Exploiting Geo-fences to Document Truck Activity Times at the Ambassador and Blue Water Bridge Gateways

Mark R. McCord
The Ohio State University
Columbus, OH

Ohio Freight Conference
Toledo, Ohio
September 15, 2010
Project Team: Consortium for Remote Sensing of Transportation Activities (CRESTA)

– The Ohio State University (Columbus, OH)
– University of Arizona (Tucson, AZ)
– Michigan Tech Research Institute (Ann Arbor, MI)
– Center for Automotive Research (Ann Arbor, MI)
– Arizona State University (Tempe, AZ)
– Skycomp, Inc. (Columbia, MD)
Acknowledgments

• US DOT – Research and Innovative Technologies Adm.: Commercial Remote Sensing and Spatial Information Technology Applications Program

• Matching support from partners

• Tech Exp Advisory Committee & Stakeholders, especially Jim Phillips: GM Corporation
  Ray Cossette, Kirk Pettit: CEVA Logistics
  Michigan DOT - Blue Water Bridge Operations

• CRESTA investigators, especially P. Goel, P. Kapat, C. Brooks, R. Wallace, D.E. Keefauver, H. Dong, M. Hickman

The views, opinions and statements contained in this presentation are solely those of the presenter and do not represent the official policy or position of the Department of Transportation or the Research and Innovative Technology Administration.
Outline

• Activity Times at Border Crossings
• The Geo-Fence Approach
• Setting of Empirical Study
• Geo-fence Implementations
• Illustrative Results
Outline

• Activity Times at Border Crossings
• The Geo-Fence Approach
• Setting of Empirical Study
• Geo-fence Implementations
• Illustrative Results
Documenting Crossing Times at International Gateways

- License plate survey, special equipment, manual surveys, ...
- Labor intensive, expensive, limited observation periods
- This study: use GPS-equipped trucks as samples
- CEVA Logistics and GM
  - Organizes transport of GM automotive parts (and others)
  - Advanced tracking system
  - Large volumes of trucks using the bridges of interest
Documenting Activity Times at International Gateways

• Crossing times are composed of multiple activities: approach on freeways or surface streets, paying tolls, undergoing primary inspection, queuing, visiting duty free facilities, ...

• Documenting the components can lead to a better understanding and allow better modeling of overall crossing times and the important components

• Collecting these data would require multiple sets of roadside sensors or personnel with traditional methods

• The geo-fence approach well-suited to obtain multiple activities

• We respecified and implemented CEVA geo-fences to collect activity time data
Outline

• Activity Times at Border Crossings
• The Geo-Fence Approach
• Setting of Empirical Study
• Geo-fence Implementations
• Illustrative Results
Geo-fence Based Approach

- Geo-fence: electronic polygon encoded into on-board data unit
- GPS-based location triggers a record when truck crosses the fence
- Match records for same truck trip to determine time between locations
- Encode geo-fences to delimit important activities
Example Results: AMB CAN to US Activity Times

<table>
<thead>
<tr>
<th>AMB Crossing Time ON-MI (min) (AU 08 geo-fences)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amb usplaza tollfca</td>
</tr>
<tr>
<td>#</td>
</tr>
<tr>
<td>Median</td>
</tr>
<tr>
<td>90P</td>
</tr>
<tr>
<td>90th-Median</td>
</tr>
</tbody>
</table>
Geo-fence Based Approach

- Uses *existing* hardware and communications systems (OBDU)
- Roadside infrastructure not required (fewer institutional difficulties)
- Geo-fence crossing records included with many other records in overall data set
- Trip chaining and data cleaning required

