Background

- Travel time reliability represents the level of consistency in travel times for the same trip for a time period. (Lomax et al. 2003)

- Most travel time reliability studies that apply GPS data are based on travel time observations retrieved from GPS data.
  - The major challenge to using GPS data is low reading frequency.

- A recently introduced GPS spot speed based reliability metric that uses speed distribution does not provide a numerical value which would allow for a quantitative evaluation.
Research Objectives

- Improve the current GPS spot speed distribution based approach to measure truck travel time reliability.
- Compare the improved measure with a number of commonly used reliability measures.
Truck Travel Time Reliability Measures

- Two types of truck travel time reliability measures (according to the data on which these approaches are based):
  - Travel time based reliability measures
  - GPS spot speed based reliability measures
Travel Time Based Reliability Measures

- Standard deviation and coefficient of variation (COV)
- Percentile method
  - The 95\textsuperscript{th} percentile travel time (also called planning time) was recommended by USDOT.
  - The SHRP 2 (Second Strategic Highway Research Program) recommended using 80\textsuperscript{th} percentile travel time since they found that events that contribute to the 80\textsuperscript{th} percentile travel time are more common events and are more likely to be influenced by operation strategies.
- Buffer Time Index (BI)
  - Buffer time: the extra travel time must add to the mean travel time to allow for on-time arrival.
  - Buffer time index = buffer time/mean travel time
Travel Time Based Reliability Measures

- **Skew**
  - Depicts the “leaning” of travel time distribution to one side of the mean.
  
  \[ Skew = \frac{T_{90} - T_{50}}{T_{50} - T_{10}} \]

- **Truck Reliability Index (RI_{80})**
  - Recommended by The American Association of State Highway and Transportation Officials (AASHTO) for the MAP-21 Program.
  - It is defined as the ratio of the total truck travel time needed to ensure on time arrival (e.g. 80\(^{th}\) percentile travel time) to the agency-determined congestion threshold travel time (e.g. 60\% of posted speed).
Limitations of Travel Time Based Methods

• Constraint of number of observations

  Sufficient travel time observations is required to ensure the estimated travel time can represent the link travel time with reasonable accuracy.

• The minimum number of travel time observations (NCHRP 2008)

\[
N = 4 \times \left[ t_{(1-\alpha/2), N-1} \times \frac{S}{CI_{1-\alpha\%}} \right]^2
\]

\( CI_{1-\alpha\%} = \) confidence interval for the true mean with probability of \((1-\alpha)\%\),

\( t_{(1-\alpha/2), N-1} = \) the t statistic for the probability of two-sided error summing to alpha with \(N-1\) degrees of freedom,

\( S = \) the standard deviation in the measured travel times.
Limitations of Travel Time Based Methods

- Loss of data accuracy
- The conversion from GPS spot speed to travel time estimates for a particular segment involves data processing and therefore may cause a loss of data accuracy.
The bimodal approach (Zhao et al. 2013)

- Truck GPS spot speed distribution follows a mixture of two Gaussian distributions.
- Travel time is unreliable if a bimodal distribution is observed. Otherwise (a unimodal distribution), travel time is reliable.

Limitation
- It does not provide a numerical value which would allow for a more quantitative evaluation.
Improved Approach

- Coefficient of variation

\[ \mu = \sum_{i=1}^{n} w_i \mu_i \]

\[ \sigma^2 = \sum_{i=1}^{n} w_i ((\mu_i - \mu)^2 + \sigma_i^2) \]

Coefficient of Variation (COV) = \( \frac{\sigma}{\mu} \)

where \( \mu = \) mean of the mixture of Gaussian distributions,
\( w_i = \) weight of the \( i \)th Gaussian distribution,
\( \mu_i = \) mean of the \( i \)th Gaussian distribution,
\( \sigma = \) standard deviation of the mixture of Gaussian distributions,
\( \sigma_i = \) standard deviation of the \( i \)th Gaussian distribution,
\( n = \) number of Gaussian distributions, \( n = 2 \).
Case Study

- Four segments
  - Segment 1 and Segment 2: the stretch of 9 miles of eastbound and westbound of Interstate 90 (I-90) near Spokane, WA.
  - Segment 3 and Segment 4: the stretch of 3.5 miles of southbound and northbound of Interstate 5 (I-5) near downtown Seattle, WA.

