SAFETY IMPACTS OF FLASHING RED ARROW PROTECTED-PERMISSIVE LEFT-TURN CONTROL

Final Summary, BRTB Traffic Signal Subcommittee Meeting
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PROTECTED-PERMISSIVE LEFT-TURN PHASING (PPLT)

Standard “doghouse” arrangement with circular green

Balances safety and capacity

Exclusive/Permissive (EP) = Protected-Permissive (PPLT)

<table>
<thead>
<tr>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Improve LT safety over permissive only</td>
<td>• Not as safe as protected phasing</td>
</tr>
<tr>
<td>• Shorter cycle length</td>
<td>• Driver confusion potential</td>
</tr>
<tr>
<td>• Less delay, queuing, congestion, emissions, fuel consumption than protected only</td>
<td>• Yellow trap limits lead-lag phasing capability to T-intersections</td>
</tr>
</tbody>
</table>
FLAShING RED ARROW (FRA) A VARIATION OF PPLT DISPLAY

NO FUNCTIONAL OR PHASING DIFFERENCES BETWEEN FRA PPLT AND “DOGHOUSE” PPLT

FRA SPECIFIC ADVANTAGES
• Temporary or permanent mitigation of PPLT left turn crash pattern when protected-only left-turn phasing is not feasible
• No Yellow Trap
• Allows for lead-lag and twice-per-cycle left turn operations
• Can be protected by time of day, or by conditional statements in controller logic

HISTORY
Used in Maryland since early 1980’s

• Documented at 99 intersections
• Currently in use at 91 intersections owned by:
  - MDOT SHA (81)
  - Anne Arundel County (6)
  - Baltimore City (2)
  - Montgomery County (2)
RESEARCH PROJECT OVERVIEW

If we convert existing left-turn display with circular green ("doghouse") to FRA – while maintaining PPLT phasing – how will it affect the crashes?

To date, no rigorous research has been found in the literature body to quantify the safety benefits of FRA PPLT compared to PPLT with circular green.

Our methodology fits in HSM and FHWA guidelines for Crash Modification Factor (CMF) development. Results are locally calibrated, remain robust to variations in before-after traffic volumes, and account for availability of crash data at each site.
23 FRA-treated intersections with the following characteristics were selected for the study:

- 11 counties in six SHA Districts
- FRA installations between 2001-2016
- 3- or 4-leg configurations
- Main road speed limit: 30-55 mph
- Main road AADT: 17000-51000
- Number of opposing thru lanes 1-3

Crash Data:
- 2 to 4 Years for “Before” condition
- 9 months to 8 years for “After” condition
<table>
<thead>
<tr>
<th>No.</th>
<th>Intersection</th>
<th>County</th>
<th>Year FRA Installed</th>
<th>Speed Limit (mph)</th>
<th>Opposing Thru Lanes</th>
<th>Major Road AADT</th>
<th>Crash Data (Years)</th>
<th>Left-turn</th>
<th>Rear-End</th>
<th>Total</th>
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<tbody>
<tr>
<td>1</td>
<td>MD 170 &amp; Amtrak Way</td>
<td>AA</td>
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<td>2</td>
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<td>50</td>
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<td>27221</td>
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<td>3</td>
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<td>0.3</td>
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<tr>
<td>4</td>
<td>US 1 &amp; Mt Vista Rd.</td>
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<td>7</td>
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</table>
**METHODOLOGY**

Estimation of the Safety Performance Function (SPF) parameters:

- A control sample of 20 signalized intersections with “traditional” PPLT was established.
- 6 years of crash data and corresponding traffic volume records.
- The left-turn crashes and total crashes had FRA control not been implemented were estimated as a function of traffic volume using the following equations:

\[
\text{Estimated Left-turn Crashes} = \exp[a + \beta_1 \ln(AADT_{\text{Major Road Left-turn}}) + \beta_2 \ln(AADT_{\text{Minor Road}})]
\]

\[
\text{Estimated Total Crashes} = \exp[a + \beta_1 \ln(AADT_{\text{Major Road}}) + \beta_2 \ln(AADT_{\text{Minor Road}})]
\]

### Crash Type Specific SPF Parameters

<table>
<thead>
<tr>
<th>Crash Model</th>
<th>Parameter</th>
<th>β</th>
<th>SE</th>
<th>P-Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) SPF parameter estimates, crashes (all severities)</td>
<td>Intercept (a)</td>
<td>-9.293</td>
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<td>&lt;.0001</td>
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<td>Ln AADT Major Road Left-turn</td>
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<td></td>
<td>Over-Dispersion (k)</td>
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<td>Intercept (a)</td>
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<td>1.991</td>
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<td>Ln AADT Major Road</td>
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<td>Over-Dispersion (k)</td>
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</table>

<table>
<thead>
<tr>
<th>(b) SPF parameter estimates, injury crashes</th>
</tr>
</thead>
<tbody>
<tr>
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<tr>
<td>Left-turn Crashes</td>
</tr>
<tr>
<td>Intercept (a)</td>
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<tr>
<td>Ln AADT Major Road Left-turn</td>
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<tr>
<td>Total Crashes</td>
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<tr>
<td>Intercept (a)</td>
</tr>
<tr>
<td>Ln AADT Major Road</td>
</tr>
<tr>
<td>Ln AADT Minor Road</td>
</tr>
<tr>
<td>Over-Dispersion (k)</td>
</tr>
</tbody>
</table>
METHODOLOGY (CONTINUED)

