \text{kg} \, (37000 \, \text{lb}); \]
\[ v: 6.71 \, \text{m/s} \, (15 \, \text{mph}); \]
\[ \Delta v: 0.89 \, \text{m/s} \, (2 \, \text{mph}); \]
\[ r: 1.3; \]
\[ C_{RR}: 0.006; \]
\[ \rho: 1.2041 \, \text{kg/m}^3; \]
\[ C_D: 0.85; \]
\[ A_F: 6.9 \, \text{m}^2. \]
Example of the Impact (cont’d)

Difference in Tractive Demand Estimation due to Grade

Difference in Tractive Demand Estimation due to Grade

<table>
<thead>
<tr>
<th>Road Grade (%)</th>
<th>Difference (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>14.96%</td>
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<tr>
<td>1</td>
<td>29.92%</td>
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<tr>
<td>2</td>
<td>44.87%</td>
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<td>3</td>
<td>59.81%</td>
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<td>4</td>
<td>74.72%</td>
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<td>5</td>
<td>89.61%</td>
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<td>6</td>
<td>104.48%</td>
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<td>7</td>
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<td>8</td>
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</tbody>
</table>

m: 16783 kg (37000 lb); 
\(v\): 6.71 m/s (15 mph); 
\(\Delta v\): 0.45 m/s (1 mph); 
\(r\): 1.3; 
\(C_{RR}\): 0.006; 
\(\rho\): 1.2041 kg/m\(^3\); 
\(C_D\): 0.85; 
\(A_F\): 6.9 m\(^2\).
Estimating Road Grades from

- **Elevation**
  - consistency is the key

- **GPS devices**
  - altitude error is always worse than the position error

- **Light detection and ranging (LIDAR) devices**
  - typical absolute accuracies range from 10 to 30 centimeters

- **National elevation dataset (NED)**

Source: NOAA Coastal Services Center
National Elevation Dataset (NED)

- NED is a seamless product updated bimonthly to incorporate the best available Digital Elevation Model (DEM).
- NED is available in spatial resolutions of 1 arc-second (roughly 30 meters), 1/3 arc-second (roughly 10 meters), and 1/9 arc-second (roughly 3 meters).
- The most recently published figure of overall absolute vertical accuracy expressed as the root mean square error (RMSE) is 2.44 meters.
Using NED for Road Grade Estimation

- Road grade estimation
  - Locations along routes
  - General Transit Feed Specification (GTFS) feeds
  - Elevation changes

- Application programming interfaces (APIs) are available
  - USGS Elevation Query Web Service
  - Make the requests with SOAP, HTTP GET, or HTTP POST

Source: U.S. Geological Survey
http://ned.usgs.gov/images/nedus2.gif
Data Wanted from a General Transit Feed Specification (GTFS) Feed

- agency.txt
- stops.txt
- routes.txt
- trips.txt
- stop_times.txt
- calendar.txt
- calendar_dates.txt
- fare_attributes.txt
- fare_rules.txt
- shapes.txt
- frequencies.txt
- transfers.txt
- feed_info.txt
### Example of Application

- **Load-based GHG emission estimation**
  - to estimate emissions as a function of engine-load
  - using a surrogate known as scaled tractive power (STP)
  - levels of roughness representing the impact of grade on operating loads

<table>
<thead>
<tr>
<th>USER INPUT</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
<th>I</th>
<th>J</th>
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<td>1. Scenario Settings</td>
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<td>Season Scenario</td>
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<td>Avg. Temperature (°F)</td>
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<td>Relative Humidity (%)</td>
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<td>Average Speed (mph)</td>
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<td>Hours in Operation per Bus per Run</td>
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<td>Plug-in Hybrid Vehicles</td>
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<td>Fuel Type</td>
<td>Conventional Diesel</td>
<td>Compressed Natural Gas (CNG)</td>
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<td>Hydrogen</td>
<td>Hydrogen</td>
<td>Conventional Diesel</td>
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</table>
Limitation of the Approach

• Natural vs. engineered geographic features
  – Most, but not all, highway facilities align to terrain
    e.g. cut and fill sections, bridges, tunnels, and overpass

• Post processing of road grade may be required
  – Based on factors of highway geometric design
Alternatives of NED

• Shuttle Radar Topography Mission (SRTM)
  – For use with a Geographic Information System (GIS) or other special application software
  – Available at the US Geological Survey's EROS Data Center

• The Google Elevation API
  – The service will interpolate and return an averaged value using the four nearest locations when Google does not possess exact elevation measurements.
  – Elevation data for locations and paths
  – Usage limits
    • 2,500 requests per day; 512 locations per request; 25,000 total locations per day.
Conclusion and Recommendation

• More realistic estimation of energy consumption for transit operations
  – Road grade has to be considered

• Road grades can be estimated with
  – NED and GTFS

• Post processing of road grade estimation based on NED may be required