- The distribution fitting was accomplished using the R software package “mixdist” (Du 2002)
### Segment 1
- Reliably fast
- Mean: 62.43
- Standard deviation: 8.04
- COV: 0.13
- Reliability Ranking: 4

### Segment 2
- Reliably fast
- Mean: 62.00
- Standard deviation: 8.48
- COV: 0.14
- Reliability Ranking: 3

### Segment 3
- Unreliable
- Mean: 37.70
- Standard deviation: 17.97
- COV: 0.48
- Reliability Ranking: 2

### Segment 4
- Unreliable
- Mean: 34.35
- Standard deviation: 18.95
- COV: 0.55
- Reliability Ranking: 1
## Reliability Measures Comparison

- **Study area**
  - A stretch of 3.5 miles of southbound Interstate 5 (I-5) through downtown Seattle

- **Ranking results**

  Reliability Ranking Results during Off-peak Period (12:00 AM – 6:00 AM)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mon</th>
<th>Tue</th>
<th>Wed</th>
<th>Thu</th>
<th>Fri</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV</td>
<td>2</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>BI</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Skew</td>
<td>3</td>
<td>5</td>
<td>4</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>RI_{80}</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>Improved GPS spot speed based method</td>
<td>3</td>
<td>5</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
</tbody>
</table>

Reliability Ranking Results during AM Peak Period (6:00 AM – 9:00 AM)

<table>
<thead>
<tr>
<th>Measures</th>
<th>Mon</th>
<th>Tue</th>
<th>Wed</th>
<th>Thu</th>
<th>Fri</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV</td>
<td>1</td>
<td>4</td>
<td>2</td>
<td>3</td>
<td>5</td>
</tr>
<tr>
<td>BI</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Skew</td>
<td>1</td>
<td>4</td>
<td>5</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>RI_{80}</td>
<td>4</td>
<td>3</td>
<td>2</td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>Improved GPS spot speed based method</td>
<td>4</td>
<td>2</td>
<td>1</td>
<td>3</td>
<td>5</td>
</tr>
</tbody>
</table>
Correlations among Travel Time Reliability Measures

### Correlations among Reliability Measures during Off-peak Period

<table>
<thead>
<tr>
<th></th>
<th>COV</th>
<th>BI</th>
<th>Skew</th>
<th>RI_{80}</th>
<th>Improved GPS Spot Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BI</td>
<td>0.639</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skew</td>
<td>0.666</td>
<td>0.408</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RI_{80}</td>
<td>0.695</td>
<td>0.735</td>
<td>0.446</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Improved GPS spot speed</td>
<td>0.556</td>
<td>0.433</td>
<td>0.420</td>
<td>0.769</td>
<td>1.000</td>
</tr>
</tbody>
</table>

### Correlations among Reliability Measures during AM Peak Period

<table>
<thead>
<tr>
<th></th>
<th>COV</th>
<th>BI</th>
<th>Skew</th>
<th>RI_{80}</th>
<th>Improved GPS Spot Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>COV</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>BI</td>
<td>0.679</td>
<td>1.000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skew</td>
<td>0.471</td>
<td>0.418</td>
<td>1.000</td>
<td></td>
<td></td>
</tr>
<tr>
<td>RI_{80}</td>
<td>0.508</td>
<td>0.595</td>
<td>0.135</td>
<td>1.000</td>
<td></td>
</tr>
<tr>
<td>Improved GPS spot speed</td>
<td>0.322</td>
<td>0.196</td>
<td>-0.223</td>
<td>0.821</td>
<td>1.000</td>
</tr>
</tbody>
</table>
Findings

- The improved GPS spot speed based reliability measure is able to provide numerical values which allows for quantitative analyses.
- Ranking of travel time reliability bottlenecks varies depending on the reliability measures used. Different measures may get different conclusions for the same underlying data.
- There are large deviations among reliability measures.
Future Research

- Provide recommendations on which measures are most appropriate for different applications.