Linking Roadway and Naturalistic Data to Study Driver Route Choice and Car-following Behavior

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Funded:
VDOT and MAUTC
Modeling Driver Heterogeneity in Route Choice Behavior Based on a Real-Life Naturalistic Driving Experiment

Co-authors: Aly Tawfik, Ph.D. and Jianhe Du, Ph.D.

Funded by: VDOT and MAUTC
Motivation

- **Equilibrium:** Nakayama et al ('01), “Drivers do not become homogeneous and rational, as equilibrium analyses presuppose; rather, there are fewer rational drivers even after a long process of learning, and heterogeneous drivers make up the system”

- **Driver Rationality:** Bogers et al ('05), “studies that focus only on a rather rational description of day-to-day learning cover only a limited part of the way route choices are made over time”

- **Driver Heterogeneity:** Iida et al ('92), “it is desirable to develop a model which is disaggregated by a type of driver because the route choice behavior varies by individual”

- **Experiment Medium:** Prato ('09) and Papinski ('11) “four main challenge areas: i) experiment medium, …”
100-Car Naturalistic Driving Data

- Geocoded home and work address in ArcGIS
- Identified commuting trips by comparing the O-D with home/work locations
- Exported route maps and removed drivers without regular commuting behavior

Sample
- 39 Drivers with a total of 68 choice situations and an average 85 Trials

Procedure
- Pre-task questionnaires, 1-Year real-life data, and Personality Inventory
Disaggregate Findings

Pattern 1: No Route Trials
Pattern 3: Variable Route Trials
Pattern 2: Single Route Trials
Pattern 4: Continuous Route Trials

C4R20-1
C4R20-2
C4R20-3
C4R20-4
Driver Choice Set

The diagram shows a bar chart with the x-axis representing Choice Set Size ranging from 1 to 10, and the y-axis representing Frequency Percentage. The chart indicates a peak in frequency for choice sets of size 2, with frequencies decreasing as the size increases.
## Variables Considered

<table>
<thead>
<tr>
<th>#</th>
<th>Variable Name</th>
<th>Variable Description</th>
<th>Variable Values</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>Variables of Driver Demographics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Age&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Age of driver i</td>
<td>19 to 57</td>
</tr>
<tr>
<td>2</td>
<td>Gender&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Gender of driver i</td>
<td>F or M&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>3</td>
<td>Ethnicity&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Ethnicity of driver i</td>
<td>W or NW&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>4</td>
<td>Education&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Education level of driver i</td>
<td>G or NG&lt;sup&gt;*&lt;/sup&gt;</td>
</tr>
<tr>
<td>5</td>
<td>Dr Years&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Number of years driver i has been licensed to drive</td>
<td>2 to 42</td>
</tr>
<tr>
<td>6</td>
<td>Dr Miles&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Number of miles driver i drives per year (in thousands)</td>
<td>15 to 40</td>
</tr>
<tr>
<td></td>
<td><strong>Variables of Driver Personality Traits</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>N&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Neuroticism of driver i</td>
<td>7 to 75</td>
</tr>
<tr>
<td>2</td>
<td>E&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Extraversion of driver i</td>
<td>14 to 66</td>
</tr>
<tr>
<td>3</td>
<td>O&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Openness to experience of driver i</td>
<td>14 to 53</td>
</tr>
<tr>
<td>4</td>
<td>A&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Agreeableness of driver i</td>
<td>12 to 66</td>
</tr>
<tr>
<td>5</td>
<td>C&lt;sub&gt;i&lt;/sub&gt;</td>
<td>Conscientiousness of driver i</td>
<td>19 to 62</td>
</tr>
<tr>
<td></td>
<td><strong>Variables of Choice Situation</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>TT&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Expected travel time of choice situation c (in minutes)</td>
<td>8 to 95</td>
</tr>
<tr>
<td>2</td>
<td>TS&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Expected travel speed of choice situation c (in km/h)</td>
<td>24 to 90</td>
</tr>
<tr>
<td>3</td>
<td>TD&lt;sub&gt;c&lt;/sub&gt;</td>
<td>Expected travel distance of choice situation c (in km)</td>
<td>6 to 108</td>
</tr>
<tr>
<td>4</td>
<td>Obs&lt;sub&gt;ic&lt;/sub&gt;</td>
<td>Number of trips observed for driver i in choice situation c</td>
<td>25 to 216</td>
</tr>
</tbody>
</table>