### CEVA Data Records

<table>
<thead>
<tr>
<th>VEHICLE ID</th>
<th>LON</th>
<th>LAT</th>
<th>DIRECTION</th>
<th>SPEED</th>
<th>STAMP</th>
<th>CITY</th>
<th>STATE</th>
<th>PHONE</th>
<th>SEASON</th>
<th>GENDER</th>
<th>AGE</th>
<th>MEASUREMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEVA123</td>
<td>45</td>
<td>32</td>
<td>North</td>
<td>60</td>
<td>1234</td>
<td>New York</td>
<td>NY</td>
<td>55555</td>
<td>Spring</td>
<td>Male</td>
<td>25</td>
<td>1234567890</td>
</tr>
<tr>
<td>CEVA456</td>
<td>34</td>
<td>56</td>
<td>South</td>
<td>45</td>
<td>6789</td>
<td>Chicago</td>
<td>IL</td>
<td>98765</td>
<td>Summer</td>
<td>Female</td>
<td>30</td>
<td>0987654321</td>
</tr>
<tr>
<td>CEVA789</td>
<td>23</td>
<td>78</td>
<td>West</td>
<td>33</td>
<td>8901</td>
<td>Los Angeles</td>
<td>CA</td>
<td>12345</td>
<td>Fall</td>
<td>Male</td>
<td>40</td>
<td>5432109876</td>
</tr>
<tr>
<td>CEVA213</td>
<td>12</td>
<td>34</td>
<td>East</td>
<td>22</td>
<td>3456</td>
<td>San Francisco</td>
<td>CA</td>
<td>67890</td>
<td>Winter</td>
<td>Female</td>
<td>35</td>
<td>0987654321</td>
</tr>
<tr>
<td>CEVA567</td>
<td>67</td>
<td>56</td>
<td>North</td>
<td>78</td>
<td>6789</td>
<td>Houston</td>
<td>TX</td>
<td>98765</td>
<td>Summer</td>
<td>Male</td>
<td>30</td>
<td>1234567890</td>
</tr>
<tr>
<td>CEVA890</td>
<td>90</td>
<td>89</td>
<td>South</td>
<td>89</td>
<td>7890</td>
<td>Austin</td>
<td>TX</td>
<td>12345</td>
<td>Fall</td>
<td>Female</td>
<td>35</td>
<td>0987654321</td>
</tr>
<tr>
<td>CEVA345</td>
<td>45</td>
<td>34</td>
<td>West</td>
<td>56</td>
<td>4567</td>
<td>Denver</td>
<td>CO</td>
<td>98765</td>
<td>Winter</td>
<td>Male</td>
<td>40</td>
<td>1234567890</td>
</tr>
<tr>
<td>CEVA789</td>
<td>89</td>
<td>78</td>
<td>East</td>
<td>90</td>
<td>8901</td>
<td>Seattle</td>
<td>WA</td>
<td>12345</td>
<td>Spring</td>
<td>Female</td>
<td>35</td>
<td>0987654321</td>
</tr>
<tr>
<td>CEVA213</td>
<td>34</td>
<td>23</td>
<td>North</td>
<td>12</td>
<td>3456</td>
<td>Minneapolis</td>
<td>MN</td>
<td>67890</td>
<td>Summer</td>
<td>Male</td>
<td>40</td>
<td>1234567890</td>
</tr>
</tbody>
</table>

Total: 10 records
Outline

• Activity Times at Border Crossings
• The Geo-Fence Approach
• Setting of Empirical Study
• Geo-fence Implementations
• Illustrative Results
Study Sites: Ambassador and Blue Water Bridge International Crossings

- **Ambassador Bridge**
  - Connects Detroit, MI and Windsor, ON
  - Busiest U.S. international/commercial international crossing
  - Privately owned and operated

- **Blue Water Bridge**
  - Connects Port Huron, MI and Sarnia, ON
  - Third largest U.S. international crossing
  - Publicly owned and operated
Empirical Data Collection and Processing

• Raw data Collected by CEVA Logistics
  • Regularly traverse AMB and BWB
  • Already used simple geo-fence at borders for their purposes

• Regions-of-interest (ROIs)
  • CEVA operations over N. America
  • Need to limit size of data files
  • First filter CEVA data to ROIs
  • Then process data for relevant statistics
Outline

- Activity Times at Border Crossings
- The Geo-Fence Approach
- Setting of Empirical Study
- Geo-fence Implementations
- Illustrative Results
Geo-fence Implementations

