Overview

- General Methodology
- Treatments
  - Installation of traffic signals - with and without left-turn lanes (NCDOT)
  - Intersection collision warning system
  - Red light indicators
- Questions
Methodology

- Define strategies
- Identify agencies and installation details
- Determine data collection period
- Develop/modify evaluation design
- Collect before period data
- Collect after period data
- Conduct evaluation (Empirical Bayes)
Study Design

- Empirical Bayes (EB) before-after
  - Establish reference group
  - Predict safety for after period assuming no treatment
  - Observe actual safety for after period with treatment
  - Compare the two

- Reference group
  - Untreated sites adjacent to treated sites
  - As similar to treated sites as possible
  - Used to calibrate safety performance functions
Installation of Traffic Signals - with and without left-turn lanes
Safety evaluation of signal Installation with and without left turn lanes

• Left turn lanes can substantially increase the cost of a signal installation project due to new right of way and relocation of utilities
  – Cost of a signal project could increase *ten fold* with left turn lanes
• Additional safety benefit of turn lanes need to be determined
• Highway Safety Manual has CMFs for the signal plus left turn lane treatment, but only for *urban* areas
Objectives

• Develop crash modification factors (CMFs) for signal installation with and without left turn lanes
• Sponsored by the North Carolina Department of Transportation (NCDOT)
• Intersections on two lane roads in rural and suburban areas
• Before condition was minor road stop controlled intersections
• Five crash types were investigated: total, injury and fatal, rear end, and two types of frontal impact
• Empirical Bayes before-after evaluation
## Crash Modification Factors

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Site Type</th>
<th>No turn lanes</th>
<th>With left turn lanes</th>
<th>Effect due to turn lanes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>CMF</td>
<td>S.E.</td>
<td>CMF</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>3 leg</td>
<td>0.716</td>
<td>0.073</td>
<td>0.541</td>
</tr>
<tr>
<td></td>
<td>4 leg</td>
<td>0.614</td>
<td>0.037</td>
<td>0.569</td>
</tr>
<tr>
<td><strong>KABC</strong></td>
<td>3 leg</td>
<td>0.803</td>
<td>0.123</td>
<td>0.465</td>
</tr>
<tr>
<td></td>
<td>4 leg</td>
<td>0.601</td>
<td>0.052</td>
<td>0.484</td>
</tr>
<tr>
<td><strong>Rear end</strong></td>
<td>3 leg</td>
<td>1.198</td>
<td>0.182</td>
<td>0.505</td>
</tr>
<tr>
<td></td>
<td>4 leg</td>
<td>1.586</td>
<td>0.183</td>
<td>0.892</td>
</tr>
<tr>
<td><strong>Fr Imp 1</strong></td>
<td>3 leg</td>
<td>0.460</td>
<td>0.087</td>
<td>0.487</td>
</tr>
<tr>
<td></td>
<td>4 leg</td>
<td>0.413</td>
<td>0.034</td>
<td>0.365</td>
</tr>
<tr>
<td><strong>Fr Imp 2</strong></td>
<td>3 leg</td>
<td>0.492</td>
<td>0.086</td>
<td>0.550</td>
</tr>
<tr>
<td></td>
<td>4 leg</td>
<td>0.415</td>
<td>0.033</td>
<td>0.424</td>
</tr>
</tbody>
</table>
Findings

• Introducing signals led to reduction in total, injury, and the frontal impact crashes
  – When left turn lanes were added, rear end crashes decreased as well
• 4 leg intersections experienced a larger reduction in frontal impact crashes
  – 4 leg intersections experienced a larger increase in rear end crashes when left turn lanes were not added (and a smaller reduction in rear end crashes when left turn lanes were added)
• Injury and fatal crashes and rear end crashes benefited the most from left turn lanes.
• Overall, frontal impact crashes did not benefit from left turn lanes
Intersection Collision Warning System
Overview of ICWS

- Stop-controlled intersections with limited ISD
- Activates on mainline and/or minor approach
  - Alert drivers on mainline to vehicles entering
  - Assist minor approach drivers selecting gaps
  - Combination
- Post-mounted or overhead
Study Questions

- Do effects vary by type of treatment?
  - Overhead versus post-mounted
  - Mainline versus minor approach
  - Combination

- Do effects vary by site characteristics?
  - Traffic volume
  - Posted speed limit
  - Geometric characteristics
## Preliminary Results – Two-Lane at Two-Lane

