Estimating Value of Travel Time and Value of Reliability Using I-394 Dynamic Toll Data

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Objective

Answer questions:

“How do freeway travelers value travel time and travel time reliability?”
“How can we use the dynamic toll data to better understand drivers' preferences?”

Propose an approach that provides

A new definition of travel time reliability
A model for estimating VOT and VOR
Methods for Estimating VOT and VOR

- **Surveys**
  - Revealed preference (Beesley, 1965)
  - State preference (Black and Towriss, 1993)
  - RP and SP (Ghosh, 2001; Small et al., 2006)

- **Loop detector data** (Liu et al., 2004; Liu et al., 2007)

- **GPS or smartphone data** (Li et al. 2005; Carrion-Madera and Levinson 2011)

- **Dynamic toll data** (Cho et al., 2011)
Shortcomings

- Surveys: costly and time-consuming to collect
- Loop detector data: hard to account for route choice
- GPS/Smartphone: costly and labor-intensive to install
I-394 MnPass System

- I-494 to Downtown Minneapolis
- Length: ~8.1 miles
- 5 tolling locations and 5 entry zones
- Dynamic pricing system
I-394 Express Lane Configuration
Datasets Available

- **MnDOT loop detector dataset**
  - Estimation of average speeds
  - 30-second resolution

- **MnPASS toll tag database**
  - Information about the uses of the I-394 HOT lanes
  - Event-based records

- **MnPASS toll rate database**
  - Posted toll prices
  - 3-minute time interval
Random Utility Model

Utility function for driver $n$ and alternative $a$:

$$ U_{na} = \beta_n' x_a + \epsilon_{na} $$

Attributes that impact drivers’ decision

$$ x_a = [T_a, R_a, C_a]' $$

Aversion parameters corresponding to observed attributes

$$ \beta_n = [\beta_n^T, \beta_n^R, \beta_n^C]' $$
VOT and VOR Estimation

\[ \text{VOT}_n = \frac{\partial U_{na}/\partial T_a}{\partial U_{na}/\partial C_a} = \frac{\beta_n^T}{\beta_n^C} \]

\[ \text{VOR}_n = \frac{\partial U_{na}/\partial R_a}{\partial U_{na}/\partial C_a} = \frac{\beta_n^R}{\beta_n^C} \]

Main Step: to estimate the aversion parameter in the disutility function

Assume that \( \beta_n^T \sim N(b^T, W^T) \) \( \beta_n^R \sim N(b^R, W^R) \) \( \beta_n^C \sim N(b^C, W^C) \)

we need to estimate the parameter vector:

\[ \Theta = [b^T, W^T; b^R, W^R; b^C, W^C] \]
The probability of a traveler choosing HOT lane can be formulated as mixed logit function

\[ P_{\text{HOT}} = \int \frac{e^{\beta' x_{\text{HOT}}}}{e^{\beta' x_{\text{HOT}}} + e^{\beta' x_{\text{GPL}}}} \cdot f(\beta \mid \Theta) d\beta \]

\[ P_{\text{GPL}} = 1 - P_{\text{HOT}} \]

The likelihood function:

\[ L(\hat{\Theta}) = \prod_{n} P_{\text{HOT}}^{y_n} P_{\text{GPL}}^{1-y_n} \]

\[ y_n = \begin{cases} 1, & \text{if driver } n \text{ selected HOT lane} \\ 0, & \text{otherwise} \end{cases} \]
Parameter Estimation Approaches

- Genetic Algorithm (GA)
  - Liu et al. (2007)

- Simulated maximum likelihood method
  - Small et al. (2005)
Additional Assumptions

- MnPASS users are regular commuters who travel on the I-394 every workday
- A MnPASS user would travel on the GPLs if we did not observe her on the HOT lanes on a specific workday

- MnPASS users have stable departure times in the morning
- We can estimate the traffic conditions when they did not travel on the HOT lane, by using the average departure time
HOT Lane Usage (2006)

438,044 records for non-holiday morning (eastbound) trips, completed by 8,979 MnPASS users

<table>
<thead>
<tr>
<th>HOT Lane Usage</th>
<th>Number of Drivers (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Monday</td>
</tr>
<tr>
<td>1,2</td>
<td>1904 (27.7)</td>
</tr>
<tr>
<td>3,4</td>
<td>914 (13.3)</td>
</tr>
<tr>
<td>[5,10]</td>
<td>1388 (20.2)</td>
</tr>
<tr>
<td>[10,25]</td>
<td>1609 (23.4)</td>
</tr>
<tr>
<td>&gt;25</td>
<td>1062 (15.4)</td>
</tr>
<tr>
<td>Total</td>
<td>6877 (100)</td>
</tr>
</tbody>
</table>
## Estimated Parameters