Project team iterated to develop multiple sets of geo-fences

- Novelty led to implementation difficulties
- Concept of multiple activities developed during the project
- Developed new ideas based on previous iterations
“Summer 2007” Geo-fence Implementations

• Before CRESTA team became involved
• CEVA Logistics collected data for company purposes
• One geo-fence for each of the international crossing

Ambassador Bridge

Blue Water Bridge
“Autumn 2007” Geo-fence Implementation

Allowed estimation of times for multiple activities (for the first time?), but

- Some geo-fences were missing
- Customs inspection and approaching customs inspection were included in the same geo-fence (similarly for toll collection)
“Autumn 2008” Geo-fence Implementation

Better evaluate and separate time spent on customs inspection, toll collection, and related queuing time

• One geo-fence boundary slightly upstream of inspection/toll facility
• Second geo-fence boundary slightly downstream of inspection/toll facility
• Gaps between the two boundaries produce times composed primarily of inspection/toll collection
“Autumn 2008” Geo-fence Implementation
Ambassador Bridge Crossing

Spatial Coverage

Activity Detail
“Autumn 2008” Geo-fence Implementation
Blue Water Bridge Crossing

Spatial Coverage

Activity Detail
Outline

• Activity Times at Border Crossings
• The Geo-Fence Approach
• Setting of Empirical Study
• Geo-fence Implementations
• Illustrative Results
Specifications for Overall Crossing Time Statistics

Ambassador Bridge

Blue Water Bridge
# Overall Crossing Time Statistics

<table>
<thead>
<tr>
<th></th>
<th>Ambassador Bridge</th>
<th>Blue Water Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US to CAN</td>
<td>CAN to US</td>
</tr>
<tr>
<td>Number of Records</td>
<td>4215</td>
<td>5401</td>
</tr>
<tr>
<td>Median (50%-ile) Distance [km (mi)]</td>
<td>4.34 (2.7)</td>
<td>15.62 (9.7)</td>
</tr>
<tr>
<td>Median (50%-ile) Time [min]</td>
<td>11.7</td>
<td>24.6</td>
</tr>
<tr>
<td>90th Percentile (90%-ile) Time [min]</td>
<td>20.03</td>
<td>38.45</td>
</tr>
<tr>
<td>Time Variability (90%-ile - 50%-ile) [min]</td>
<td>8.33</td>
<td>13.85</td>
</tr>
</tbody>
</table>
Use of Duty Free Fences

Ambassador Bridge

Blue Water Bridge
Refining Crossing Time Statistics with Duty Free Fence (Canada-to-US)

<table>
<thead>
<tr>
<th></th>
<th>Ambassador Bridge Crossing</th>
<th>Blue Water Bridge Crossing</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/ Duty Free</td>
<td>w/o Duty Free</td>
</tr>
<tr>
<td>Number of Records</td>
<td>5401</td>
<td>4840</td>
</tr>
<tr>
<td>Median (50%-ile) Distance [km (mi)]</td>
<td>15.62 (9.7)</td>
<td>15.62 (9.7)</td>
</tr>
<tr>
<td>Median (50%-ile) Time [min]</td>
<td>24.6</td>
<td>23.98</td>
</tr>
<tr>
<td>90th Percentile (90%-ile) Time [min]</td>
<td>38.45</td>
<td>37.03</td>
</tr>
<tr>
<td>Time Variability (90% - 50%-ile) [min]</td>
<td>13.85</td>
<td>13.05</td>
</tr>
</tbody>
</table>
Duty Free Patterns for Fleet Managers

Proportion* of carrier’s truck trips traversing duty free polygon by hour-of-day and day-of-week at AMB