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Total</th>
<th>Fatal and Injury</th>
<th>Right Angle</th>
<th>Rear-end</th>
<th>Daytime</th>
<th>Night time</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB estimate without strategy</td>
<td>895.06</td>
<td>450.66</td>
<td>469.06</td>
<td>117.84</td>
<td>682.64</td>
<td>129.77</td>
</tr>
<tr>
<td>Observed crashes with strategy</td>
<td>652</td>
<td>329</td>
<td>407</td>
<td>45</td>
<td>533</td>
<td>119</td>
</tr>
<tr>
<td>CMF</td>
<td>0.73</td>
<td>0.73</td>
<td>0.87</td>
<td>0.38</td>
<td>0.78</td>
<td>0.91</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.05</td>
<td>0.06</td>
<td>0.07</td>
<td>0.07</td>
<td>0.05</td>
<td>0.10</td>
</tr>
</tbody>
</table>
## Preliminary Results – Four-Lane at Two-Lane

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Total</th>
<th>Fatal and Injury</th>
<th>Right Angle</th>
<th>Rear-end</th>
<th>Daytime</th>
<th>Night time</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB estimate without strategy</td>
<td>422.33</td>
<td>212.10</td>
<td>245.30</td>
<td>42.52</td>
<td>354.18</td>
<td>88.64</td>
</tr>
<tr>
<td>Observed crashes with strategy</td>
<td>383</td>
<td>208</td>
<td>233</td>
<td>34</td>
<td>329</td>
<td>54</td>
</tr>
<tr>
<td>CMF</td>
<td>0.90</td>
<td>0.98</td>
<td>0.94</td>
<td>0.78</td>
<td>0.93</td>
<td>0.60</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.07</td>
<td>0.09</td>
<td>0.11</td>
<td>0.18</td>
<td>0.08</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Red Light Indicator Lights (RLIL)
Overview of RLIL

- RLIL activates simultaneously with red signal phase
- Enforcement officer receives visible indication of red phase
- Help law enforcement more efficiently and safely issue citations
Study Questions

- Multiple crash types
  - Total crashes
  - Injury crashes
  - Angle crashes
  - Left-turn crashes
  - Rear-end crashes
  - Disobeyed-signal crashes

- Do effects vary by treatment conditions?

- Do effects vary by site characteristics?
Volunteer State

Florida

- 108 intersections
  - 365 site-years before
  - 599 site-years after
- Installed 2004 - 2010
- White and blue indicators
- Major route AADT
  - Min: 5,955
  - Mean: 34,950
  - Max: 75,250
- Minor route AADT
  - Min: 945
  - Mean: 12,840
  - Max: 57,820
## Preliminary Results

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Total</th>
<th>Fatal and Injury</th>
<th>Right Angle</th>
<th>Left-Turn</th>
<th>Rear-End</th>
<th>Disobey</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB estimate without strategy</td>
<td>5,537.51</td>
<td>2,772.83</td>
<td>1,071.77</td>
<td>311.93</td>
<td>2,663.29</td>
<td>524.12</td>
</tr>
<tr>
<td>Observed crashes with strategy</td>
<td>5,012</td>
<td>2,411</td>
<td>927</td>
<td>305</td>
<td>2,329</td>
<td>351</td>
</tr>
<tr>
<td>CMF</td>
<td>0.91</td>
<td>0.87</td>
<td>0.86</td>
<td>0.98</td>
<td>0.87</td>
<td>0.67</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.02</td>
<td>0.03</td>
<td>0.04</td>
<td>0.08</td>
<td>0.03</td>
<td>0.05</td>
</tr>
</tbody>
</table>
## Preliminary Results – Disaggregate

<table>
<thead>
<tr>
<th>Indicator Type</th>
<th>Total</th>
<th>Fatal and Injury</th>
<th>Right Angle</th>
<th>Left-Turn</th>
<th>Rear-End</th>
<th>Disobey</th>
</tr>
</thead>
<tbody>
<tr>
<td>White Incandescent</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>(67)</td>
<td>0.89</td>
<td>0.86</td>
<td>0.85</td>
<td>0.98</td>
<td>0.84</td>
<td>0.59</td>
</tr>
<tr>
<td></td>
<td>(0.03)</td>
<td>(0.03)</td>
<td>(0.05)</td>
<td>(0.09)</td>
<td>(0.03)</td>
<td>(0.05)</td>
</tr>
<tr>
<td>Blue LED (41)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.95</td>
<td>0.88</td>
<td>0.89</td>
<td>0.96</td>
<td>0.94</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>(0.04)</td>
<td>(0.04)</td>
<td>(0.07)</td>
<td>(0.14)</td>
<td>(0.05)</td>
<td>(0.10)</td>
</tr>
</tbody>
</table>
## Preliminary Results – Disaggregate

