Effectiveness of Centerline Rumble Strips and Cable Median Barriers

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Timothy J. Gates, PhD, PE

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Lane Departure Crashes in Michigan

- From 2004 to 2007, lane departure crashes accounted for:
  - 17.2% of all crashes in Michigan
  - 47.4% of fatal crashes in Michigan

- MDOT lane departure initiatives:
  - Non-Freeways: 4000+ miles of rumble strips
  - Freeways: 300+ miles of cable median barriers
MDOT’s Non-Freeway Rumble Strip Initiative

- Statewide implementation on undivided trunklines from 2008-2010
  - CLRS
    - Speed limit of 55 mph
    - Paved roadway width > 20 ft
  - CLRS+SRS
    - Speed limit of 55 mph
    - Paved shoulders ≥ 6 ft wide
MDOT Rumble Strip Research

Objectives

- Two-phase MDOT research
- Determine impact of CLRS on:
  - Driver behavior
  - Bicyclists
  - Noise
  - Crashes and injuries

Phase 1

Phase 2
RUMBLE STRIP EVALUATION #1: Driver Behavior Impacts
Driver Behavior Study

- Before-and-after observational study of driver behavior on 10 roadways
  - Lateral placement within the travel lane
  - Encroachments onto the centerline
  - Encroachments onto the edgeline
  - Passing attempts
  - High risk behavior
Data Collection

- Pole mounted HD video cameras
  - 20 ft high
  - 1000’ of roadway per camera
  - One camera for curves
  - Two opposing cameras in passing zones
  - 4 to 10 hours per location
  - Dry/daytime
  - Same location B & A
Passing Zone Data Extraction

- 700+ hours
- Manual review
- For each vehicle:
  - Was the vehicle in passing position?
  - Was a pass attempted?
  - Was the pass completed?
  - Was the pass aborted?
  - Other erratic behavior
Curve Data Extraction

For each vehicle:
- Left curve vs. right curve
- Lateral lane position
  - Curve
  - Adjacent tangent section
- Encroachments
  - Tire touch
  - Tire across
Measures of Effectiveness

- **Passing Events**
  - % attempting a passing maneuver
  - % aborting a passing maneuver

- **Encroachments**
  - % encroaching onto the centerline
  - % encroaching onto the edgeline

- **Lane Positioning**
  - % left
  - % center
  - % right
Passing Results

~78,000 total vehicular observations

<table>
<thead>
<tr>
<th>MOE</th>
<th>Before RS</th>
<th>After RS</th>
<th>Significant?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Passing Attempts (as % of Total Vehicles)</td>
<td>1.6%</td>
<td>1.5%</td>
<td>No</td>
</tr>
<tr>
<td>Passing Attempts (as % of Vehicles in Passing Position)</td>
<td>9.9%</td>
<td>10.6%</td>
<td>No</td>
</tr>
<tr>
<td>Aborted Passing Attempts (as % of Total Passing Attempts)</td>
<td>2.3%</td>
<td>2.3%</td>
<td>No</td>
</tr>
</tbody>
</table>
Encroachment Results

~50,000 total vehicular observations

<table>
<thead>
<tr>
<th>Geometry</th>
<th>EDGELINE Encroachments*</th>
<th>CENTERLINE Encroachments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
</tr>
<tr>
<td><strong>Tangent</strong></td>
<td>10.5%</td>
<td>6.6%</td>
</tr>
<tr>
<td><strong>Left Curves</strong></td>
<td>13.2%</td>
<td>4.5%</td>
</tr>
<tr>
<td><strong>Right Curves</strong></td>
<td>11.6%</td>
<td>6.6%</td>
</tr>
</tbody>
</table>

Reduced “Corner Cutting”

