Evaluation of Technologies for Travel Time Estimation

September 10, 2009

Present to
New Jersey Department of Transportation
Evaluation of Technologies for Travel Time Estimation

Agenda

- Introduction
- Work Scope
- Travel Time Data Analysis and Comparison (INRIX/Bluetooth vs. Co-Pilot)
- Travel Time Data Analysis and Comparison (TRANSMIT vs. Co-Pilot)
- Impacts of Incidents on Travel Time
- Conclusions
Technologies for Travel Time Estimation

- INRIX
- Bluetooth Sensors
- TRANSMIT Readers
- Co-Pilot Devices
Work Scope

- Evaluate the accuracy of technologies (TRANSMIT, Bluetooth, and INRIX) for travel time estimation

- Collect the ground truth travel times by probe vehicles carrying Co-pilot devices

- Process data and analyze results

- Recommendations
Evaluation of Technologies for Travel Time Estimation

Study Segment with TRANSMIT Readers

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Study Segment with Bluetooth Sensors

LINK 1
LINK 2
LINK 3
LINK 4
## Data Availability

<table>
<thead>
<tr>
<th>TMC</th>
<th>Highway</th>
<th>Dates</th>
</tr>
</thead>
<tbody>
<tr>
<td>120+04400</td>
<td>I - 78</td>
<td>✓</td>
</tr>
<tr>
<td>120+04470</td>
<td>I - 287</td>
<td>✓</td>
</tr>
<tr>
<td>120+04473</td>
<td>I - 287</td>
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</tr>
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<td>120+04476</td>
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<td>✓</td>
</tr>
<tr>
<td>120+04479</td>
<td>I - 287</td>
<td>✓</td>
</tr>
<tr>
<td>120-04469</td>
<td>I - 287</td>
<td>✓</td>
</tr>
<tr>
<td>120-04472</td>
<td>I - 287</td>
<td>✓</td>
</tr>
<tr>
<td>120-04475</td>
<td>I - 287</td>
<td>✓</td>
</tr>
<tr>
<td>120-04478</td>
<td>I - 287</td>
<td>✓</td>
</tr>
</tbody>
</table>

*: Yellow colored cells represent that Co-Pilot data is available
✓: Available Bluetooth Data by TMC
TRANSMIT: 24-7 on the study I-287 segment
Travel Time Analysis and Comparison (INRIX/Bluetooth Data vs. Co-Pilot Data)
Evaluation of Technologies for Travel Time Estimation

**Link 1 on I-287 N (04/09/09), Scenario I**

![Graph showing speed vs. time for Link 1 on I-287 N (04/09/09)]

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot

**TIME (hh:mm)**
- 7:00
- 7:15
- 7:30
- 7:45
- 8:00
- 8:15
- 8:30
- 8:45
- 9:00
- 9:15
- 9:30
- 9:45
- 10:00
- 10:15
- 10:30
- 10:45
- 11:00

**SPEED (MPH)**
- 0
- 10
- 20
- 30
- 40
- 50
- 60
- 70
- 80

**Legend:**
- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot

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Link 1 on I-287 S (04/09/09), Scenario I

Speed vs. Time on Link 1, I-287 S (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot
Evaluation of Technologies for Travel Time Estimation

Link 2 on I-287 N (04/09/09), Scenario I

Speed vs. Time on Link 2, I-287 N (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot

TIME (hh:mm) vs. SPEED (MPH)
Link 2 on I-287 S (04/09/09), Scenario 1

![Speed vs. Time on Link 2, I-287 S (04/09/2009)](image)

- **Bluetooth Mean**
- **Bluetooth Mean with +std**
- **Bluetooth Mean with -std**
- **INRIX Mean**
- **Co-Pilot**

**TIME (hh:mm)**: 7:00, 7:15, 7:30, 7:45, 8:00, 8:15, 8:30, 8:45, 9:00, 9:15, 9:30, 9:45, 10:00, 10:15, 10:30, 10:45, 11:00

**SPEED (MPH)**: 0, 10, 20, 30, 40, 50, 60, 70, 80

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Evaluation of Technologies for Travel Time Estimation
Evaluation of Technologies for Travel Time Estimation

Link 3 on I-287 N (04/09/09), Scenario I

Speed vs. Time on Link 3, I-287 N (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot

TIME (hh:mm)
Evaluation of Technologies for Travel Time Estimation

Link 3 on I-287 S (04/09/09), Scenario I

Speed vs. Time on Link 3, I-287 S (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot
Evaluation of Technologies for Travel Time Estimation

