Heavy Vehicle Encroachment Trajectories

TRB First International Roadside Safety Conference
June 12–15, 2017
San Francisco, California

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RSAPv3 Vehicle Trajectories

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<tr>
<th>VEHICLE MIX</th>
<th>FHWA CLASS</th>
<th>Trajectory Information</th>
<th>Trajectory Grid Name</th>
<th>Redirection Grid Name</th>
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<tbody>
<tr>
<td>RSAP VEHICLES</td>
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<td>Trajectory Information</td>
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<td></td>
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<tr>
<td>Light Tractor Trailer</td>
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<td>TrajectoryGrid3</td>
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<td>RedirectionTrucks</td>
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<tr>
<td>Average Tractor Trailer</td>
<td>8-13</td>
<td>TrajectoryGrid3</td>
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<td>RedirectionTrucks</td>
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<tr>
<td>Heavy Tractor Trailer</td>
<td>8-13</td>
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<td>RedirectionTrucks</td>
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<tr>
<td>Light Single Unit Truck</td>
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<td>Average Single Unit Truck</td>
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<td>TrajectoryGrid4</td>
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<td>RedirectionTrucks</td>
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</table>
RSAPv3 Vehicle Trajectories

- The **vehicle path** during an encroachment is incorporated into RSAPv3 using real-world trajectories to implicitly account for driver reactions.

- Each trajectory stored in the RSAPv3 database includes:
  - Vehicle path (i.e., x–y coordinates).
  - Encroachment angle.
  - Encroachment speed.
  - Roadside/median terrain.
  - Roadway curve and grade.
  - Posted speed limit.
  - Terrain of the cross-section.
Knowledge of the path and vehicle departure speed allows RSAPv3 to compute the speed and position of the vehicle as it moves along the roadside and detect any intersections with hazards that might be located along the vehicle path.
Currently, the RSAv3 trajectory database is limited to the 890 passenger vehicle trajectories collected under NCHRP Project 17–22.

Understanding a heavy vehicle trajectory during an encroachment is crucial to several aspects of roadside safety including barrier test level section.

Three methods of obtaining the necessary heavy vehicle trajectories:
- Collect new heavy vehicle trajectory data,
  - Find crash or encroachment databases that include heavy vehicle trajectories or
  - Assume heavy vehicles have similar trajectories to passenger vehicles if limited to reasonable speeds and angles.
Wright conducted a study of heavy vehicle crashes for the Georgia Department of Transportation in 1985 which include roadway characteristics – but no vehicle paths.

The LTCCS data includes scene diagrams which might be used to approximate a trajectory.

NCHRP 17–22 is limited to passenger vehicle trajectories.
The Federal Motor Carrier Safety Administration (FMCSA) and the National Highway Traffic Safety Administration (NHTSA) compiled a nationally representative sample of large truck crashes in the Large Truck Crash Causation Study (LTCCS).

The data include scaled scene diagrams and a description of the circumstances.

68 single large truck left departure crashes were found in the data.
LTCCS Data

- Data contains only heavy vehicle data.
  - Class 6 Single Unit Trucks → 16%
  - Class 9 Tractor Trailers → 72%
  - Other Classes → 12%

- 68 cases involved heavy vehicles departing the left side of the roadway.

- Posted speed limit known in 66 of the 68 left-side ROR crashes.

- Departure angle estimated from scaled scene diagram.

- Nothing in data for departure speed or terrain → attempted to estimate terrain.
Departure Angle by PSL for 66 LTCCS ROR Crashes

Most Data Below 33°

Average = 12.6°
NCHRP 17–22 Passenger Vehicle Encroachment Speed by PSL

Departure Speed (MPH)

Posted Speed Limit (MPH)

Average Departure Speed = 0.96 PSL Normal Distribution
NCHRP 17–22 Passenger Vehicle Departure Angle by PSL

Departure Angle (degrees)

Posted Speed Limit (MPH)

35 45 50 55 60 65 70 75 80 85 90

Slide 14
Ray, Carrigan and Plaxico,
Heavy vehicles cannot obtain the same departure speed and angle as passenger vehicles.

A simple point-mass procedure was used in BCAP/GSBR for limiting the possible encroachment angles:

$$\theta_{max} = \cos^{-1}\left[1 - \frac{S_0 f_{max} g}{V^2}\right]$$

where:

$\Theta_{max}$ = The maximum likely encroachment angle in degrees,

$S_0$ = The vehicle offset from the edge of the travelled way in feet,

$f_{max}$ = The maximum available coefficient of friction,

$g$ = The gravity constant (i.e., 32.2 ft/s$^2$) and

$V$ = The departure velocity in ft/s.
Assumptions

- 1989 AASHTO Guide Specification for Bridge Railing
  - maximum available side friction for SUTs \( \rightarrow 0.6 \).
  - maximum available side friction for TTs \( \rightarrow 0.45 \).