*Only sites where SRS were installed
## Lane Positioning Results

### CLRS-Only

<table>
<thead>
<tr>
<th>Geometry</th>
<th>LEFT of Center</th>
<th>CENTERED</th>
<th>RIGHT of Center</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Significant?</td>
</tr>
<tr>
<td>Tangent</td>
<td>22.3%</td>
<td>18.6%</td>
<td>Yes</td>
</tr>
<tr>
<td>Left Curves</td>
<td>40.8%</td>
<td>19.4%</td>
<td>Yes</td>
</tr>
<tr>
<td>Right Curves</td>
<td>6.3%</td>
<td>7.1%</td>
<td>No</td>
</tr>
</tbody>
</table>

### CLRS & SRS

<table>
<thead>
<tr>
<th>Geometry</th>
<th>LEFT of Center</th>
<th>CENTERED</th>
<th>RIGHT of Center</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>Significant?</td>
</tr>
<tr>
<td>Tangent</td>
<td>32.9%</td>
<td>9.6%</td>
<td>Yes</td>
</tr>
<tr>
<td>Left Curves</td>
<td>20.0%</td>
<td>4.5%</td>
<td>Yes</td>
</tr>
<tr>
<td>Right Curves</td>
<td>21.5%</td>
<td>1.8%</td>
<td>Yes</td>
</tr>
</tbody>
</table>
Conclusions - Driver Behavior

- Centerline rumble strips
  - Improve central lane positioning tendencies
  - Decrease centerline encroachments
    - “Corner-cutting” through left-curves
  - Do not negatively impact passing maneuvers

- Shoulder rumble strips (in addition to CLRS)
  - Additional improvements to central lane positioning
  - Decrease edgeline encroachments
    - “Corner-cutting” through right curves
RUMBLE STRIP EVALUATION #2: Impacts on Driver Behavior while Passing Bicyclists
Data Collection

- Four video cameras per site
- 2 WSU bikers per site
  - Continuous 1 mile loops
  - One biker always on either side
- 10 loops ridden in each position
  - Center of shoulder
  - Left shoulder edge
  - Right lane edge
- 5 hours
For each vehicle passing a bicyclist:
- Bicyclist positioning within the lane or shoulder
- Vehicle type
- Number of cyclists
- Opposing vehicle presence
- Did the vehicle contact the centerline?
- Did the vehicle cross at least halfway into the opposing lane?
Full CLRS Crossover
Group of Cyclists (No CLRS)
## Bicycle Study Results

<table>
<thead>
<tr>
<th>MOE</th>
<th>% of Vehicles</th>
<th>Percent Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>w/o CLRS</td>
<td>w/ CLRS</td>
</tr>
<tr>
<td>Vehicle Contacted the Centerline</td>
<td>79.0%</td>
<td>71.1%</td>
</tr>
<tr>
<td>Vehicle Crossed at Least Halfway into Opposing Lane</td>
<td>19.7%</td>
<td>14.2%</td>
</tr>
</tbody>
</table>

* Statistically Significant
Conclusions – Bicyclist Impacts

- While passing bicyclists where CLRS are present, drivers are:
  - Less likely to contact or cross the centerline
    - Particularly for individual bicyclists
  - More likely to crowd the bicyclist
    - This increases the more leftward the bicyclists’ position
- “Share the Road” signs had little impact on the lateral positioning of vehicles
RUMBLE STRIP EVALUATION #3: Roadside Noise Impacts
Field Study

- 12 sites
- Chrysler minivan used as test vehicle (55 mph)
- 40 test vehicle passes per site
  - “Controlled pass-by” (CPB) method
  - 20 on CLRS
  - 20 off CLRS
  - Additional 20 passes on SRS (where present)
- Random truck pass-bys were also recorded
  - All were “off” rumble strips
- 3 center depth measurements per site
Objectives

- Determine increases in roadside noise associated with rumble strips
- Determine effects of:
  - Depth
  - Pavement type
  - Baseline noise
Example Noise Measurement