<table>
<thead>
<tr>
<th>Area Type</th>
<th>Total</th>
<th>Fatal and Injury</th>
<th>Right Angle</th>
<th>Left-Turn</th>
<th>Rear-End</th>
<th>Disobey</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rural (16)</td>
<td>0.68 (0.05)</td>
<td>0.60 (0.06)</td>
<td>0.48 (0.08)</td>
<td>0.85 (0.19)</td>
<td>0.69 (0.07)</td>
<td>0.40 (0.09)</td>
</tr>
<tr>
<td>Urban (92)</td>
<td>0.93 (0.02)</td>
<td>0.90 (0.03)</td>
<td>0.91 (0.04)</td>
<td>0.99 (0.08)</td>
<td>0.89 (0.03)</td>
<td>0.70 (0.05)</td>
</tr>
</tbody>
</table>
Questions
Recently Developed Roadway CMFs

Nancy Lefler, VHB
ATSIP Traffic Records Forum, 2014
Overview

- **Treatments**
  - Median barriers and rumble strips
  - Edgeline rumble stripEs on curves
  - Combination of edgeline and centerline rumble strips

- **Questions**
Median Barriers with Rumble Strips
Cable Median Barrier with Inside Shoulder Rumble Strips

- Cable median barriers introduced in the United States in the 60’s
- Very few studies have examined the combination of cable barrier with inside shoulder rumble strips
- Data from Kentucky, Illinois, Wisconsin, and Missouri used in a before-after evaluation
Objectives

- Develop crash modification factors (CMFs) for combination of cable median barrier and inside shoulder rumble strips
- Empirical Bayes before-after evaluation
- Kentucky, Illinois, and Wisconsin
  - Before period: rumble strip without barrier
  - After period: rumble strip with barrier
  - Head-on & opposite direction sideswipe crashes were used as proxy for cross median crashes
- Missouri
  - Before period: no rumble strip or barrier
  - After period: rumble strip with barrier
  - Cross median indicator was available to determine whether a crash was crossmedian
## Crash Modification Factors

<table>
<thead>
<tr>
<th>State</th>
<th>Crash Type</th>
<th>EB Expected After</th>
<th>Observed After</th>
<th>CMF (S.E.)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Kentucky</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1151.3</td>
<td>1443</td>
<td>1.253 (0.041)</td>
</tr>
<tr>
<td></td>
<td>Injury (KABC)</td>
<td>269.5</td>
<td>292</td>
<td>1.082 (0.072)</td>
</tr>
<tr>
<td></td>
<td>Injury (KAB)</td>
<td>156.5</td>
<td>155</td>
<td>0.989 (0.088)</td>
</tr>
<tr>
<td></td>
<td>Cross median</td>
<td>36.3</td>
<td>19</td>
<td>0.520 (0.125)</td>
</tr>
<tr>
<td><strong>Illinois</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>2168.1</td>
<td>2765</td>
<td>1.275 (0.033)</td>
</tr>
<tr>
<td></td>
<td>Injury (KABC)</td>
<td>594.2</td>
<td>519</td>
<td>0.873 (0.047)</td>
</tr>
<tr>
<td></td>
<td>Injury (KAB)</td>
<td>452.9</td>
<td>429</td>
<td>0.946 (0.057)</td>
</tr>
<tr>
<td></td>
<td>Cross median</td>
<td>23.3</td>
<td>12</td>
<td>0.512 (0.152)</td>
</tr>
<tr>
<td><strong>Missouri</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1781.0</td>
<td>2221</td>
<td>1.247 (0.034)</td>
</tr>
<tr>
<td></td>
<td>Injury (KABC)</td>
<td>589.1</td>
<td>439</td>
<td>0.745 (0.040)</td>
</tr>
<tr>
<td></td>
<td>Injury (KAB)</td>
<td>171.0</td>
<td>134</td>
<td>0.783 (0.073)</td>
</tr>
<tr>
<td></td>
<td>Cross median</td>
<td>24.3</td>
<td>1</td>
<td>0.040 (0.040)</td>
</tr>
</tbody>
</table>
Summary of Findings