Link 4 on I-287 N (04/09/09), Scenario I

Speed vs. Time on Link 4, I-287 N (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot

TIME (hh:mm)

SPEED (MPH)
Evaluation of Technologies for Travel Time Estimation

Link 4 on I-287 S (04/09/09), Scenario I

Speed vs. Time on Link 4, I-287 S (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot
The standard error of the mean (SEM)

$$\sigma_{\text{SEM}} = \frac{\sigma}{\sqrt{N}}$$

where

$$\sigma = \sqrt{\frac{\sum_{i=1}^{N} (e_i - \bar{e}_i)^2}{N - 1}}$$

and

$$\bar{e}_i = \frac{1}{N} \sum_{t=1}^{N} e_t , \quad e_t = v_t - c_i .$$

The average absolute speed error (AASE)

$$e_{\text{AASE}} = \frac{1}{N} \sum_{t=1}^{N} |e_t|$$

The speed error bias (SEB)

$$e_{\text{SEB}} = \frac{1}{N} \sum_{t=1}^{N} e_t$$
# Bluetooth/INRIX vs Co-Pilot Data
*(Scenario I)*

<table>
<thead>
<tr>
<th>Link No.</th>
<th>Device</th>
<th>SEM (MPH)</th>
<th>AASE (MPH)</th>
<th>SEB (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>S</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>Bluetooth</td>
<td>1.26</td>
<td>1.02</td>
<td>4.60</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>1.53</td>
<td>1.18</td>
<td>6.58</td>
</tr>
<tr>
<td>2</td>
<td>Bluetooth</td>
<td>1.16</td>
<td>1.16</td>
<td>4.55</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>1.60</td>
<td>1.08</td>
<td>6.15</td>
</tr>
<tr>
<td>3</td>
<td>Bluetooth</td>
<td>3.43</td>
<td>1.38</td>
<td>10.09</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>3.81</td>
<td>1.29</td>
<td>12.99</td>
</tr>
<tr>
<td>4</td>
<td>Bluetooth</td>
<td>1.26</td>
<td>1.52</td>
<td>5.09</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>1.11</td>
<td>1.25</td>
<td>6.42</td>
</tr>
<tr>
<td>ALL</td>
<td>Bluetooth</td>
<td>0.62</td>
<td>5.51</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>0.69</td>
<td>6.69</td>
<td>-2.70</td>
</tr>
</tbody>
</table>
Definitions of INRIX/Bluetooth Data

- **Scenario I**: Number of vehicles traversing a link within an interval *after* the time point reporting the average speed (e.g., 8:00 AM represents 8:00 AM ~ 8:15 AM)

- **Scenario II**: Number of vehicles traversing a link within an interval *before* the time point reporting the average speed (e.g., 8:00 AM represents 7:45 AM ~ 8:00 AM)
Evaluation of Technologies for Travel Time Estimation

Link 3 on I-287 N (04/09/09), Scenario I

Speed vs. Time on Link 3, I-287 N (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot

TIME (hh:mm)

SPEED (MPH)
Evaluation of Technologies for Travel Time Estimation

Link 3 on I-287 N (04/09/09), Scenario II

Speed vs. Time on Link 3, I-287 N (04/09/2009)

- Bluetooth Mean
- Bluetooth Mean with +std
- Bluetooth Mean with -std
- INRIX Mean
- Co-Pilot
## Bluetooth/INRIX vs Co-Pilot Data (Scenario II)

<table>
<thead>
<tr>
<th>Link No.</th>
<th>Device</th>
<th>SEM (MPH)</th>
<th>AASE (MPH)</th>
<th>SEB (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>S</td>
<td>N</td>
</tr>
<tr>
<td>1</td>
<td>Bluetooth</td>
<td>1.16</td>
<td>1.04</td>
<td>4.35</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>1.46</td>
<td>1.28</td>
<td>6.78</td>
</tr>
<tr>
<td>2</td>
<td>Bluetooth</td>
<td>1.25</td>
<td>1.16</td>
<td>5.25</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>1.49</td>
<td>1.02</td>
<td>5.98</td>
</tr>
<tr>
<td>3</td>
<td>Bluetooth</td>
<td>1.64</td>
<td>1.28</td>
<td>4.92</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>3.49</td>
<td>1.18</td>
<td>11.22</td>
</tr>
<tr>
<td>4</td>
<td>Bluetooth</td>
<td>1.13</td>
<td>1.39</td>
<td>4.15</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td>1.11</td>
<td>1.33</td>
<td>6.70</td>
</tr>
<tr>
<td><strong>ALL</strong></td>
<td>Bluetooth</td>
<td><strong>0.46</strong> (0.62*)</td>
<td>4.65 (5.51*)</td>
<td><strong>0.32</strong> (0.39*)</td>
</tr>
<tr>
<td></td>
<td>INRIX</td>
<td><strong>0.66</strong> (0.69*)</td>
<td>6.52 (6.69*)</td>
<td>-2.84 (-2.70*)</td>
</tr>
</tbody>
</table>

