New in the MUTCD:
The Flashing Yellow Arrow

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University of Wisconsin - Madison
The FYA Story…

- Research started in early 1990’s
- My goal today is to tell you a 12 year story in 25 minutes or less
- And, I’m going to violate the first rule of presenting a good story…
  – I’m going to show you the last page first!
FYA Display Alternatives

1.

2.

3.

4. Indicates Flashing
• Now, the rest of the story...
PPLT Control

• Protected/Permissive Left-Turn (PPLT) Phasing
• Developed to increase operational efficiency
  – Exclusive phase for left-turns
  – Permissive phase for left-turns
  – All within the same signal cycle
  – Increase capacity / reduce delay
• Separate traffic signal
• PPLT Displays
  – 5-sections
  – Green arrow protected indication
  – Circular green permissive indication
  – For “shared” displays
    • Simultaneous through indication
Problems?

• Some traffic engineers think the circular green permissive indication is problematic
  – Dual meaning
• At least 4 variations of the permissive indication have been implemented
• Wide array of display arrangements and supplemental signs
Geographic Location of Unique PPLT Indications
Variety of PPLT Displays

Delaware

Michigan

Washington

Maryland

Seattle, WA

Cupertino, CA

Reno, NV

Sparks, NV
Driver confusion?
• **Project objective:** to evaluate the safety and effectiveness of different signal displays used with PPLT control
  – Determine PPLT usage in the U.S.
  – Evaluate safety and operational effects
  – Evaluate drivers’ understanding of various PPLT display arrangements and indications
  – Evaluate field implementations of selected display(s)
Research Objective

- Evaluate driver comprehension of selected PPLT signal displays using a driving simulator
- Evaluate driver behavior analysis utilizing data from both dynamic and static evaluation instruments
Agency Survey

• **Objective** - Determine the extent of PPLT signal display usage in the United States

• 107,219 intersections analyzed

• 30,870 intersections with PPLT signal phasing
Predominant PPLT Signal Display

5-SECTION CLUSTER
5-SECTION VERTICAL
4-SECTION VERTICAL
3-SECTION VERTICAL
5-SECTION HORIZONTAL
Photographic Driver Study

- 2,465 drivers
- 73,950 scenarios
- 58% male - 41% female
- Driver’s age
  - 27% < 24
  - 44% 24 to 44
  - 21% 45 to 65
  - 7% > 65
Permissive Indications

Permitted Indication

<table>
<thead>
<tr>
<th>Indication</th>
<th>Percent Correct Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>Green Ball</td>
<td>70.5</td>
</tr>
<tr>
<td>Flashing Yellow Ball</td>
<td>85.8</td>
</tr>
<tr>
<td>Flashing Yellow Arrow</td>
<td>75.2</td>
</tr>
<tr>
<td>Flashing Red Ball</td>
<td>63.8</td>
</tr>
<tr>
<td>Flashing Red Arrow</td>
<td>55.6</td>
</tr>
</tbody>
</table>
Driving Simulator
# Signal Displays

<table>
<thead>
<tr>
<th>Scenario&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Description</th>
<th>Lens Color and Arrangement</th>
<th>Left-Turn Indication&lt;sup&gt;b&lt;/sup&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Protected Mode</td>
</tr>
<tr>
<td>1,2</td>
<td>GB 5-section cluster</td>
<td><img src="image" alt="GB 5-section" /></td>
<td><img src="image" alt="GB 5-section Protected Mode" /></td>
</tr>
<tr>
<td>3,4</td>
<td>FYA 5-section cluster</td>
<td><img src="image" alt="FYA 5-section" /></td>
<td><img src="image" alt="FYA 5-section Protected Mode" /></td>
</tr>
<tr>
<td>5,6</td>
<td>GB/FYA – Sparks 5-section cluster</td>
<td><img src="image" alt="GB/FYA – Sparks" /></td>
<td><img src="image" alt="GB/FYA – Sparks Protected Mode" /></td>
</tr>
</tbody>
</table>

<sup>a</sup> Scenario numbering is not explicitly stated in the table, but can be inferred from the context.

<sup>b</sup> The left-turn indication images are not described in the text, but are represented in the table.