<sup>*</sup> M: male, F: female, W: white, NW: non-white, NG: no post-graduate degree, G: have a post-graduate degree
## Driver Choice Set and Switching

<table>
<thead>
<tr>
<th>Significant Variables</th>
<th>Route Switching Model (Beta)</th>
<th>Choice Set Size Model * (Gamma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-1.38</td>
<td>– 0.284</td>
</tr>
<tr>
<td>University Education</td>
<td>-0.81</td>
<td>– 0.098</td>
</tr>
<tr>
<td>Driven Miles</td>
<td>-0.30</td>
<td>n/s</td>
</tr>
<tr>
<td>Neuroticism</td>
<td>n/s</td>
<td>0.049</td>
</tr>
<tr>
<td>Extraversion</td>
<td>0.56</td>
<td>n/s</td>
</tr>
<tr>
<td>Openness to Experience</td>
<td>-0.97</td>
<td>– 0.25</td>
</tr>
<tr>
<td>Conscientiousness</td>
<td>0.46</td>
<td>0.079</td>
</tr>
<tr>
<td>Expected Travel Time</td>
<td>0.35</td>
<td>n/s</td>
</tr>
<tr>
<td>Expected Travel Speed</td>
<td>-0.55</td>
<td>– 0.058</td>
</tr>
<tr>
<td>Number of Observations</td>
<td>n/s</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Findings

- **Choice Set**
  - Smaller choice set:
    - Drivers without post-graduate degrees and higher scores of openness to experience
  - Larger choice set:
    - Higher values of neuroticism and conscientiousness, lower travel speeds
    - Finally, it is satisfying that the number of observations was found to marginally increase the choice set size.

- **Route Switching**
  - Personality trait variables seem were as important as variables of travel experience (travel speed).
  - Drivers’ openness to experience was the most important variable
Application

Population Distributions
- Personal Variables
- Personality Traits

Population

Transportation Models

Road Network

Choice Situation Characteristics

Route Choice Model

Driver-Type Model

Past Experience
Modeling Driver Car-following Behavior using Naturalistic Driving Data

Co-authors: John Sangster, MS and Jianhe Du, Ph.D.

Funded by: MAUTC
Data Reduction

- Multiple drivers identified using GIS; homogeneous roadway segment.
Data Reduction

- Car-following events verified visually
Data Reduction

- Interpolation of data feeds
Dataset Extracted from Database

- Green indicates steady-state travel, red for deceleration, and blue for acceleration.
Dataset Extracted from Database

- Full database (Hundred Car Study) includes 108 drivers, 337,000 hours of data, 207,000 trips.
- GIS identified 15 drivers commuting on Dulles Airport Access Road.
- Validated data available for 7 drivers.
- Final dataset includes 7 drivers, 1,732 car-following events totaling 789 minutes.
Car-following models analyzed

- Gaxis-Herman-Rothery (GHR) Model
  - GHR-1 model incorporated in ACC systems

- Gipps Model
  - Incorporated in the AIMSUN software

- Intelligent Driver Model (IDM)
  - Extension of the Gipps model

- Rakha-Pasumarthy-Adjerid (RPA) Model
  - Van Aerde steady-state model
  - Vehicle dynamics acceleration constraints and collision avoidance constraints
Car-following simulation results

- Gaxis-Herman-Rothery (GHR) Model

\[
\ddot{x}_{n+1}(t) = \left\{ \frac{\alpha \dot{x}_{n+1}(t)^2}{[\Delta x_{n\rightarrow n+1}(t - \tau)]^l} \right\} \cdot [\Delta \dot{x}_{n\rightarrow n+1}(t - \tau)]
\]
Car-following simulation results