<table>
<thead>
<tr>
<th>Weekday</th>
<th>Mean (b)</th>
<th>Standard Dev. (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Est (b)</td>
<td>SE (b)</td>
</tr>
<tr>
<td>Mon</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (T)</td>
<td>-14.04</td>
<td>0.37</td>
</tr>
<tr>
<td>Reli (V)</td>
<td>-26.36</td>
<td>0.38</td>
</tr>
<tr>
<td>Toll (C)</td>
<td>-1.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Tue</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (T)</td>
<td>-4.06</td>
<td>0.20</td>
</tr>
<tr>
<td>Reli (V)</td>
<td>-13.81</td>
<td>0.23</td>
</tr>
<tr>
<td>Toll (C)</td>
<td>-0.77</td>
<td>0.02</td>
</tr>
<tr>
<td>Wed</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (T)</td>
<td>-7.99</td>
<td>0.28</td>
</tr>
<tr>
<td>Reli (V)</td>
<td>-16.71</td>
<td>0.26</td>
</tr>
<tr>
<td>Toll (C)</td>
<td>-0.67</td>
<td>0.02</td>
</tr>
<tr>
<td>Thu</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (T)</td>
<td>-5.82</td>
<td>0.32</td>
</tr>
<tr>
<td>Reli (V)</td>
<td>-17.30</td>
<td>0.31</td>
</tr>
<tr>
<td>Toll (C)</td>
<td>-0.73</td>
<td>0.02</td>
</tr>
<tr>
<td>Fri</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time (T)</td>
<td>-20.12</td>
<td>0.57</td>
</tr>
<tr>
<td>Reli (V)</td>
<td>-36.50</td>
<td>0.59</td>
</tr>
<tr>
<td>Toll (C)</td>
<td>-1.05</td>
<td>0.02</td>
</tr>
</tbody>
</table>
## Estimated VOT and VOR

<table>
<thead>
<tr>
<th>Weekday</th>
<th>VOT ($/hr) [25-%tile, 75-%tile]</th>
<th>VOR ($/hr) [25-%tile, 75-%tile]</th>
<th>Reliability Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monday</td>
<td>13.86 [-5.69, 12.74]</td>
<td>25.99 [-8.11, 25.21]</td>
<td>1.88</td>
</tr>
<tr>
<td>Tuesday</td>
<td>5.27 [-5.05, 8.03]</td>
<td>17.95 [-6.36, 18.94]</td>
<td>3.41</td>
</tr>
<tr>
<td>Wednesday</td>
<td>11.98 [-8.95, 10.92]</td>
<td>25.06 [-10.19, 17.69]</td>
<td>2.09</td>
</tr>
<tr>
<td>Thursday</td>
<td>7.96 [-8.87, 14.83]</td>
<td>23.64 [-11.64, 19.50]</td>
<td>2.97</td>
</tr>
<tr>
<td>Friday</td>
<td>19.08 [-9.79, 21.46]</td>
<td>34.61 [-13.41, 31.68]</td>
<td>1.81</td>
</tr>
<tr>
<td>Average</td>
<td>11.63 [-7.67, 13.59]</td>
<td>25.45 [-9.94, 22.60]</td>
<td>2.19</td>
</tr>
</tbody>
</table>
Main Findings

Negative values of VOT and VOR suggest that other factors impact drivers choice b.t. GPL and HOT lanes

The wide range of the 25 to 75 percentile intervals shows the heterogeneity in willingness-to-pay

High reliability ratios indicates that drivers are willing to pay more for travel time reliability than for travel time savings

Mean values of VOT and VOR for Friday are much higher than other weekdays
Conclusions

- Dynamic toll data
  - A reliable, low-cost, and well-organized source for travel choice information

- A methodology for estimating VOT and VOR
  - An alternative definition of travel-time reliability to account for drivers’ perception of congestion

- Limitations of the proposed method
  - The model relies on two main assumptions
  - Drivers’ socio-demographic characteristics are not included
Thanks

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The Simulated Log-Likelihood Function

Apply Monte Carlo simulation techniques to approximate the integrals in the likelihood function:

$$SLL(\hat{\theta}) = \sum_{n} \left[ y_n \ln P_{\text{HOT}} + (1 - y_n) P_{\text{GPL}} \right]$$

where the simulated probability is defined as:

$$P_{\text{HOT}} = \frac{1}{K} \cdot \sum_{k=1}^{K} \Gamma_{\text{HOT}}(\beta_k)$$

$$\Gamma_{\text{HOT}}(\beta_k) = \frac{e^{\beta_k' x_{\text{HOT}}}}{e^{\beta_k' x_{\text{HOT}}} + e^{\beta_k' x_{\text{GPL}}}}$$
Main Problem

Only incomplete data are available

MnPASS data indicates the situations when travelers paid the tolls; no traffic condition data available for MnPASS owners not using HOV lane

\[
SLL(\hat{\theta}) = \sum_{n} \left[ y_n \ln P_{\text{HOT}} + (1 - y_n) P_{\text{GPL}} \right]
\]

\[
= \sum_{n} y_n \ln P_{\text{HOT}}
\]

\[ \beta \rightarrow +\infty \] when maximizing the simulated log-likelihood function
Data Preparation (1)

- Focus the data preparation on the eastbound morning trips on weekdays.

- For a specific weekday (e.g., Monday, Tuesday, Wednesday), eliminate the records if a MnPASS owner used the HOT lane less than 5 times (implying that the owner may not be a commuter on that weekday).

- Eliminate those trips departed before 6:00 am and after 10:00 am (light traffic before 6:00 am, and the diamond lane became free after 10:00 am).
Data Preparation (2)

Concentrate the estimation on all weekdays across the whole year 2006 (i.e., Monday, Tuesday, Wednesday Thursday, and Friday)

Loop detector data was used to estimate instantaneous travel times on the HOT lane and GPLs of I-394

The travel time variability was calculated by taking the difference between 90-percentile and the instantaneous travel times on that day; if the value is negative, set the travel time variability as zero

Travel times and travel time variability were smoothed to remove “noise”

Toll information was provided by MnPASS toll rate database