- Recorded peak noise (dBA) for each pass-by
## Site Characteristics

<table>
<thead>
<tr>
<th>Highway</th>
<th>Pavement Type</th>
<th>Rumble Strip Type</th>
<th>Depth (in) (CLRS, SRS)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M-57 (A)</td>
<td>Chipseal</td>
<td>CLRS</td>
<td>0.25</td>
</tr>
<tr>
<td>M-57 (B)</td>
<td>Chipseal</td>
<td>CLRS</td>
<td>0.44</td>
</tr>
<tr>
<td>M-179</td>
<td>Chipseal</td>
<td>CLRS</td>
<td>0.69</td>
</tr>
<tr>
<td>M-72 (A)</td>
<td>Chipseal</td>
<td>CLRS</td>
<td>0.50</td>
</tr>
<tr>
<td>M-72 (B)</td>
<td>Chipseal</td>
<td>CLRS</td>
<td>0.56</td>
</tr>
<tr>
<td>M-28</td>
<td>Chipseal</td>
<td>CLRS</td>
<td>0.31</td>
</tr>
<tr>
<td>M-55</td>
<td>Chipseal</td>
<td>CLRS &amp; SRS</td>
<td>0.38, 0.5</td>
</tr>
<tr>
<td>M-19</td>
<td>HMA</td>
<td>CLRS</td>
<td>0.44</td>
</tr>
<tr>
<td>M-136</td>
<td>HMA</td>
<td>CLRS</td>
<td>0.38</td>
</tr>
<tr>
<td>M-43</td>
<td>HMA</td>
<td>CLRS &amp; SRS</td>
<td>0.56, 0.56</td>
</tr>
<tr>
<td>M-25</td>
<td>HMA</td>
<td>CLRS &amp; SRS</td>
<td>0.44, 0.44</td>
</tr>
<tr>
<td>US-41</td>
<td>HMA</td>
<td>CLRS &amp; SRS</td>
<td>0.44, 0.50</td>
</tr>
</tbody>
</table>

Avg. CLRS Depth = 0.45” (same for chipseal and HMA)
Controlled Pass-by Results

![Graph showing mean peak noise levels for different vehicle characteristics. The graph includes mean (Typ.) and 95% confidence interval (Typ.) annotations. The x-axis represents the characteristic of the vehicle pass, and the y-axis represents the mean peak noise in dBA. Test Vehicle Baseline, Test Vehicle On CLRS, Test Vehicle On SRS, and Tractor Trailer are listed on the x-axis.]
CLRS Depth Effects

- **CLRS Depth ≥ 0.5 inch**
  - Mean Peak Noise = 84.62 dBA

- **CLRS Depth < 0.5 inch**
  - Mean Peak Noise = 77.82 dBA

95% Confidence Interval (Typ.)
Other Noise Effects

- Greater noise on chipseal pavements vs. HMA
  - Additional 2.6 decibels
  - Same effect on or off rumble strips
- Depth effect is greater on HMA than chipseal
  - HMA: 2.3 decibels per 1/16 inch
  - Chipseal: 1.4 decibels per 1/16 inch
In-Vehicle Noise

- How much noise is necessary to warn drivers?
  - No specific recommendations for rumble strips
  - 10 to 15 decibel increase above ambient provides sufficient warning stimulus (train horn literature)
  - Above 15 decibel increase may elicit startle response

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>1/4”</th>
<th>5/16”</th>
<th>3/8”</th>
<th>7/16”</th>
<th>1/2”</th>
<th>9/16”</th>
<th>5/8”</th>
<th>11/16”</th>
</tr>
</thead>
<tbody>
<tr>
<td>HMA</td>
<td>13.3</td>
<td>13.5</td>
<td>13.8</td>
<td>14.0</td>
<td>14.3</td>
<td>14.6</td>
<td>14.8</td>
<td>15.1</td>
</tr>
</tbody>
</table>
Recommended RS Depth