*Note: Images and colors are placeholders and should be interpreted as illustrations.*
### Signal Displays

<table>
<thead>
<tr>
<th>Scenario&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Description</th>
<th>Lens Color and Arrangement</th>
<th>Left-Turn Indication&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Protected Mode</th>
<th>Permitted Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>7,8</td>
<td>FYA 4-section vertical</td>
<td><img src="image1" alt="Lens Colors" /></td>
<td><img src="image2" alt="Left-Turn Indication" /></td>
<td><img src="image3" alt="Protected Mode" /></td>
<td><img src="image4" alt="Permitted Mode" /></td>
</tr>
<tr>
<td>9,10</td>
<td>GB 5-section vertical</td>
<td><img src="image5" alt="Lens Colors" /></td>
<td><img src="image6" alt="Left-Turn Indication" /></td>
<td><img src="image7" alt="Protected Mode" /></td>
<td><img src="image8" alt="Permitted Mode" /></td>
</tr>
<tr>
<td>11,12</td>
<td>FYA 5-section vertical</td>
<td><img src="image9" alt="Lens Colors" /></td>
<td><img src="image10" alt="Left-Turn Indication" /></td>
<td><img src="image11" alt="Protected Mode" /></td>
<td><img src="image12" alt="Permitted Mode" /></td>
</tr>
</tbody>
</table>

R = RED  Y = YELLOW  G = GREEN  Y = FLASHING YELLOW
• Display Performance Goals
  – Clearly distinguish between protected & permissive
  – Minimize confusion
  – Reduce assumption of right-of-way
  – Eliminate yellow trap
  – Allow protected-only or permissive-only
  – Eliminate need for:
    • Special signing
    • Special lenses or louvers
Study Summary

- 464 Drivers
  - 231 University of Massachusetts
  - 233 Texas Transportation Institute
- 228 males; 204 females completed the study
- 4,613 Scenarios evaluated
- Ages 21 to 79
Study Results

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GB</td>
</tr>
<tr>
<td>2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>RB</td>
</tr>
<tr>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GB</td>
</tr>
<tr>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FYA</td>
</tr>
<tr>
<td>5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GB</td>
</tr>
<tr>
<td>6</td>
<td></td>
</tr>
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<td></td>
<td>RB</td>
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<tr>
<td>7</td>
<td></td>
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<td></td>
<td>GB</td>
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<td>8</td>
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<td></td>
<td>RB</td>
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<td>9</td>
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<td></td>
<td>GB</td>
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<td>10</td>
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<td></td>
<td>RB</td>
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<tr>
<td>11</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GB</td>
</tr>
<tr>
<td>12</td>
<td></td>
</tr>
<tr>
<td></td>
<td>FYA</td>
</tr>
</tbody>
</table>

- GB: 5-Section Cluster
- FYA: 5-Section Cluster
- GB/FYA: 5-Section Cluster
- GB/FYA: 4-Section Vertical
- GB: 5-Section Vertical
- GB: 5-Section Vertical

TTI
UMass
## PPLT Display Components

<table>
<thead>
<tr>
<th>PPLT Display Component</th>
<th>Level</th>
<th>Obser.</th>
<th>Percent Correct</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Permissive Indication</strong></td>
<td>GB</td>
<td>845</td>
<td>77 ± 3</td>
<td>0.110</td>
</tr>
<tr>
<td></td>
<td>FYA</td>
<td>1264</td>
<td>73 ± 2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>GB/FYA</td>
<td>419</td>
<td>72 ± 4</td>
<td></td>
</tr>
<tr>
<td><strong>Display Arrangement</strong></td>
<td>5-Sect. Cluster</td>
<td>1260</td>
<td>73 ± 2</td>
<td>0.604</td>
</tr>
<tr>
<td></td>
<td>4-Sect. Vertical</td>
<td>422</td>
<td>75 ± 4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>5-Sect. Vertical</td>
<td>846</td>
<td>75 ± 3</td>
<td></td>
</tr>
<tr>
<td><strong>Location</strong></td>
<td>Shared</td>
<td>627</td>
<td>73 ± 3</td>
<td>0.303</td>
</tr>
<tr>
<td></td>
<td>Exclusive</td>
<td>1901</td>
<td>75 ± 2</td>
<td></td>
</tr>
<tr>
<td><strong>Thru Indication</strong></td>
<td>GB</td>
<td>627</td>
<td>74 ± 2</td>
<td>0.788</td>
</tr>
<tr>
<td></td>
<td>RB</td>
<td>1901</td>
<td>74 ± 2</td>
<td></td>
</tr>
</tbody>
</table>
Study Results

Findings of the driving simulator experiment include:

- Data showed a high level of comprehension with no variation between the different PPLT displays tested.

- The test drivers responded correctly 91 percent of the time with no statistical difference between the 12 PPLT displays.