Selected steps in the Empirical Bayes estimation procedure:

• Compute the number of crashes that would have taken place in the after period had FRA control not been implemented:

\[ B = m_a \times y_a \]

where, \( y_a \) = number of years in the after period

• Compute the variance for the number of crashes that would have taken place had FRA control not been implemented:

\[ \text{Var}(B) = m_b \times \frac{(R \times y_a)^2}{\left( \frac{k}{P_a} + y_b \right)^2} \]

• Determine the crash-type specific CMFs and the variance in the CMF value

\[
CMF = \frac{\sum A}{\sum B} \frac{1}{1 + \frac{\text{var}(\Sigma B)}{(\sum B)^2}}
\]

\[
\text{var}(CMF) = \frac{\left( \frac{\text{var}(\Sigma A)}{(\sum A)^2} + \frac{\text{var}(\Sigma B)}{(\sum B)^2} \right)^2}{\left[ 1 + \frac{\text{var}(\Sigma B)}{(\sum B)^2} \right]^2}
\]

A resulting CMF value of less than 1 indicates the modification reduced the crash frequency at an intersection.
Crash Modification Factor (CMF): unbiased estimate of index of effectiveness. It represents a factor of change in crash frequency resulting from a countermeasure.

Here, the treatment is changing the display on PPLT from 5-section signal head arrangement with circular green to PPLT on 3-section signal head with Flashing Red Arrow.
DISCUSSION

- Overall, the results show a 47% expected decrease in left-turn crash frequency and 25% decrease in the total crash frequency when PPLT with circular green is converted to PPLT with FRA.
- Left-turn injury crashes drop by 37%, and total injury crashes decrease 29%.
- General trend of significant crash reduction is not disrupted by FRA installations with short “after” crash history. Recent FRA deployments will be monitored to fully evaluate the long-term FRA impact there.
- AADT increase does not seem to have a negative impact on the number of crashes. Intersections with the highest AADT are among those with most significant safety improvement.
- Posted speed does not seem to have a distinguishable effect on safety (for example, some of the worst and best performing intersections have same posted speed and similar AADT).
- Location (county) of a site does not reveal an effect on safety pattern.
SUMMARY

• Application of FRA PPLT alleviates a LT safety problem while maintaining operational efficiency of a traditional PPLT display with circular green

• When conversion to fully protected phasing not feasible or easily attainable, FRA can be used as a temporary or a permanent countermeasure

• Allows for greater flexibility in phase sequence than doghouse PPLT: can use FRA with lead-lag or twice-per-cycle LT phasing

• Restricting LT operations to protected-only by time of day possible with FRA

• To address unique LT safety problems, FRA display allows for cycle-by-cycle suppression of the permissive LT with advanced controller logic
UPDATED LEFT-TURN PHASING GUIDELINES

Left Turn Phase Guidelines

Begin
Is Left Turn Demand > 2 Per Cycle? (Average in Highest Hour)

** Consider EXCLUSIVE - PERMISSIVE (E-P)

1 or 2 Lanes
- 1 Lane: Is Volume cross product > 70,000?
- 2 Lanes: Is Volume cross product > 144,000?

YES
NO

1 Lane
- Is Opposing Prevailing Speed > 45 mph?
- Is Sight Distance Restricted?
- Is there a severe left-turn crash problem which could not be corrected by Exclusive Phasing?

YES
NO

3 Lanes
- Is Volume cross product > 100,000?

YES
NO

Consider PERMISSIVE

Consider EXCLUSIVE

Consider PERMISSIVE

Yes
NO

Consider EXCLUSIVE

Consider EXCLUSIVE

Exclusive Left Turn Phase Guidelines

Is there sufficient time of day variation in left-turn or opposing demand that would justify E-P phasing?

YES
NO

Is opposing speed > 45 mph?

YES
NO

Is sight distance restricted?

YES
NO

Is there a severe left-turn crash problem that could be corrected by exclusive phasing?

YES
NO

Consider EXCLUSIVE

Consider EXCLUSIVE

Consider EXCLUSIVE

Consider TRADITIONAL E-P

Consider TRADITIONAL E-P

Exclusive-Permissive Left Turn Phase Guidelines

Is the left-turn movement on the main-road approach to a half-signal or Maryland-T?

YES
NO

Are motorists able to safely judge gaps in oncoming traffic?
(Do drivers appropriately comprehend the circular green phase as permissive?)

YES
NO

Consider PERMISSIVE

Consider PERMISSIVE

Are there severe crash patterns involving left turns within the intersection?

YES
NO

Consider CONFIGURATION

Consider CONFIGURATION

Note: This procedure applies to locations that have a separate left turn lane.
Note 2: Use this phasing pattern with the understanding that non-left-turn crashes may increase.

An opposing speed > 45 mph indicates a potential left-turn crash problem. Consider exclusive phasing realizing that non-left-turn crashes may increase.

See Exclusive-Permissive Left Turn Phases Guidelines

See Exclusive-Permissive Left Turn Phases Guidelines

MDOT
MARYLAND DEPARTMENT OF TRANSPORTATION
STATE HIGHWAY ADMINISTRATION
QUESTIONS?

Have a detailed question? Need the full report?

Please contact:

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