**Regression Results for Roadside Noise during CPB**

<table>
<thead>
<tr>
<th>Pavement Type</th>
<th>CPB Off Rumble Stips (dBₐ)</th>
<th>Predicted Peak Roadside Noise (50') during CLRS Contact (dBₐ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1/4”</td>
<td>5/16”</td>
</tr>
<tr>
<td>HMA</td>
<td>70.4</td>
<td>72.9</td>
</tr>
<tr>
<td>Chipseal</td>
<td>72.1</td>
<td>78.1</td>
</tr>
</tbody>
</table>

- Depths between 3/8” and 5/8” are recommended
  - Adequate in-vehicle noise
  - Roadside noise controlled
  - Allows for chipseal without re-milling
RUMBLE STRIP EVALUATION #4: Safety Impacts (Phase 2 Evaluation)
Rumble Strip Segments

- Confirmation of rumble strip installation
  - Installation dates and start/end points
  - 1,249 segments and 4,078 centerline miles
- Data obtained for each confirmed segment
  - Sufficiency data
  - Other geometric data
  - Traffic volumes
  - Target crashes
Target Crash Identification

- Queried non-intersection crashes 3 years before and after installation (exclude install yr)
  - 70,000+ candidates
- Manual review of UD-10
  - Diagram & description
  - Re-assignment of crash type
- Target crash definition
  - Cross-centerline crash preventable by CLRS
  - 6,000+ resulting target crashes
Target Crash Examples

Passenger advised that the driver fell asleep and went off the roadway near a hit-and-run culvert which caused under-carriage damage and pinned the driver in the car.

Vehicle #1 was W/1B on US-2, lost control, crossed the highway and rolled over in the south ditch, landing upright.
## Empirical Bayes Results

<table>
<thead>
<tr>
<th>Crash Category</th>
<th>Segments with CLRS Only</th>
<th></th>
<th></th>
<th>Segments with CLRS/SRS</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before</td>
<td>After</td>
<td>% Reduction (EB Analysis)</td>
<td>Before</td>
<td>After</td>
<td>% Reduction (EB Analysis)</td>
</tr>
<tr>
<td>Total Crashes</td>
<td>26,578</td>
<td>23,428</td>
<td>15.8</td>
<td>10,810</td>
<td>9,372</td>
<td>17.2</td>
</tr>
<tr>
<td>Target Crashes</td>
<td>2,780</td>
<td>1,911</td>
<td>27.3</td>
<td>1,195</td>
<td>745</td>
<td>32.8</td>
</tr>
<tr>
<td>Target – Wet Pavement</td>
<td>293</td>
<td>143</td>
<td>52.9</td>
<td>139</td>
<td>54</td>
<td>55.6</td>
</tr>
<tr>
<td>Target – Wintry Pavement</td>
<td>1,426</td>
<td>1,206</td>
<td>1.4</td>
<td>599</td>
<td>500</td>
<td>4.6</td>
</tr>
<tr>
<td>Target – Passing</td>
<td>306</td>
<td>166</td>
<td>42.8</td>
<td>126</td>
<td>83</td>
<td>35.7</td>
</tr>
<tr>
<td>Target – Impaired Driving</td>
<td>334</td>
<td>225</td>
<td>28.8</td>
<td>126</td>
<td>78</td>
<td>39.9</td>
</tr>
<tr>
<td>Target – Fatal</td>
<td>80</td>
<td>41</td>
<td>44.2</td>
<td>27</td>
<td>15</td>
<td>51.4</td>
</tr>
<tr>
<td>Target – A injury</td>
<td>205</td>
<td>145</td>
<td>32.0</td>
<td>113</td>
<td>61</td>
<td>32.5</td>
</tr>
<tr>
<td>Target – B injury</td>
<td>332</td>
<td>187</td>
<td>39.3</td>
<td>119</td>
<td>81</td>
<td>53.7</td>
</tr>
<tr>
<td>Target – C injury</td>
<td>403</td>
<td>307</td>
<td>27.9</td>
<td>202</td>
<td>114</td>
<td>35.2</td>
</tr>
<tr>
<td>Target – PDO</td>
<td>1,760</td>
<td>1,231</td>
<td>16.2</td>
<td>734</td>
<td>474</td>
<td>28.5</td>
</tr>
</tbody>
</table>
Conclusions – Safety Impacts