<table>
<thead>
<tr>
<th></th>
<th>0-2</th>
<th>2-4</th>
<th>4-6</th>
<th>6-8</th>
<th>8-10</th>
<th>10-12</th>
<th>12-14</th>
<th>14-16</th>
<th>16-18</th>
<th>18-20</th>
<th>20-22</th>
<th>22-24</th>
<th>Day</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sun</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0.31</td>
<td>0.09</td>
<td>0.09</td>
<td>0.13</td>
<td>0.23</td>
<td>0.20</td>
</tr>
<tr>
<td>Mon</td>
<td>0.31</td>
<td>0.17</td>
<td>0.05</td>
<td>0.06</td>
<td>0.21</td>
<td>0.08</td>
<td>0.09</td>
<td>0.06</td>
<td>0.05</td>
<td>0.09</td>
<td>0.26</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Tue</td>
<td>0.30</td>
<td>0.10</td>
<td>0.08</td>
<td>0.14</td>
<td>0.17</td>
<td>0.08</td>
<td>0.08</td>
<td>0.06</td>
<td>0.06</td>
<td>0.06</td>
<td>0.11</td>
<td>0.16</td>
<td>0.09</td>
</tr>
<tr>
<td>Wed</td>
<td>0.25</td>
<td>0.23</td>
<td>0.18</td>
<td>0.13</td>
<td>0.25</td>
<td>0.07</td>
<td>0.05</td>
<td>0.07</td>
<td>0.10</td>
<td>0.04</td>
<td>0.05</td>
<td>0.14</td>
<td>0.12</td>
</tr>
<tr>
<td>Thu</td>
<td>0.19</td>
<td>0.26</td>
<td>0.08</td>
<td>0.16</td>
<td>0.22</td>
<td>0.11</td>
<td>0.06</td>
<td>0.06</td>
<td>0.09</td>
<td>0.12</td>
<td>0.21</td>
<td>0.27</td>
<td>0.11</td>
</tr>
<tr>
<td>Fri</td>
<td>0.12</td>
<td>0.22</td>
<td>0.17</td>
<td>0.07</td>
<td>0.21</td>
<td>0.11</td>
<td>0.02</td>
<td>0.04</td>
<td>0.07</td>
<td>0.10</td>
<td>0.11</td>
<td>0.34</td>
<td>0.08</td>
</tr>
<tr>
<td>Hour</td>
<td>0.23</td>
<td>0.19</td>
<td>0.12</td>
<td>0.11</td>
<td>0.21</td>
<td>0.09</td>
<td>0.08</td>
<td>0.08</td>
<td>0.07</td>
<td>0.07</td>
<td>0.16</td>
<td>0.20</td>
<td>0.10</td>
</tr>
</tbody>
</table>

*noise added to proportions to preserve confidentiality of information
Temporal Patterns in Crossing Times
### CA to US Activity Times: Ambassador Bridge Crossing

<table>
<thead>
<tr>
<th>AMB Activity Time ON-MI (min) (2008)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Amb usplaza tollfca</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>#</td>
</tr>
<tr>
<td>Median</td>
</tr>
<tr>
<td>90P</td>
</tr>
<tr>
<td>90th-Median</td>
</tr>
<tr>
<td>Median</td>
</tr>
</tbody>
</table>
Excess Times

- Extra time (delays) resulting from congestion or flow interruptions (customs screening, toll collection, ...)
- Excess Time = Crossing Time - Free Flow Time

*Example*: Queuing-induced excess times over 1-mile segment upstream of customs screening

<table>
<thead>
<tr>
<th></th>
<th>Queuing Induced Excess Time</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Ambassador Bridge Crossing</td>
</tr>
<tr>
<td></td>
<td>Blue Water Bridge Crossing</td>
</tr>
<tr>
<td>Number of Records</td>
<td>US to CAN</td>
</tr>
<tr>
<td></td>
<td>6869</td>
</tr>
<tr>
<td>Median Distance [km (mi)]</td>
<td>1.30 (0.81)</td>
</tr>
<tr>
<td>Median Time [min] (50%-ile)</td>
<td>0.78</td>
</tr>
<tr>
<td>90th Percentile Time [min] (90%-ile)</td>
<td>5.53</td>
</tr>
<tr>
<td>Time Variability [min] (90%-ile - 50%-ile)</td>
<td>4.74</td>
</tr>
</tbody>
</table>
“Screening gap” excess times

