Evaluating Driver Braking and Stopping Behavior at Rural Intersections using SHRP 2 Naturalistic Driving Study Data

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Outline

- Background and Study Objectives
- Braking Model
  - Data reduction, Analysis and Results
- Stopping Model
  - Data reduction, Analysis and Results
- Conclusions
- Future Work
Background

- 30% of total crashes and 6% of fatal crashes in rural areas occur at intersections

- Crashes at rural intersections are often due to drivers not seeing the intersection or inappropriate gap selection (Preston et al, 2004)
Background

- Previous research on braking has been done using simulators, closed course studies or controlled instrumented vehicles with test drivers (Montella et al. 2011, Muttart et al 2011, and Bao and Boyle 2008)

- Previous stopping models have used field collected data and surveys to model stopping behavior at intersections and focused on urban intersections (Woldemanuel & Hankes, 2011)

- SHRP 2 Naturalistic Driving Study provides a means to address shortcomings
SHRP 2 Naturalistic Driving Study (NDS)

Largest naturalistic study done to date

Drivers had their car instrumented with equipment to capture data as they drove

- Approximately 3,400 drivers of all genders and ages
- Approximately 4,000 data years including 5 million trip files and 30 million data miles
- 6 states (FL, IN, NY, NC, PA and WA)
SHRP 2 Naturalistic Driving Study (NDS)

Captured a variety of data

- Vehicle network data (i.e. speed, acceleration, pedal position)
- Accelerometer data (3 axis)
- GPS coordinates
- Forward and rear radar
- Cameras

Image source: VTTI
Data from mobile data collection and other existing roadway data along with supplemental data.

Data collected includes:

- **Mobile data collection (~25,000 collection miles)**
  - Roadway alignment, shoulder width and type, signing, lighting, intersection locations, rumble strips, etc.

- **Existing roadway data**
  - Asset management data, ADT, type of pavement, rest areas, etc.

- **Supplemental data**
  - Crash data, changes to laws, etc.
Study Objective

Develop models of driver braking and stopping behavior at rural intersections using the SHRP 2 NDS and RID

- Opportunity to study how driver, environmental and roadway characteristic interact to affect braking distance
SHRP 2 NDS Data Received

- 4,000 traces through 58 received
- 339 traces through 35 intersections used in braking analysis
- 358 traces at 20 intersections used in stopping analysis
Braking Model
Braking Point Determination

- Intersection was geolocated in time series data and then time and distance were used to determine distance from intersection.

- Braking point determined using the brake pedal indicator and distance was extracted.
Analysis

Linear Mixed Effects model

Variables tested

- Dependent: Braking distance in meters
- Independent: roadway, environmental and driver

Best fit model was chosen

- AIC was used to compare models
- 95% significance for variables to be included
- Linear model assumptions were checked
# Braking Model Results

<table>
<thead>
<tr>
<th>Variable</th>
<th>Estimate</th>
<th>Std error</th>
<th>P value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>259.16</td>
<td>34.55</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>Amount over/under the speed limit (mph)</td>
<td>2.93</td>
<td>0.53</td>
<td>&lt;.001</td>
</tr>
<tr>
<td>On pavement signing present (1=yes, 0=no)</td>
<td>62.41</td>
<td>32.32</td>
<td>0.05</td>
</tr>
<tr>
<td>Advanced stop/intersection warning signs present (1=yes, 0 =no)</td>
<td>-26.53</td>
<td>13.61</td>
<td>0.05</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Factors for Speed and Stop sign presence</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed limit 25 mph with no stop sign (1 = yes, 0=no)</td>
<td>-144.44</td>
<td>67.15</td>
<td>0.03</td>
</tr>
<tr>
<td>Speed limit 25 mph with stop sign (1 = yes, 0=no)</td>
<td>-220.81</td>
<td>64.43</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Speed limit 35 mph with stop sign (1 = yes, 0=no)</td>
<td>-185.80</td>
<td>23.58</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Speed limit 40 mph with stop sign (1 = yes, 0=no)</td>
<td>-133.34</td>
<td>36.25</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Speed limit 45 mph with no stop sign (1 = yes, 0=no)</td>
<td>0.84</td>
<td>36.93</td>
<td>0.98</td>
</tr>
<tr>
<td>Speed limit 45 mph with stop sign (1 = yes, 0=no)</td>
<td>-78.45</td>
<td>37.50</td>
<td>0.04</td>
</tr>
<tr>
<td>Speed limit 55 mph with no stop sign (1 = yes, 0=no)</td>
<td>-95.22</td>
<td>33.85</td>
<td>0.005</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variance</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver ID Random Effect</td>
<td>2896</td>
</tr>
<tr>
<td>Intersection ID Random Effect</td>
<td>3534</td>
</tr>
<tr>
<td>Residual</td>
<td>1824</td>
</tr>
</tbody>
</table>
Stopping Model
Stopping Speed Determination