- CLRS reduced target cross-centerline crashes, particularly injury and fatal crashes
- Crash reductions were most pronounced where both CLRS and SRS were installed
- Reductions during adverse weather conditions reinforce anecdotal evidence that rumble strips improve lane-keeping during inclement weather
- Reductions involving passing or impaired drivers suggest improvements to high risk behavior
Benefit/Cost Ratio

- **Installation Costs**
  - 12 cents/ft
  - 10 year replacement cycle
  - $455,700 annually

- **Crash Benefits**
  - 400+ crashes prevented annually
  - $26,774,000 annually

- **Benefit/Cost Ratio**
  - 3% discount rate: \( B/C = 53 \)
  - 7% discount rate: \( B/C = 38 \)
Evaluating Safety Impacts of MDOT’s High-Tension Cable Median Barrier Installation Program

Peter Savolainen
Associate Professor
Iowa State University
Introduction

- Cross median crashes on freeways tend to lead to severe injury outcomes:
  - In Michigan, 683 head on crashes in interstates from 2008-2012, resulting in 33 fatalities and 78 incapacitating injuries

- Primary countermeasure to reduce these crashes is median barrier installation:
  - Concrete Barrier
  - Beam Guardrail
  - Cable Barrier
Cable Median Barrier

- Deflects laterally to absorb collision force
- Can be installed on up to 4:1 cross slopes
- Relatively easy to repair
- Cheaper to install than concrete or beam

Costs compared to other barrier types (data from WA):
- Cable barrier: $46 per foot
- ‘W-beam’ guardrail: $53 per foot
- Concrete barrier: $187 per foot
Cable Barrier Strike
MDOT Cable Median Barrier Program

Since 2008, MDOT has installed 300+ miles of cable median barrier on freeways with a high number of fatal cross-median crashes.
Data Collection – Installation Data

- MDOT provided installation data for all sections of cable median barrier, including:
  - Route number and MDOT region
  - Physical Road (PR) start and end points
  - Install date
  - Cable median type
Data Collection – Geometric Data

- Used MDOT Sufficiency File to obtain relevant data for freeway segments including:
  - Median type and width
  - Shoulder type and width
  - Number of lanes and width
- Other relevant data collected manually using Google Earth and Street View
Data Collection –
Other Relevant Data

- AADT (from MDOT Sufficiency File)
- Installation (engineering+construction) Costs
- Maintenance/Repair Costs
- Annual Precipitation and Snowfall (NOAA)
Data Collection – Target Crashes

- Identify median-involved crashes at cable median barrier locations (2004-2013 data):
  - Prior to cable barrier installation
  - After cable barrier installation
    - Exclude construction year

- Identify crashes on freeway sections with:
  - Concrete barrier
  - Traditional guardrail
  - No median barrier (w/ median < 100 ft.)
Data Collection – Manual UD-10 Review

Veh. #1 left the roadway on W/B I-196 for an unknown reason. Veh. #1 entered the median and then rolled over into the path of E/B Veh. #2. Driver #1 was deceased at the scene. Driver #2 had right foot and elbow pain, a deep laceration to the hand, left shoulder pain and numerous glass lacerations.

Vehicle 1 states that he was east on I-94 traveling in the driving lane when a Red traveling in the passing lane began passing him. He states that Jeep began to lose control and turn sideways coming into his lane. He states that to avoid hitting the jeep he hit his brakes which caused him to spin on the icy roads. He lost control and hit the cable barriers. There was not any contact between the red Jeep and Vehicle 1. The driver of vehicle one complained of minor injury. He was transported to Bronson by Pride Care. No citation was issued as the crash was clearly caused by the red Jeep coming into Vehicle 1 lane forcing him to take evasive action. There was no other information on the red Jeep.