- Gipps Model

\[
\dot{x}_{n+1}(t) = \min \left\{ \dot{x}_{n+1}(t-\tau) + 2.5\dot{x}_{d\text{-max}} \cdot \Delta t \cdot \left[ 1 - \frac{\dot{x}_{n+1}(t-\tau)}{\dot{x}_{d\text{-min}}} \right] \cdot \sqrt{0.025 + \frac{\dot{x}_{n+1}(t-\tau)}{\dot{x}_{d\text{-min}}}} , \right. \\
\left. \dot{x}_{d\text{-min}} \cdot \Delta t \right. \\
\left( \frac{2[\Delta x_{n\rightarrow n+1}(t-\tau) - \Delta x_j]}{\ddot{x}_n(t-\tau)^2} - \frac{\dot{x}_n(t-\tau) \cdot \Delta t}{\ddot{x}_{(n)-\text{min}}} \right) 
\]
Car-following simulation results

- Intelligent Driver Model (IDM)

\[
\ddot{x}_{n+1}(t) = \frac{1}{T_2 \delta_{d-max}} \left\{ 1 - \left[ \frac{\dot{x}_{n+1}(t)}{\dot{x}_d} \right]^\delta \right\} \left( \Delta x_j - \frac{\Delta x_{n \rightarrow n+1}(t)}{\sqrt{x_d-max \cdot |\dot{x}_d-min|}} \right)^2
\]
Car-following simulation results

- Rakha-Pasumarthy-Adjerid (RPA) Model
### Car-following simulation results

- **Comparison of Error Measures**

<table>
<thead>
<tr>
<th>Model</th>
<th>D124</th>
<th>D304</th>
<th>D316</th>
<th>D350</th>
<th>D358</th>
<th>D363</th>
<th>D462</th>
<th>Aggregate</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHR Model</td>
<td>0.00079</td>
<td>0.00082</td>
<td>0.00096</td>
<td>0.00080</td>
<td>0.00104</td>
<td>0.00046</td>
<td>0.00069</td>
<td>0.00033</td>
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<tr>
<td>Gipps Model</td>
<td>0.00064</td>
<td>0.00033</td>
<td>0.00030</td>
<td>0.00094</td>
<td>0.00028</td>
<td>0.00019</td>
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<tr>
<td>IDM</td>
<td>0.00142</td>
<td>0.00172</td>
<td>0.00101</td>
<td>0.00181</td>
<td>0.00069</td>
<td>0.00068</td>
<td>0.00328</td>
<td>0.00026</td>
</tr>
<tr>
<td>RPA Model</td>
<td>0.00086</td>
<td>0.00037</td>
<td>0.00044</td>
<td>0.00118</td>
<td>0.00034</td>
<td>0.00019</td>
<td>0.00087</td>
<td>0.00021</td>
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</table>
Results of Comparative Analysis

- RPA model is seen to miss aggressive portion of the observed car-following data.
- Naturalistic data identified specific issue.
  - When lead vehicle enters lane creating smaller than desired space headway, follower decelerates at moderate rate.

![Graph showing speed vs. spacing](image)
Car-following simulation results

- Sample Event

![Graph showing car-following simulation results](image_url)
## Car-following simulation results

- **Comparison of Error Measures**

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<tr>
<td>Van Aerde Model</td>
<td>0.00073</td>
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<td>0.00019</td>
<td>0.00087</td>
<td>0.00021</td>
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<tr>
<td>Revised RPA Model</td>
<td><strong>0.00065</strong></td>
<td><strong>0.00032</strong></td>
<td><strong>0.00029</strong></td>
<td><strong>0.00088</strong></td>
<td><strong>0.00029</strong></td>
<td><strong>0.00015</strong></td>
<td><strong>0.00036</strong></td>
<td><strong>0.00015</strong></td>
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<td>0.00026</td>
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<td>RPA</td>
<td><strong>0.00063</strong></td>
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<td>0.00082</td>
<td><strong>0.00026</strong></td>
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<td><strong>0.00038</strong></td>
<td><strong>0.00035</strong></td>
<td><strong>0.00012</strong></td>
</tr>
</tbody>
</table>
Model Coverage

- Coverage using 90th percentile range.
Conclusions

- Naturalistic data provides a wealth of data for use in studying traveler behavior:
  - Departure time trends
  - Route set size
  - Route choice behavior
  - Car-following behavior

- Augmentation with other data sources to give larger picture can also be beneficial