Minimum speed at the intersection was extracted from time series data for 358 traces

- 20 two way stop controlled intersections
- 57 unique drivers

Categorized into one of three types of stopping behavior (Woldemanuel & Hankes, 2011)

- Complete stop: Minimum speed \( \leq 0.5 \) mph
- Rolling stop: Minimum speed \( >0.5 \) and \( < 5 \) mph
- No stop: Minimum speed \( \geq 5 \) mph
Analysis

Ordinal Logistic regression was used to model the probability (odds) of a driver making a *no, rolling or complete stop* at a rural intersection

- 20% confidence interval used due to small sample sizes of factors
- AIC was used to compare models
- no stop < rolling stop < complete stop

\[
\log \left( \frac{p_i}{1-p_i} \right) = \beta_0 + B_1 x_1 + \beta_2 x_2 + \beta_3 x_3
\]
# Stopping Model Results

<table>
<thead>
<tr>
<th>Parameter description</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>p-value</th>
<th>% of samples</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash history (1= 1+ crashes, 0=no crashes)</td>
<td>-2.3054</td>
<td>0.7182</td>
<td>0.0013</td>
<td>13.97</td>
</tr>
<tr>
<td>Type of movement (1= right, 0 = left or through)</td>
<td>-2.2716</td>
<td>0.3977</td>
<td>&lt;0.001</td>
<td>41.62</td>
</tr>
<tr>
<td>Approach grade (1= uphill/downhill, 0 = flat)</td>
<td>1.3073</td>
<td>0.6040</td>
<td>0.0304</td>
<td>15.08</td>
</tr>
<tr>
<td>Stop bar present (1=yes, 0=no)</td>
<td>0.9672</td>
<td>0.6756</td>
<td>0.1523</td>
<td>6.70</td>
</tr>
</tbody>
</table>

**Threshold coefficients**

<table>
<thead>
<tr>
<th>Threshold coefficients</th>
<th>Estimate</th>
<th>Std. Error</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>No stop to rolling stop</td>
<td>-2.1405</td>
<td>0.3846</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Rolling stop to full stop</td>
<td>0.2671</td>
<td>0.3652</td>
<td>0.2324</td>
</tr>
</tbody>
</table>

**Random Effects**

<table>
<thead>
<tr>
<th>Random Effects</th>
<th>Variance</th>
<th>Std. Dev</th>
</tr>
</thead>
<tbody>
<tr>
<td>Driver ID</td>
<td>0.7422</td>
<td>0.8615</td>
</tr>
<tr>
<td>Intersection ID</td>
<td>0.3315</td>
<td>0.5757</td>
</tr>
</tbody>
</table>
# Odds Ratios

<table>
<thead>
<tr>
<th>Parameter description</th>
<th>Odds Ratio Est.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crash history (1= one or more crashes, 0=no crashes,)</td>
<td>0.0997</td>
</tr>
<tr>
<td>Type of movement (1= right, 0 = left or through)</td>
<td>0.1031</td>
</tr>
<tr>
<td>Approach grade (1= uphill/downhill, 0 = flat)</td>
<td>3.6962</td>
</tr>
<tr>
<td>Stop bar present (1=yes, 0= no)</td>
<td>2.6306</td>
</tr>
</tbody>
</table>
Conclusions

Sample size limitations for both studies

Preliminary braking model found:

- On pavement signing increased braking distance
- Advanced warning signs decreased braking distance
- Drivers speed and speed limit of road affect braking distance
Conclusions

Stopping model found:

- Drivers turning right and drivers with a crash history are more likely to not come to a full stop at the intersection.
- Drivers are more likely to stop at intersections with approaches located on grades and those with stop bars.
Future Work

Beginning 2\textsuperscript{nd} Phase

- Will incorporate additional roadway information and look at additional countermeasures
- Increase sample sizes
- Incorporate driver distraction and glance data on a subset of data
- Include additional rural intersection types
Acknowledgements

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Questions?

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