* Results of Scenario I
Analysis of Travel Time and Comparison
(TRANSMIT Data vs. Co-Pilot Data)
Evaluation of Technologies for Travel Time Estimation

Link 1 on I-287 N (04/09/09)

Speed vs. Time on Link 1, I-287 N (04/09/2009)

TRANSMIT
Co-Pilot

SPEED (MPH)
TIME (hh:mm)

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Link 1 on I-287 S (04/09/09)

Speed vs. Time on Link 1, I-287 S (04/09/2009)

SPEED (MPH)

TIME (hh:mm)

TRANSMIT
Co-Pilot
Link 2 on I-287 N (04/09/09)

Speed vs. Time on Link 2, I-287 N (04/09/2009)
Link 3 on I-287 N (04/09/09)

Speed vs. Time on Link 3, I-287 N (04/09/2009)

- TRANSMIT
- Co-Pilot
Link 3 on I-287 S (04/09/09)
Evaluation of Technologies for Travel Time Estimation

Link 4 on I-287 S (04/09/09)

Speed vs. Time on Link 4, I-287 S (04/09/2009)

TIME (hh:mm)
0
10
20
30
40
50
60
70
80

SPEED (MPH)

7:00 7:15 7:30 7:45 8:00 8:15 8:30 8:45 9:00 9:15 9:30 9:45 10:00 10:15 10:30 10:45 11:00

TRANSMIT
Co-Pilot
Link 5 on I-287 N (04/09/09)

Speed vs. Time on Link 5, I-287 N (04/09/2009)

SPEED (MPH)

TIME (hh:mm)

TRANSMIT
Co-Pilot
Link 5 on I-287 S (04/09/09)

Speed vs. Time on Link 5, I-287 S (04/09/2009)

- TRANSMIT
- Co-Pilot
## TRANSMIT Data vs Co-Pilot Data

<table>
<thead>
<tr>
<th>Link No.</th>
<th>Link Length (Miles)</th>
<th>SEM (MPH)</th>
<th>AASE (MPH)</th>
<th>SEB (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>N</td>
<td>S</td>
<td>Both</td>
</tr>
<tr>
<td>1</td>
<td>6.78</td>
<td>1.55</td>
<td>1.97</td>
<td>1.31</td>
</tr>
<tr>
<td>2</td>
<td>5.79</td>
<td>1.43</td>
<td>1.13</td>
<td>0.93</td>
</tr>
<tr>
<td>3</td>
<td>4.16</td>
<td>1.14</td>
<td>0.99</td>
<td>0.75</td>
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<tr>
<td>4</td>
<td>3.78</td>
<td>1.11</td>
<td>1.31</td>
<td>0.85</td>
</tr>
<tr>
<td>5</td>
<td>20.76</td>
<td>1.13</td>
<td>1.13</td>
<td>0.79</td>
</tr>
<tr>
<td>ALL</td>
<td>41.27</td>
<td>0.58</td>
<td>0.69</td>
<td>0.45</td>
</tr>
</tbody>
</table>
### TRANSMIT, Bluetooth, INRIX vs Co-Pilot Data

<table>
<thead>
<tr>
<th>Link No.</th>
<th>Segment Length (Mile)</th>
<th>SEM (MPH)</th>
<th>AASE (MPH)</th>
<th>SEB (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>TRANSMIT</td>
<td>41.27</td>
<td>0.45</td>
<td>4.87</td>
<td>0.78</td>
</tr>
<tr>
<td>Bluetooth</td>
<td>0.46</td>
<td>0.46</td>
<td>4.65</td>
<td>0.32</td>
</tr>
<tr>
<td>INRIX</td>
<td>0.66</td>
<td>0.66</td>
<td>6.52</td>
<td>-2.84</td>
</tr>
</tbody>
</table>
Analysis of Travel Time and Comparison Under Incident Conditions