Driver advised he is unsure of what occurred. He states he drove slightly onto the right shoulder and then lost control of his vehicle. From evidence on scene, U/O determined that #1 did run off the road onto the right shoulder where he lost control of the vehicle, traveled across both lanes of travel, striking the median guard cables. At this point the vehicle, slid under the guard cables into the ditch. Impact with the cables and support pole caused heavy damage to the vehicle.
Before and After Evaluation

- Total target crashes:
  - Before period: 3,784
  - After period: 4,090
## Before and After Crash Rates

<table>
<thead>
<tr>
<th>Crash Severity/Type</th>
<th>Average Annual Crash Rate (crashes per 100 MVMT)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Before Period</td>
</tr>
<tr>
<td>All Target Crashes</td>
<td>15.60</td>
</tr>
<tr>
<td>Target PDO &amp; C Crashes</td>
<td>12.90</td>
</tr>
<tr>
<td>Target B Crashes</td>
<td>1.85</td>
</tr>
<tr>
<td>Target K &amp; A Crashes</td>
<td>1.15</td>
</tr>
<tr>
<td>Median Crossover Crashes</td>
<td>2.66</td>
</tr>
<tr>
<td>Target Rollover Crashes</td>
<td>4.88</td>
</tr>
</tbody>
</table>
## Cable Barrier Performance

<table>
<thead>
<tr>
<th>Cable Barrier Crash Outcome Scenario</th>
<th>After Period Cable Barrier Strikes by Type and Severity</th>
<th>Percent of Total Cable Barrier Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PDO</td>
<td>C</td>
</tr>
<tr>
<td>Contained by cable barrier in median</td>
<td>No.</td>
<td>2,861</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>87.2%</td>
</tr>
<tr>
<td>Struck cable barrier and re-directed back onto travel lanes</td>
<td>No.</td>
<td>222</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>79.3%</td>
</tr>
<tr>
<td>Penetrated cable barrier but contained in median</td>
<td>No.</td>
<td>55</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>64.0%</td>
</tr>
<tr>
<td>Penetrated cable barrier and entered opposing lanes (struck opp. veh)</td>
<td>No.</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>0.0%</td>
</tr>
<tr>
<td>Penetrated cable barrier and entered opposing lanes (did not strike opp. veh)</td>
<td>No.</td>
<td>10</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>43.5%</td>
</tr>
<tr>
<td>Total Cable Barrier Crashes</td>
<td>No.</td>
<td>3,148</td>
</tr>
<tr>
<td></td>
<td>%</td>
<td>85.7%</td>
</tr>
</tbody>
</table>
Comparison with Other Barrier Types

- Thrie-beam: 2,339 target crashes (210 mi.)
- Concrete barrier: 11,925 target crashes (226 mi.)
## Comparison With Other Barrier Types

<table>
<thead>
<tr>
<th>Barrier Type</th>
<th>Percent Vehicles Contained in Median</th>
<th>Percent Vehicles Penetrating</th>
<th>Percent Vehicles Re-Directed Back onto Travel Lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cable Barrier</td>
<td>89.3%</td>
<td>3.1%</td>
<td>7.6%</td>
</tr>
<tr>
<td>Thrie-Beam</td>
<td>83.4%</td>
<td>0.8%</td>
<td>15.8%</td>
</tr>
<tr>
<td>Concrete Barrier</td>
<td>68.9%</td>
<td>0.1%</td>
<td>31.1%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Cable Barrier</th>
<th>Thrie-Beam Guardrail</th>
<th>Concrete Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No.</td>
<td>%</td>
<td>No.</td>
</tr>
<tr>
<td>Single-Vehicle</td>
<td>3,214</td>
<td>87.5%</td>
<td>1,891</td>
</tr>
<tr>
<td>Multi-Vehicle</td>
<td>460</td>
<td>12.5%</td>
<td>448</td>
</tr>
<tr>
<td>Total</td>
<td>3,674</td>
<td>100.0%</td>
<td>2,339</td>
</tr>
</tbody>
</table>
Development of SPFs

