BATTERY ELECTRIC VEHICLE (BEV) RANGE ESTIMATION TOOL

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**Project Background**

- With multiple new BE powertrains under development, there is an urgent need to optimize component sizing and select the right configuration for different real-world vehicle applications.
- Accurate estimation of the range of a BEV based on different configurations is critical for the successful adoption and integration of electric vehicles into our daily lives.
- It is also important to have a graphical user interface in place due to the necessity of data visualization and interactivity.

![Kenworth K270E/K370E Battery Electric Trucks](image)

**Common Digital Dashboard Display of Range Estimation on Electric Vehicles**

**Energy Consumption Prediction**

- According to last year's capstone project sponsored by PACCAR, an equation obtained from machine learning model has been proposed to predict energy consumption of vehicles.

\[ P_{\text{read}} = \frac{1}{2} \cdot \rho \cdot C_d \cdot F_A \cdot v^3 + R R G \cdot M_{\text{veh}} \cdot g \cdot v + M_{\text{veh}} \cdot \frac{dv}{dt} + M_{\text{veh}} \cdot g \cdot \Delta h / \text{dt} \]

<table>
<thead>
<tr>
<th>Terms</th>
<th>Coefficients</th>
<th>Estimated Coefficient</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air resistance</td>
<td>-</td>
<td>0.5</td>
<td>kg/m²</td>
</tr>
<tr>
<td>Coefficient (Cd)</td>
<td>Frontal Arma (F/A)</td>
<td>0.67</td>
<td>m/s²</td>
</tr>
<tr>
<td>Rolling resistance</td>
<td>Rolling coefficient (RRCO) Mass of vehicle (M_on)</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Mass of vehicle (M_on)</td>
<td>0.08</td>
<td>g/m³</td>
</tr>
<tr>
<td></td>
<td>grav(tg)</td>
<td></td>
<td>1379 kg/m³</td>
</tr>
<tr>
<td></td>
<td>Mass of vehicle (M_on)</td>
<td>0.08</td>
<td>m³</td>
</tr>
<tr>
<td></td>
<td>grav(tg)</td>
<td></td>
<td>3.6</td>
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<tr>
<td></td>
<td>Mass of vehicle (M_on)</td>
<td>0.08</td>
<td>%</td>
</tr>
<tr>
<td></td>
<td>grav(tg)</td>
<td></td>
<td>0.0068</td>
</tr>
</tbody>
</table>

**Algorithm Workflow**

1. Fetch segment parameters based on route, including distance (km), number of stops, and road slope.
2. Iterate through each segment and calculates energy consumption based on:
   - Grade resistance for each segment based on the slope and total weight.
   - Total tractive force as a sum of rolling resistance, aerodynamic drag, and grade resistance.
3. Power for propulsion in each segment.
4. Energy consumption for each segment based on power required and time spent.
5. Energy consumption during stops in each segment.
6. Energy recovery due to regenerative braking in each segment.
7. Sum up total net energy consumption.
8. Divide battery capacity to get range ratio.
9. Calculate total range distance by multiplying total route distance.

**Range Estimation Equation**

Based on the model developed last year, we further developed range estimation equation as shown:

- \( F_{\text{rolling}} = C_{rr} \cdot M_{\text{total}} \cdot g \)
- \( F_{\text{air}} = \frac{1}{2} \cdot C_d \cdot A_{\text{frontal}} \cdot \rho \cdot v^2 \)
- \( F_{\text{grade}} = M_{\text{total}} \cdot g \cdot \sin(\text{angle}) \)

\[ P_{\text{required}} = (F_{\text{rolling}} + F_{\text{air}} + F_{\text{grade}}) \cdot v_{\text{route}} / 100 \]

\[ E_{\text{stop}} = E_{\text{stop}} + \text{Stop} \]

\[ E_{\text{recovery}} = E_{\text{stop}} + \text{Braking} \]

\[ E_{\text{net}} = \sum P_{\text{required}} \cdot t_{\text{rolling}} + E_{\text{stop}} - E_{\text{recovery}} \]

\[ R_{\text{range}} = \frac{C_{\text{battery}}}{E_{\text{net}}} \]

\[ E_{\text{perhour}} = E_{\text{net}} / \text{Total} \]

\[ S_{\text{trucked}} = S_{\text{total}} / \text{times} \]

**Graphical User Interface Design & Implementation**

- The algorithm for range estimation is programmed as a Python script and a `Tinter` (Python’s de facto toolkit) based GUI was developed to generate route data through Google Map API and formulated it into data files for the use of range calculation.
- The Python programs are considered as the calculator engine.
- In the next steps, we developed the HTML version of it for potential web hosting to enhance the accessibility of the tool.

https://faculty.washington.edu/dblaning/bev_paccar/bev_paccar_range_estimator.html

**Future Work and Acknowledgments**

For future work, we have several directions in mind to improve this range estimation tool.

**Testing & Algorithm Validation:** With real-world collected data, we can test and improve our existing algorithm to make it more accurate. For instance, in our current algorithm, the stationary time is set to a constant value. However, we believe that there should be a better way to calculate live stationary time as the driver is operating the vehicle.

**GUI Upgrade:** Due to the time limitation of the project, the GUI implemented is quite naive. At the beginning of this project, we proposed conceptual React based GUI sketches with integrated functionality design as follow. We plan to implement the React based GUI and migrate the current calculator engine to it for better usability, responsive design and platform independence.

Sincere thanks to our industry mentor, Nick Hertlein and faculty mentor, Prof. David B Laning for their invaluable guidance. Also, thanks to PACCAR INC, University of Washington and ECE department for the supportive learning environment.

**Test & Verification**

<table>
<thead>
<tr>
<th>Speed (mph)</th>
<th>5 mph</th>
<th>10 mph</th>
<th>25 mph</th>
<th>35 mph</th>
<th>40 mph</th>
<th>60 mph</th>
<th>75 mph</th>
<th>95 mph</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy</td>
<td>92.251%</td>
<td>97.742%</td>
<td>97.963%</td>
<td>95.092%</td>
<td>97.115%</td>
<td>92.251%</td>
<td>95.253%</td>
<td></td>
</tr>
</tbody>
</table>

The average testing accuracy of the model on real-world datasets provided by PACCAR is 76.85%. We can see that our model performs well in low and high-speed scenarios.