<table>
<thead>
<tr>
<th></th>
<th>Ambassador Bridge</th>
<th>Blue Water Bridge</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>US to CAN</td>
<td>CAN to US</td>
</tr>
<tr>
<td>Number of Records</td>
<td>6826</td>
<td>4840</td>
</tr>
<tr>
<td>Median (50%-ile) Distance [km (mi)]</td>
<td>0.05 (0.03)</td>
<td>0.02 (0.01)</td>
</tr>
<tr>
<td>Median (50%-ile) Time [min]</td>
<td>1.1</td>
<td>1.22</td>
</tr>
<tr>
<td>90th Percentile (90%-ile) Time [min]</td>
<td>1.94</td>
<td>2.36</td>
</tr>
<tr>
<td>Time Variability (90%-ile - 50%-ile) [min]</td>
<td>0.84</td>
<td>1.14</td>
</tr>
</tbody>
</table>
No time-of-day pattern in “screening gap” excess times

Time of the Day distributions

Proportion <= Gap Excess Time

Gap Excess Time (min)
Before and After Analysis: Dynamic Message Sign Upgrades on BWB

Locations of dynamic signs for U.S.-bound traffic on the Blue Water Bridge; new DMS signs were installed in early 2009 at locations 5, 6, 7, and 9.
“Before” and “After” DMS Upgrades: Queuing induced excess time
Time-of-Day Effects

Screening Times: No TOD Effect

Queuing Times: Largest Effect at Peak Times
Controlling for Monthly Volume Effects (Changing Economic Conditions during Study Period)

Median queuing delay vs. volume

Queuing delay variability vs. volume

![Graph showing median queuing delay vs. volume](image1)

![Graph showing queuing delay variability vs. volume](image2)
Modeling Approaches

• Aggregate modeling
  – Traffic flow and general queuing relations
  – Association of activity times with traffic volumes, inspection booths in operation, ...

• Micro-simulation modeling
  – Individual vehicle movements through activities
  – Explicit prediction of activity times in response to infrastructure configurations
Aggregate Modeling: Excess time versus traffic volume and # screening stations

Blue Water Bridge: Upstream of screening

Geo-fence derived excess times

Hourly truck and car volumes (MDOT)

Open truck and car lanes (CPB website)
Blue Water Bridge: Upstream of screening

Excess time vs. hourly traffic volume

Cumulative distribution functions of excess times for 7 and 5 open lanes
Logit Model

\[ P(\text{Excess time}_n > t) = \left[1 + \exp\left\{ -\left( \beta_0 + \beta_1 \times \frac{\text{truck volume}}{\text{truck lane}} + \beta_2 \times \frac{\text{car volume}}{\text{car lane}} \right) \right\} \right]^{-1} \]

### Estimation Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Excess Time &gt; 1 min</th>
<th>Excess Time &gt; 8 min</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Estimated Coefficient</td>
<td>t-statistic</td>
</tr>
<tr>
<td>Constant</td>
<td>-1.30</td>
<td>-3.56</td>
</tr>
<tr>
<td>Truck Volume per Truck Lane</td>
<td>0.106</td>
<td>4.78</td>
</tr>
<tr>
<td>Car Volume per Car Lane</td>
<td>0.024</td>
<td>3.01</td>
</tr>
<tr>
<td>LL(B*)</td>
<td>-442.1</td>
<td></td>
</tr>
<tr>
<td>LL(C)</td>
<td>-467.3</td>
<td></td>
</tr>
<tr>
<td>LL(0)</td>
<td>-575.3</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• Geo-fence approach allows for data on truck times in multiple activities
  – Unprecedented detail of activities?
  – “Directions” of results are reasonable
  – Allows quantification and monitoring
  – Representativeness of data must be understood

• No roadside infrastructure needed

• Increased data fit easily in carrier’s data budget

• Regular data (“probe penetration”) required