Safety Performance Functions (SPFs) developed:

\[ \lambda_i = X_{Li} \exp(\beta_0 + \beta_1 X_{1i} + \beta_2 X_{2i} + \ldots + \beta_k X_{ki}) \]

Where:
- \( \lambda_i \): Predicted number of crashes/yr per segment
- \( X_{Li} \): Length of segment in miles
- \( \beta_0 \): Intercept term
- \( \beta_i \): Estimable parameters
- \( X_i \): Explanatory variables (AADT, median width, etc.)
SPF Results – Crash Severity

Predicted PDO/C Target Crashes Before and After Cable Median Barrier Installation

- PDO/C Before
- PDO/C After

Predicted K/A Target Crashes Before and After Cable Median Barrier Installation

- K/A Before
- K/A After

Predicted B Target Crashes Before and After Cable Median Barrier Installation

- B Before
- B After
SPF Results – Control Segments (w/o barrier)
Evaluation of Effectiveness – Empirical Bayes Analysis

- Determine the best estimate of safety effectiveness of installing cable median barrier:
  - Before and After Empirical Bayes Design

- Accounts for possible regression-to-the-mean effect and selectivity bias
- Uses combination of actual pre-installation crashes and predicted crashes from regression model
Evaluation of Effectiveness – CMFs from EB analysis

- Crash modification factors (CMFs) were developed using EB analysis:
  - PDO/C Crashes: 155 percent increase
  - B Crashes: 1 percent increase
  - K/A Crashes: 33 percent decrease
## Factors Affecting PDO/C-injury Crashes

<table>
<thead>
<tr>
<th>Criterion</th>
<th>Values</th>
<th>Percent Change in PDO/C/Crashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of lanes</td>
<td>2 lanes</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>3 or more lanes</td>
<td>39.7% decrease</td>
</tr>
<tr>
<td>Lateral clearance</td>
<td>More than 20.0 ft</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>10.0 to 20.0 ft</td>
<td>58.2% increase</td>
</tr>
<tr>
<td></td>
<td>Less than 10.0 ft</td>
<td>144.2% increase</td>
</tr>
<tr>
<td>Snowfall</td>
<td>0.0 to 39.9 inches</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>40.0 to 49.9 inches</td>
<td>27.3% increase</td>
</tr>
<tr>
<td></td>
<td>50.0 to 69.9 inches</td>
<td>70.2% increase</td>
</tr>
<tr>
<td></td>
<td>70.0 inches or above</td>
<td>122.3% increase</td>
</tr>
<tr>
<td>Horizontal Curvature</td>
<td>No Curve</td>
<td>Baseline</td>
</tr>
<tr>
<td></td>
<td>Curve w/ radius 2,500-3500 feet</td>
<td>70.2% increase</td>
</tr>
<tr>
<td></td>
<td>Curve w/ radius &lt;2,500 feet</td>
<td>104.2% increase</td>
</tr>
</tbody>
</table>
Economic Analysis

- **Cable Barrier Costs:**
  - Installation: $155,622 per mile
  - Maintenance/Repair: $849 per repair (crash)

- **“Blended” Crash Costs:**
  - PDO/C/B crash: $9,100 per crash
  - K or A injury: $258,300 per person

- **Time-of-Return:** 13.36 years
Conclusions

- Cable median barriers 97% effective in preventing penetrations
- Cross-median crash rate reduced 87% after cable barrier installation
- Cable barrier resulted in fewer injuries and lower rate of re-direction onto roadway compared with other barrier types
- K/A crashes reduced by 33%
- Cable barrier is cost effective solution to reducing cross-median crashes
Questions?

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