- Cross median crashes decreased significantly in all states
- Largest reduction in cross median crashes were in Missouri
  - Combined effect of rumble strips and barrier?
  - Different definition for cross median?
- Total crashes increased significantly in all states (due to collisions with barriers)
- Data from Wisconsin will not be included in the final recommendations - lack of detailed information about crash severity in the before period
Edgeline Rumble StripEs on Curves
Shoulder Rumble Strips

- Alert drivers they are drifting off the road
- Especially dangerous if there are steep cliffs
ELRS on Curves

- Pavement marking applied directly over rumble
- ELRS applications
  - Milled rumble strips
  - Audible vibratory pavement markings
ELRS on Curves

- Goals
  - Provide better visibility for nighttime, wet pavement markings
  - Alert motorists as they depart the travel lane
Study Design – Study Questions

- Multiple crash types
  - Total
  - Fatal and injury
  - Run-off-road
  - Nighttime
  - Nighttime run-off-road

- Do effects vary by type of treatment?

- Do effects vary by site characteristics?
Volunteer States

- **Florida**
  - 32 curves
  - 6.41 miles
  - Audible-vibratory

- **Kentucky**
  - 229 curves
  - 15.6 miles
  - Milled strips

- **Mile-years of data**
  - 210.36 Before
  - 99.41 After
Results – Milled Rumble StripEs

- **Applicability**
  - Crash rate 3.40 crashes/mile/year before
  - Average AADT before 1,576
  - Average paved shoulder width 1.36 feet
  - Average degree of curve (radius) 23.4 degrees (245 feet)

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Total</th>
<th>Injury</th>
<th>Run-Off-Road</th>
<th>Night</th>
<th>Night Run-Off-Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed crashes with strategy</td>
<td>86</td>
<td>26</td>
<td>50</td>
<td>21</td>
<td>17</td>
</tr>
<tr>
<td>CMF</td>
<td>0.72</td>
<td>0.69</td>
<td>0.70</td>
<td>0.68</td>
<td>0.86</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.09</td>
<td>0.14</td>
<td>0.11</td>
<td>0.15</td>
<td>0.21</td>
</tr>
</tbody>
</table>
Results – Audible Vibratory Pavement Markings

- **Applicability**
  - Crash rate 1.79 crashes/mile/year before
  - Average AADT before 4,422
  - Average paved shoulder width 4.19 feet
  - Average degree of curve (radius) 2.33 degrees (2,460 feet)

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Total</th>
<th>Injury</th>
<th>Run-Off-Road</th>
<th>Night</th>
<th>Night Run-Off-Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observed crashes with strategy</td>
<td>81</td>
<td>51</td>
<td>35</td>
<td>38</td>
<td>20</td>
</tr>
<tr>
<td>CMF</td>
<td>0.70</td>
<td>0.89</td>
<td>0.76</td>
<td>0.79</td>
<td>0.97</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.09</td>
<td>0.14</td>
<td>0.14</td>
<td>0.14</td>
<td>0.23</td>
</tr>
</tbody>
</table>
## Results – Aggregate

**Applicability**
- Rural two-lane and rural multilane curves
- Milled rumble strips and audible vibratory markings

<table>
<thead>
<tr>
<th>Crash Type</th>
<th>Total</th>
<th>Injury</th>
<th>Run-Off-Road</th>
<th>Night</th>
<th>Night Run-Off-Road</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB estimate without strategy</td>
<td>234.87</td>
<td>94.74</td>
<td>116.93</td>
<td>78.92</td>
<td>40.14</td>
</tr>
<tr>
<td>Observed crashes with strategy</td>
<td>167</td>
<td>77</td>
<td>85</td>
<td>59</td>
<td>37</td>
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<tr>
<td>CMF</td>
<td>0.71</td>
<td>0.81</td>
<td>0.73</td>
<td>0.75</td>
<td>0.92</td>
</tr>
<tr>
<td>Standard error</td>
<td>0.06</td>
<td>0.10</td>
<td>0.09</td>
<td>0.10</td>
<td>0.16</td>
</tr>
</tbody>
</table>
Combination of Edgeline and Centerline Rumble Strips
Description of Treatment