- Data showed no statistical difference in driver comprehension when the data was analyzed by permissive indication, display, through indication, and location of the display.
Video-Based Static Evaluation
Fail Critical Responses

1. GB (216) | RB (218)
2. GB (216) | GB (215) | RB (215)
3. GB (216) | GB (215) | RB (216)
4. GB (216) | GB (215) | RB (216)
5. GB (216) | GB (215) | RB (216)
6. GB (216) | GB (215) | RB (216)
7. GB (216) | GB (215) | RB (216)
8. GB (216) | GB (215) | RB (216)
9. GB (216) | GB (215) | RB (216)
10. GB (216) | GB (215) | RB (216)
11. GB (216) | GB (215) | RB (216)
12. GB (216) | GB (215) | RB (216)
Results

Findings of the static experiment include:

- 83% (of 5,230 scenarios) correct response.
- Circular green significantly higher fail critical responses.
- Displays with the FYA permissive indication had significantly more correct responses than displays with the circular green permissive indication.
- PPLT displays with the four-section vertical display face had a significant amount of correct responses.
## Correct & Fail-Safe Responses

<table>
<thead>
<tr>
<th>Sc</th>
<th>Arrangement</th>
<th>Permitted Indication</th>
<th>Thru Indic</th>
<th>Percent Correct and FS Simulation</th>
<th>Percent Correct and FS Static</th>
<th>Difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Simulation</td>
<td>Static</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5-sec cluster</td>
<td>GB</td>
<td>GB</td>
<td>88</td>
<td>78</td>
<td>10</td>
</tr>
<tr>
<td>2</td>
<td>5-sec cluster</td>
<td>GB</td>
<td>RB</td>
<td>92</td>
<td>62</td>
<td>30</td>
</tr>
<tr>
<td>3</td>
<td>5-sec cluster</td>
<td>FYA</td>
<td>GB</td>
<td>90</td>
<td>86</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>5-sec cluster</td>
<td>FYA</td>
<td>RB</td>
<td>90</td>
<td>76</td>
<td>14</td>
</tr>
<tr>
<td>5</td>
<td>5-sec cluster</td>
<td>GB/FYA</td>
<td>GB</td>
<td>94</td>
<td>85</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>5-sec cluster</td>
<td>GB/FYA</td>
<td>RB</td>
<td>88</td>
<td>86</td>
<td>2</td>
</tr>
<tr>
<td>7</td>
<td>4-sec vertical</td>
<td>FYA</td>
<td>GB</td>
<td>92</td>
<td>89</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>4-sec vertical</td>
<td>FYA</td>
<td>RB</td>
<td>91</td>
<td>83</td>
<td>8</td>
</tr>
<tr>
<td>9</td>
<td>5-sec vertical</td>
<td>GB</td>
<td>GB</td>
<td>91</td>
<td>70</td>
<td>21</td>
</tr>
<tr>
<td>10</td>
<td>5-sec vertical</td>
<td>GB</td>
<td>RB</td>
<td>89</td>
<td>70</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>5-sec vertical</td>
<td>FYA</td>
<td>GB</td>
<td>87</td>
<td>86</td>
<td></td>
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<td>12</td>
<td>5-sec vertical</td>
<td>FYA</td>
<td>RB</td>
<td>89</td>
<td>83</td>
<td></td>
</tr>
</tbody>
</table>
Conclusions

• No Significant Difference in 12 PPLT Displays
  – Permissive Indication
  – Circular Green Permissive Indication

• First Observed Display
  – Driver Expectancy
  – Learning of Permissive Indications

• What Drivers Do vs. What Drivers Say
  – Drivers Often Base Decisions on Traffic
Project Results

- Flashing yellow arrow permissive left-turn indications was found to have a number of advantages:
  - Well understood
  - Significantly reduces left-turn confusion
  - No supplemental signs
  - Accommodate all phasing schemes
  - Operational

- Add to the MUTCD
FYA Display Alternatives

1.  
   
2.  
   
3.  
   
4.  

Indicates Flashing
FYA Implementation Sites

Implemented
Woodburn, Oregon (ODOT)
Broward County, Florida
Did you know that Jackson County is one of only two locations in the state in which flashing yellow arrows are being used for turn lanes? The other is Woodburn, which has two of the signals.

Jackson County has five signals, with a sixth planned. They are at the intersections of East Pine St. and Hamrick Rd. and Sage Rd. and Mason Way, as well as on Table Rock Road at Biddle, Vilas and Antelope roads.

The Federal Highway Administration is conducting a nationwide study by authorizing agencies to use flashing yellow arrows. Jackson County applied for and was approved to be part of the research. The project began in May and is part of a three-year study.

Typically, at intersections where left-turn lanes are present and a separate left-turn signal is displayed, vehicles may freely turn left while the green arrow is displayed. This is known as a protected left turn. When the red arrow is displayed, a driver must stop.

This is a safe but inefficient way to deal with left turns. To increase efficiency, a circular green indicator comes on after the green arrow goes off. This allows drivers to make left turns but requires them to yield to oncoming traffic. Unfortunately, studies have shown that drivers sometimes don’t clearly understand what is allowed and what isn’t with the circular green light.

In looking for a signal that clearly gives the message to left turners to yield to oncoming traffic, the flashing yellow light was developed.

