Safety Evaluation of the Flashing Yellow Arrow Treatment

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Acknowledgments

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  - Nevada DOT
  - North Carolina DOT
  - City of Norman, Oklahoma
  - Oklahoma DOT
  - City of Edmond, Oklahoma
  - Oregon DOT
Conversion to Flashing Yellow Arrow (FYA)
Background

- Past studies showed decrease in crashes after FYA (unless converted from protected left turn)
- Most studies used only one state
- NCHRP 17-35 used multiple states but only had 32 sites which had not been protected before FYA
Objective

- Measure overall safety effect of FYA conversion through an before-after empirical Bayes study
- Use large group of converted signals from multiple states
- Develop CMFs for:
  - Total intersection crashes
  - Intersection Injury and fatal crashes
  - Intersection Rear End Crashes
  - Intersection Angle Crashes
  - Intersection Left Turn Crashes
  - Intersection Left Turn with Opposing Through Crashes (LTOT)
Data

- Oklahoma
- Oregon
- Nevada
- North Carolina
Oklahoma

- City of Norman conducted a “blanket” installation of FYA from 2011 to 2013
- All signalized intersections with exclusive left turn lanes
- Most were 5-section protected-permissive signal heads to 4-section FYA heads
- Reference/comparison group had to be identified from another similar city (Edmond)

Source: Oklahoma State Travel Map 2016
Oregon

- Oregon DOT has been installing FYA statewide for years (early adopter)
- Preconversion mix of protected-permissive (majority), permissive, and protected
- Almost all FYA are 4-section head
- Reference/comparison group identified from statewide signal inventory

Source: ESRI
Nevada

- Statewide installations of FYA from 2011 to 2013
- All were 5-section protected-permissive signal head to a 4-section FYA head
- Early installations were high crash locations; later ones more systemic
- Reference/comparison group identified from planned FYA installations and very recent FYA installations

Source: ESRI
North Carolina

- NCDOT provided data from their evaluation of FYA
- Reference/comparison sites identified from lists of future FYA installations and very recent FYA installations
- Preconversion mix of protected-permissive (majority), permissive, and protected

Source: NCDOT
# Treatment Categories

<table>
<thead>
<tr>
<th>Category</th>
<th># Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional PPLT to FYA PPLT on one road (3-leg)</td>
<td>40</td>
</tr>
<tr>
<td>Traditional PPLT to FYA PPLT on one road (4-leg)</td>
<td>136</td>
</tr>
<tr>
<td>Traditional PPLT to FYA PPLT on both roads (4-leg)</td>
<td>64</td>
</tr>
<tr>
<td>Permissive or traditional PPLT to FYA permissive on one road (4-leg)</td>
<td>25</td>
</tr>
<tr>
<td>Permissive to FYA permissive on one road (4-leg)</td>
<td>12</td>
</tr>
<tr>
<td>At least one protected approach to FYA PPLT (4-leg)</td>
<td>18</td>
</tr>
<tr>
<td>At least one protected approach to FYA PPLT with time of day changes (4-leg)</td>
<td>12</td>
</tr>
</tbody>
</table>

**Note:** 307 treated sites and 408 Reference/Comparison Sites from the 4 States
Safety Performance Functions (SPFs)

- Separate SPFs by State by Crash Type
  - AADT (Major and Minor)
  - Number of Legs
  - Left turn phasing (maximum left turn protection)
  - Number of through lanes on the major road
  - Presence/absence of median on the major road
  - Number of approaches with left turn lanes

- SPF Form:

\[ Y = \exp(a_0 + a_1 X_1 + a_2 X_2 + \ldots + a_n X_n) \]

- \( Y \) = predicted number of crashes
- \( X \)'s are site characteristics
- \( a \)'s are coefficients
## CMF Results – Conversions from Protected/Permissive and Permissive