- Vehicle offset \( \rightarrow \) half a typical 12–ft lane width

- If the observed passenger vehicle departure angle was greater than \( \Theta_{\text{max}} \), the trajectory was eliminated as a possible representation of SUT or TT encroachments.
315 of the 890 trajectories suitable for SUT trajectories.
315 of the 890 trajectories suitable for SUT trajectories.
TT Trajectory Departure Angle by PSL

➢ 253 of the 890 trajectories suitable for TT trajectories.
TT Trajectory Departure Speed by PSL

➢ 253 of the 890 trajectories suitable for TT trajectories.
Results

- The maximum encroachment angle used in RSAPv3 for both SUT and TT is 32 degrees.
- The maximum encroachment angle used in BCAP/GSBR was 36 degrees.
- The measured encroachment angles in the LTCCS database were generally less than 33 degrees.
- The LTCCS data appears to confirm the simple point-mass approach used in BCAP/GSBR.
The current RSAPv3 trajectory database includes:

- 315 limited passenger vehicle trajectories to represent single-unit trucks.
- 253 limited passenger vehicle trajectories to represent tractor-trailer trucks.
- This is the best we have at the moment, but...

Up–coming NCHRP Problem Statement for next year for collecting encroachment data → Let’s remember to collect all vehicle types.
Acknowledgments

The LTCCS data was analyzed by Dr. Clay Gabbler and his students at Virginia Tech.

The research discussed herein was conducted as part of NCHRP Projects 22–12(03), 17–54 and 12–90 for which RoadSafe LLC is the prime contractor.

The authors wish to thank the research panels and NCHRP program officer Mark Bush for their thoughtful insight and comments.
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<thead>
<tr>
<th>Heavy Vehicle Type</th>
<th>Frequency</th>
<th>Percentage</th>
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<tbody>
<tr>
<td>Single unit truck (4,500kg &lt; GVWR &lt; 8,850kg)</td>
<td>4</td>
<td>5.88</td>
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<tr>
<td>Single unit truck (8,850kg &lt; GVWR &lt;= 12,000kg)</td>
<td>2</td>
<td>2.94</td>
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<tr>
<td>Single unit truck (GVWR &gt; 12,000kg)</td>
<td>11</td>
<td>16.18</td>
</tr>
<tr>
<td>Single unit truck (GVWR unknown)</td>
<td>1</td>
<td>1.47</td>
</tr>
<tr>
<td>Truck-tractor with no cargo trailer</td>
<td>1</td>
<td>1.47</td>
</tr>
<tr>
<td>Truck-tractor pulling one trailer</td>
<td>49</td>
<td>72.06</td>
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<tr>
<td><strong>Total</strong></td>
<td><strong>68</strong></td>
<td><strong>100.00</strong></td>
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### FHWA Vehicle Classifications

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<tr>
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<tbody>
<tr>
<td>2 axles, 2 or 3 tires</td>
<td>2 axles, can have 1- or 2-axle trailers</td>
<td>2 axles, 4-tire single units</td>
<td>2 or 3 axles, full length</td>
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<tr>
<td><img src="image1" alt="Motorcycle" /></td>
<td><img src="image2" alt="Passenger Car" /></td>
<td>Can have 1 or 2 axle trailers</td>
<td><img src="image3" alt="Bus" /></td>
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<tbody>
<tr>
<td>2 axles, 6 tires (dual rear tires), single-unit</td>
<td>3 axles, single unit</td>
<td>4 or more axles, single unit</td>
<td>3 or 4 axles, single trailer</td>
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<td><img src="image4" alt="2-Axle Truck" /></td>
<td><img src="image5" alt="3-Axle Truck" /></td>
<td><img src="image6" alt="4 or More-Axle Truck" /></td>
<td><img src="image7" alt="Single Trailer 3- or 4-Axle Truck" /></td>
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</table>

<table>
<thead>
<tr>
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</thead>
<tbody>
<tr>
<td>5 axles, single trailer</td>
<td>6 or more axles, single trailer</td>
</tr>
<tr>
<td><img src="image8" alt="5-Axle Trailer Truck" /></td>
<td><img src="image9" alt="6 or More-Axle Trailer Truck" /></td>
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<thead>
<tr>
<th>11. Multi-Trailers 5 or Less-Axle Trucks</th>
<th>12. Multi-Trailers 6-Axle Trucks</th>
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<tbody>
<tr>
<td>5 or less axles, multiple trailers</td>
<td>6 axles, multiple trailers</td>
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<td><img src="image11" alt="Multi-Trailers 6-Axle Truck" /></td>
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<table>
<thead>
<tr>
<th>13. Multi-Trailers 7 or More-Axle Trucks</th>
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<tbody>
<tr>
<td>7 or more axles, multiple trailers</td>
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<tr>
<td><img src="image12" alt="Multi-Trailers 7 or More-Axle Truck" /></td>
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