It allows the left-hand turn that was formerly prohibited by the red arrow, but cautions drivers they must turn only when able to do so safely — in other words, by yielding to oncoming traffic.

Parts of the study include crash reports, motorist comments and traffic flow data, which are then forwarded to the federal government.

Comments would be appreciated as the study progresses. Address them to Jackson County Traffic Engineer Eric Niemeyer, c/o Jackson County Roads Department, or call 774-6230.

Dace Cochran, a patrol sergeant with the Jackson County Sheriff’s Department, writes a column on police issues. Questions or issues you’d like to see him address? Write him in care of the Mail Tribune Newsroom, P.O. Box 1108, Medford, OR 97501, or e-mail cochradc@jacksoncounty.org.
“My opinion is that if the intersection had flashing yellow arrows at the turn-lane, this accident may have been avoided… When I see a green light, my first reaction is “go” so I sometimes find myself responding to that trained response rather than the one that says “don’t go when another car is coming.” Alternatively, when I see a flashing yellow arrow, there is no question that I need to watch what I’m doing, look for approaching vehicles, and turn when it’s safe…”
Driver Comprehension and Behavioral Analysis of the Flashing Yellow Arrow Permissive Indication

- FYA Dual Indication Display Analysis
- Literature Review
- Analysis of Impact for FYA on Solid Yellow Arrow
- Eye Tracking Experiment
- FYA Driver Expectancy Analysis
- Impact of FYA on Pedestrian Applications
- Driver Comprehension
- Driver Comprehension and Behavioral Analysis of the Flashing Yellow Arrow Permissive Indication
- Pedestrian Comprehension
- Comprehension of Circular Green by PPLT Signal Position
Overview of Experimental Methodology

- Driving Simulator
  - 4 Experiments Total
- Follow-Up Static Evaluation
- Independent Static Evaluations
  - 6 Experiments Total
  - 2 Geographic Locations
- 950 Participants
- 11,600 Permissive Left-Turn Scenarios
HPL Driving Simulator

- 1995 Saturn Sedan
- 3 Projection Screens
- $150^\circ$ Field-of-View
- 60 Hz Refresh Rate
- Bose Surround Sound
- $1024 \times 768$ Resolution
Driving Simulator Experiment

- Development of Simulated Environment
  - Modules
  - Multiple factors
  - Counterbalancing
  - Opposing Gaps
  - Switch to test indication
- Beta Testing
- Experimental Procedure
- Data Collection & Analysis
Driver Eye Movement for Left-Turns

- Simulator Experiment
  - Eye and Head Tracker
- 3 Permissive Indications
- Traffic Scheme
• Driver Comprehension
• Fixations – Areas of Interest
  – Sequential Ordering
  – Duration (focus or glance)
Eye Tracking Experiment Findings

- Consistent Cues
- Consistent Scan Pattern by Driver
  - Opposing Traffic
  - Right to Left

<table>
<thead>
<tr>
<th></th>
<th>With Traffic</th>
<th>Without Traffic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cues Used</td>
<td>30</td>
<td>38</td>
</tr>
<tr>
<td>Opposing Traffic</td>
<td>28</td>
<td>35</td>
</tr>
<tr>
<td>Right to Left</td>
<td>32</td>
<td>40</td>
</tr>
</tbody>
</table>
Current Activities

• NCHRP 20-7
  – Field evaluation of installations
• New Language in the MUTCD
• Removal of ‘experimental’ status
• Rapidly growing number of installations
“Protected/Permissive Mode—The signal indications for protected/permissive mode left turns shall be provided by a separate four-section signal face that shall be capable of displaying, from top to bottom or left to right, one of the following sets of signal indications:

- Steady left-turn RED ARROW, steady left-turn YELLOW ARROW, flashing left-turn YELLOW ARROW, and steady left-turn GREEN ARROW signal indications, or
- Steady CIRCULAR RED, steady left-turn YELLOW ARROW, flashing left-turn YELLOW ARROW, and steady left-turn GREEN ARROW signal indications.”
“During the permissive left-turn movement, the left-turn signal face shall display a flashing left-turn YELLOW ARROW signal indication.”

“During the permissive left-turn movement, the signal faces for through traffic on the opposing approach shall simultaneously display green or yellow signal indications. If pedestrians crossing the lane or lanes used by the permissive left-turn movement to depart the intersection are controlled by pedestrian signal heads, the signal indications displayed by those pedestrian signal heads shall not be limited to any particular display.”
“A supplementary LEFT TURN YIELD ON FLASHING YELLOW (symbolic yellow arrow) (R10-XX) sign (see Figure 2B-19) may be placed adjacent to the left-turn signal face.”
The FYA Story...

• And now you know...the rest of the story!
Questions?

Have a good day!