- The application of center line and shoulder rumble strips on two-lane rural roads
- Intended to reduce crashes by alerting drivers that they are about to leave the travelled lane
- Research is available for shoulder or center line rumble strips used in isolation
- Knowledge of the combined treatment is limited
Objective

What is the effect of combining installations of shoulder or edgeline rumble strips with centerline rumble strips?

a) More than the sum of its parts.
b) Equal to the addition of the two effects.
c) The combined effect will have a marginal increase over the use of one.
d) The combined effect will be less than the individual effect.
Study Objectives

Objective was to estimate the safety effectiveness of this strategy as measured by crash frequency. Target crash types included:

- Total crashes (all types and severities combined).
- Injury crashes (K, A, B, and C injuries on KABCO scale).
- Run-off-road crashes (all severities combined).
- Head-on crashes (all severities combined).
- Sideswipe-opposite-direction crashes (all severities combined).
- *Intersection-related and animal crashes were excluded.*
Study Objectives

- A further objective was to address questions of interest such as:
  - Do effects vary by level of traffic volumes?
  - Do effects vary by the frequency of crashes before treatment?
  - Do effects vary by posted speed?
  - Do effects vary by lane width and shoulder width?
  - The evaluation of overall effectiveness included the consideration of the installation costs and crash savings in terms of the benefit-cost ratio.
States Contributing Data

- Kentucky, Missouri and Pennsylvania
- Sites are two-lane rural roads

**KY**
- SRS placed both on edge and in shoulder
- Includes projects where both installed at same time as part of resurfacing and as retrofits
- SRS existed previously in both cases

**MO**
- SRS placed on edgeline
- Installed at same time with no rumbles prior

**PA**
- SRS placed both on edge and in shoulder
- Installed at same time with no rumbles prior
## Aggregate Results – All States

<table>
<thead>
<tr>
<th></th>
<th>Total</th>
<th>Injury</th>
<th>Run-Off-Road</th>
<th>Head-On</th>
<th>Sideswipe-Opposite-Direction</th>
<th>Head-On+ Sideswipe-Opposite-Direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>EB estimate of</td>
<td>2409.00</td>
<td>986.63</td>
<td>712.11</td>
<td>102.64</td>
<td>101.41</td>
<td>204.05</td>
</tr>
<tr>
<td>crashes expected</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>in the after</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>period without</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>strategy</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Count of crashes</td>
<td>1,927</td>
<td>761</td>
<td>529</td>
<td>65</td>
<td>78</td>
<td>143</td>
</tr>
<tr>
<td>observed in the</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>Estimate of CMF</td>
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<td>0.771</td>
<td>0.742</td>
<td>0.632</td>
<td>0.767</td>
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<td>Standard error</td>
<td>0.025</td>
<td>0.034</td>
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</table>
Aggregate Results – Comparison to Previous Studies

- SRS NCHRP Report 641
  - CMF of 0.85 recommended for SVROR. The effect of combining center line and shoulder rumble strips further reduces run-off-road crashes with a CMF of 0.74 for dual application

- CLRS NCHRP Report 641
  - CMFs of 0.91 for total crashes, 0.88 for FI crashes, and 0.70 for head-on plus sideswipe-opposite-direction crashes recommended
  - The new results, estimate CMFs of 0.80 for all severities and 0.77 for fatal+injury for dual application, indicate that shoulder rumble strips further reduce all crashes.
  - However, the CMF of 0.70 for head-on plus sideswipe-opposite-direction crashes suggests that dual application does not further reduce crashes of this type, which is intuitive.
Summary

- The CMFs below are recommended
- Compared to Report 641, results suggest that the combined treatment further reduces run-off-road crashes. It also appears that shoulder rumble strips do not further reduce head-on plus sideswipe-opposite-direction crashes.

### Recommended CMFs.

<table>
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<th>Total</th>
<th>Injury</th>
<th>Run-Off-Road</th>
<th>Head-On</th>
<th>Sideswipe Opposite-Direction</th>
<th>Head-On+ Sideswipe-Opposite-Direction</th>
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<tbody>
<tr>
<td>CMF</td>
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</tbody>
</table>
Thank you!

Contact:
Nancy Lefler
nlefler@vhb.com
919-334-5604

For more information on FHWA DCMF: