Investigation of Design Speed Characteristics on Freeway Ramps Using SHRP2 Naturalistic Driving Data

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Acknowledgement

- Based on research conducted on “Comparison of SHRP2 Naturalistic Driving Data to Geometric Design Speed Characteristics on Freeway Ramps”

- Sponsored by:
Introduction

• Existing ramp design guidelines based on practices from decades past
• Recent research conclusions based on more recent field data, but data often limited
• Current research project uses naturalistic data from SHRP2 NDS
• Objective: identify relationships between roadway characteristics and speed, based on speeds of SHRP2 drivers
Current Policies

- AASHTO Green Book
  - Section 10.9.6: Desirable for ramp design speeds to approximate low-volume highway running speed, but not always practical
  - Table 10.1: Applies to the sharpest or controlling ramp curve

<table>
<thead>
<tr>
<th>Highway design speed (mph)</th>
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<td><strong>Upper range (85%)</strong></td>
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<td><strong>Middle range (70%)</strong></td>
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<td><strong>Lower range (50%)</strong></td>
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</table>
| **Corresponding minimum radius (ft)** | | | | | | | | | | | See Green Book Table 3-7
Current Policies

• AASHTO Green Book (7th Edition)
  – Section 10.9.6.2: Desirable for ramp design speeds to approximate low-volume highway running speed, but not always practical
  – Table 10.1: Applies to the sharpest or controlling ramp curve

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<th>Highway design speed (mph)</th>
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See Green Book Table 3-7
Current Policies

- Individual states
  - Online search of 20 states in NCHRP 15-56
  - 16 states had design manuals with text corresponding to *Green Book*
    - 11 states nominally the same or specifically referred to *Green Book*
    - 5 states were very similar but had some unique features also (e.g., Table 10-1 was reproduced using only values that were multiples of 5 mph)
Previous Research

• Variety of models predict ramp speed
  – Curves on loop ramps (NCHRP 3-105, NCHRP 17-45/HSM)
  – Advisory speeds on exit ramps (Venglar, et al)

• Models are based on:
  – Factors such as lane/shoulder width, curve radius, SCL type, etc.
  – Data from a limited number of ramps and/or vehicles
Data Collection Considerations

• Methods
  – Lidar
  – Road sensors
  – Instrumented vehicles

• Pros and cons
  – Tradeoffs between number of vehicles/sites and detail in dataset
Benefits of SHRP2 Dataset

• Data from 3,000+ participants in six states
• ~3,500 human-years of time series data

• Reduced data primarily used to analyze crashes and near-crash events, but can also be used for detailed driving data for a large sample of drivers on a wide variety of roadway segments
Site Data Collection

- **InSight Trip Density Maps**
  - Six participating states
  - Ramps with trips by 50-200 unique participants
  - Ramp configuration (e.g., diamond, loop, curve)
  - Entrance or exit ramp
Site Data Collection

• Google Earth
  – Same locations as InSight
  – GPS coordinates
  – Urban/rural
  – Confirm ramp type
  – Confirm origin/destination routes
Site Selection

- Identified 1686 ramps (>130 from each state)
  - About 1.4 million recorded trips
  - ~8 trips / participant / ramp
  - 173,000 unique participant-ramp combinations

- Filters and qualifiers removed:
  - Non-Interstate ramps, metered ramps, multiple ramps per interchange
  - Ramps with < 200 total trips, ramps with multiple LinkIDs
Site Selection

- Final list of 100 ramps, almost 11,000 participant-ramp combinations

<table>
<thead>
<tr>
<th>State</th>
<th>Configuration</th>
<th>Direction of Travel</th>
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<tbody>
<tr>
<td></td>
<td>Curve</td>
<td>Diamond</td>
</tr>
<tr>
<td>FL</td>
<td>816</td>
<td>2049</td>
</tr>
<tr>
<td>IN</td>
<td>0</td>
<td>150</td>
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<tr>
<td>NC</td>
<td>796</td>
<td>1770</td>
</tr>
<tr>
<td>NY</td>
<td>475</td>
<td>391</td>
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<tr>
<td>PA</td>
<td>406</td>
<td>523</td>
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<tr>
<td>WA</td>
<td>398</td>
<td>842</td>
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<tr>
<td>Total</td>
<td>2891</td>
<td>5725</td>
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</table>
Trip Data Collection

• Requested detailed SHRP2 NDS time series data for first trip by each unique participant on each ramp
  – Time series recorded each 0.1 s
  – Primary vehicle variables (e.g., speed, 3D acceleration and rotation rates)
  – Secondary vehicle variables (e.g., steering wheel position, pedal position)
• Dataset included 2 s before the ramp and after the ramp
Roadway Data Collection

- First option: SHRP2 RID (very few ramps available)
- Second option: Google Earth
  - Divided ramps into curve and tangent segments, measured lengths and radii
  - Measured lane/shoulder widths
  - GPS coordinates for begin/end of each segment
Final Dataset

- Removed trips with sensor errors and other features that prevented complete speed profile
- Combined trip data with roadway data into series of spreadsheets with one row per 0.1 s interval of data
- Reduced dataset contained:
  - 10,834 trips on 100 ramps
  - 1,731,753 individual speed readings (statistically significant)
Speeds on Curved Ramp Segments

- \( \nu_{\text{curve,ent}} = 0.51 \nu_{\text{fwy}} + 56.5R - 41.5R^2 + 0.68TC_{FF} - 1.07 \)
- \( \nu_{\text{curve,exit}} = 0.20 \nu_{\text{fwy}} + 79.9R - 61.1R^2 - 0.154Ramp_{pct} + 11.75TC_{FF} + 10.17TC_{SIG} + 12.30 \)

- Average speed on the curve
- Good for radii up to 0.7 mi
- Destination has an intuitive effect
Speeds on Tangent Ramp Segments

- \( v_{tangent,ent} = 0.84v_{PT} + 0.081Seg_{pct} - 2.29\, Next_C - 4.05\, Prev_C + 10.78 \)

- \( v_{tangent,exit} = 0.98v_{PT} - 0.115Seg_{pct} + 2.31\, Next_C + 0.83\, Prev_C + 0.60 \)

- Speed anywhere on the segment
- Establishes a baseline speed to begin the segment
Speed Profile on Ramp Proper

- $\nu_{\text{curve}} = \beta_0 + \beta_1 \nu_{PC} + \beta_2 R + \beta_3 R^2 + \beta_4 T C_{Si} + \beta_5 T C_{FF} + \beta_6 Pre_C + \beta_7 Pre_N + \beta_8 Next_C + \beta_9 Next_N$
- $\nu_{\text{tangent}} = \beta_0 + \beta_1 \nu_{PT} + \beta_2 T C_{Si} + \beta_3 T C_{FF} + \beta_4 Pre_C + \beta_5 Pre_N + \beta_6 Next_C + \beta_8 Next_N$

- Speed at quarter points of each segment
- Eqns used in series with calibrated coefficients (listed in paper)
Conclusions

• SHRP2 NDS has potential to be used (with other data sources) to develop realistic speed models related to geometric design characteristics

• Robust data source, with caveat that “too much” data can affect model development

• Curve radius, as expected, had great (non-linear) effect

• Destination more influential than origin on speed selection
Questions?

- Marcus Brewer
- m-brewer@tti.tamu.edu

- Paper # 19-05395 (this paper)
- Paper # 19-05389 (data processing paper led by Jayson Stibbe)