<table>
<thead>
<tr>
<th>Treatment Category</th>
<th>Total</th>
<th>KABC</th>
<th>LT</th>
<th>LTOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional PPLT to FYA PPLT on one road (3-leg)</td>
<td>0.85</td>
<td>0.79</td>
<td>0.80</td>
<td>0.85</td>
</tr>
<tr>
<td>Traditional PPLT to FYA PPLT on one road (4-leg)</td>
<td>0.89</td>
<td>0.80</td>
<td>0.75</td>
<td>0.62</td>
</tr>
<tr>
<td>Traditional PPLT to FYA PPLT on both roads (4-leg)</td>
<td>0.82</td>
<td>0.78</td>
<td>0.62</td>
<td>0.51</td>
</tr>
<tr>
<td>Permissive or traditional PPLT to FYA permissive on one road (4-leg)</td>
<td>1.00</td>
<td>0.81</td>
<td>0.73</td>
<td>0.73</td>
</tr>
<tr>
<td>Permissive to FYA permissive on one road (4-leg)</td>
<td>0.92</td>
<td>0.79</td>
<td>0.61</td>
<td>0.55</td>
</tr>
</tbody>
</table>

**Note:** CMFs in bold statistically different from 1.0 at the 0.05 significance level
## CMF Results – Conversions from Protected

<table>
<thead>
<tr>
<th>Treatment Category</th>
<th>Total</th>
<th>KABC</th>
<th>LT</th>
<th>LTOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least one protected approach to FYA PPLT (4-leg)</td>
<td>1.05</td>
<td>1.01</td>
<td>1.55</td>
<td>1.91</td>
</tr>
<tr>
<td>At least one protected approach to FYA PPLT with time of day changes (4-leg)</td>
<td>0.97</td>
<td>1.09</td>
<td>1.27</td>
<td>1.15</td>
</tr>
</tbody>
</table>

**Note:** CMFs in bold statistically different from 1.0 at the 0.05 significance level
## CMF by State for Traditional PPLT to FYA PPLT on one road (4-leg)

<table>
<thead>
<tr>
<th>State</th>
<th>Total</th>
<th>KABC</th>
<th>LT</th>
<th>LTOT</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oklahoma</td>
<td>1.13</td>
<td>0.92</td>
<td>0.80</td>
<td>0.73</td>
</tr>
<tr>
<td>Oregon</td>
<td>0.72</td>
<td>0.71</td>
<td>0.58</td>
<td>0.58</td>
</tr>
<tr>
<td>Nevada</td>
<td>0.96</td>
<td>0.94</td>
<td>1.18</td>
<td>n/a</td>
</tr>
<tr>
<td>North Carolina</td>
<td>0.89</td>
<td>0.77</td>
<td>0.63</td>
<td>0.61</td>
</tr>
</tbody>
</table>

**Note:** CMFs in bold statistically different from 1.0 at the 0.05 significance level
Economic Analysis

- Benefit
  - Crash rates from study sites
  - Crash costs from USDOT

- Cost
  - Oklahoma and Oregon provided cost information; Illinois DOT evaluation report also contained cost information
  - Assumed cost was $6,000 per approach leg (conservative)
  - Service life assumed to be 10 years
  - Assumed no additional annual maintenance cost compared to the previous signal head
Crash Modification Function for LTOT crashes in Category 2

- Traditional PPLT to FYA PPLT on one road (4-leg)

\[ CMF = 0.694 \times (\text{Exp bef per year})^{-0.2626} \]

*Exp bef per year* = the EB expected LTOT crashes per year at the intersection level in the before period (i.e., before the FYA was implemented).
## Economic Analysis

<table>
<thead>
<tr>
<th>Treatment Category</th>
<th>B/C ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>Traditional PPLT to FYA PPLT on one road (3-leg)</td>
<td>84:1</td>
</tr>
<tr>
<td>Traditional PPLT to FYA PPLT on one road (4-leg)</td>
<td>69:1</td>
</tr>
<tr>
<td>Traditional PPLT to FYA PPLT on both roads (4-leg)</td>
<td>56:1</td>
</tr>
<tr>
<td>Permissive or traditional PPLT to FYA permissive on one road (4-leg)</td>
<td>144:1</td>
</tr>
<tr>
<td>Permissive to FYA permissive on one road (4-leg)</td>
<td>89:1</td>
</tr>
</tbody>
</table>
Limitations

- Left turn volumes were not available

- Evaluation focused on intersection level crashes
  - Could not reliably determine approach level crashes from coded crash reports
Questions?