(TRANSMIT Data vs. Co-Pilot Data)
<table>
<thead>
<tr>
<th>Incident No.</th>
<th>Event Type</th>
<th>Location &amp; Description</th>
<th>Date</th>
<th>Start Time (hh:mm)</th>
<th>End Time (hh:mm)</th>
<th>Duration (hh:mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Disabled vehicle</td>
<td>SB - at Exit 10 - CR 527/Easton Ave. Right lane closed</td>
<td>04/07/09</td>
<td>7:24</td>
<td>7:29</td>
<td>05:00</td>
</tr>
<tr>
<td>2</td>
<td>Accident</td>
<td>NB - at Exit 30 - North Maple Ave. Center lane closed</td>
<td>04/07/09</td>
<td>10:02</td>
<td>10:29</td>
<td>27:00</td>
</tr>
<tr>
<td>3</td>
<td>Accident</td>
<td>SB - at South of Exit 9 - CR 622/River Rd. Left lane closed</td>
<td>4/16/09</td>
<td>9:25</td>
<td>9:34</td>
<td>0:09</td>
</tr>
<tr>
<td>4</td>
<td>Accident</td>
<td>NB - North of Exit 8 – Possum town Rd. Left lane closed</td>
<td>4/16/09</td>
<td>9:51</td>
<td>11:40</td>
<td>1:49</td>
</tr>
</tbody>
</table>
TRANSMIT Readers vs Incident Locations
Travel Distance vs. Time (Link 5, I-287 N, 04/07/09)
Speed vs. Time on Link 5, I-287 N (04/07/2009)

TRANSMIT
Co-Pilot
Travel Distance vs Time (Link 2, I-287 S, 04/07/09)
Speed vs. Time on Link 2, I-287 S (04/07/2009)
Travel Distance vs Time (Link 2, I-287 N 04/16/09)
Travel Distance vs Time (Link 2, I-287 S, 04/16/09)
Link 2 on I-287 S (04/16/09)

Speed vs. Time on Link 2, I-287 S (04/16/2009)

- **TRANSMIT**
- **Co-Pilot**

TIME (hh:mm) vs. SPEED (MPH)
### Comparison of TRANSMIT vs Co-Pilot Data Under Incident Conditions

<table>
<thead>
<tr>
<th>Link No.</th>
<th>Direction</th>
<th>Date</th>
<th>SEM (MPH)</th>
<th>AASE (MPH)</th>
<th>SEB (MPH)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Yes*</td>
<td>No**</td>
<td>Yes*</td>
</tr>
<tr>
<td>2</td>
<td>SB</td>
<td>04/07/09</td>
<td>0.81</td>
<td>1.13</td>
<td>3.34</td>
</tr>
<tr>
<td>2</td>
<td>SB</td>
<td>04/16/09</td>
<td>2.79</td>
<td>8.81</td>
<td>7.67</td>
</tr>
<tr>
<td>5</td>
<td>NB</td>
<td>04/07/09</td>
<td>1.18</td>
<td>1.13</td>
<td>3.55</td>
</tr>
<tr>
<td>2</td>
<td>NB</td>
<td>04/16/09</td>
<td>2.40</td>
<td>1.45</td>
<td>8.37</td>
</tr>
<tr>
<td>ALL</td>
<td></td>
<td></td>
<td>1.12</td>
<td>0.72</td>
<td>6.01</td>
</tr>
</tbody>
</table>

* Incident condition  
** No incident condition
Conclusions

- The accuracy of the INRIX/Bluetooth vs. Co-pilot data and TRANSMIT vs. Co-pilot data were evaluated.
- The travel speed estimated with the Bluetooth sensors is closer to the speeds of vehicle probes compared to the INRIX data.
- The estimated speed with INRIX data seems biased because of negative SEB.
- The INRIX/Bluetooth data with Scenario II definition is better than Scenario I.
- The travel speeds of probe vehicles fitted well on the TRANSMIT data, except on Link1 of I-287 S.
- The link length on I-287 seems not affecting the accuracy of speed estimation with TRANSMIT (04/09/09 Thursday 7 AM to 10 AM).
- TRANSMIT speed estimates were a little more closer to Co-pilot data under regular condition than incident condition.
- Both the data collected by probe vehicles and by TRANSMIT can reveal the change of speed if traffic conditions are influenced by incidents.
Evaluation of Technologies for Travel Time Estimation

Recommended Further Studies

- **INRIX**
  - Potential bias samples: % data from truck fleet – under estimate speed, few data on roadways prohibit trucks, truck biased lane, etc
  - Accuracy between freeways and arterials
  - Closed, parallel roadways
  - Data transmit latency
  - OD vs. TMC based estimation

- **Bluetooth Sensors**
  - Detection rate by lane – location/spacing of sensors
  - Detecting speeds on consecutive links
  - Data latency issues with real-time operation
  - OD vs. TMC based estimation

- **TRANSMIT Readers**
  - Link with/without rest areas
  - Congestion response time
  - OD based travel time estimation