SECOND INTERIM REPORT

FOR

NCHRP 3 - 54(2)

EVALUATION OF TRAFFIC SIGNAL DISPLAYS

FOR PROTECTED/PERMISSIVE LEFT-TURN CONTROL

July 2002

by

Kittelson & Associates, Inc.

In Association with

Siemens Gardner Transportation Systems

The University of Massachusetts – Amherst

Texas Transportation Institute
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NOTE: THIS DOCUMENT IS A WORKING DRAFT AND HAS NOT BEEN APPROVED BY NCHRP

This work was sponsored by the National Academy of Sciences in cooperation with the National Cooperative Highway Research Program (NCHRP), which is administered by the Transportation Research Board of the National Research Council.

The research reported herein was performed under NCHRP Project 3-54 by Kittelson & Associates, Inc. in association with Siemens Gardner Transportation Systems, the University of Massachusetts – Amherst, and the Texas Transportation Institute.

Disclaimer

This copy is an uncorrected draft as submitted by the research agency. The opinions and conclusions expressed or implied in the report are those of the research agency. They are not necessarily those of the Transportation Research Board, the National Academy of Sciences, the Federal Highway Administration, the Department of Transportation, or the individual panel members who participated in the National Cooperative Highway Research Program.
DEFINITIONS

The following list of definitions is intended to clarify the manner in which they are used in this report. All terms may not be used. The authors have attempted to be consistent in the use of different terms used throughout this interim report and various working papers. However, there has been a change in direction within the industry and in particular within the national committee on terminology. Currently, there is a disconnect in terminology as directed by the panel members for this project and the terminology used in the MUTCD. The authors will reach agreement with the research panel on the correct terminology to be used in the final report. For now, the definitions provided below attempts to cross reference various terminology used in this interim report and other sources within the traffic industry.

**Change Interval:** The yellow change interval follows the green right-of-way interval to warn traffic of an impending change in the right-of-way assignment. The yellow change interval may be followed by a red clearance interval.

**Cluster Head:** Also referred to as a doghouse display. Cluster head refers to a particular arrangement of signal indications where four of them are clustered together in the form of a square, and the fifth signal indication is mounted directly on the top, either centered or off to one side.

**Cycle Length:** See signal cycle.

**Doghouse:** See cluster head.

**Display:** The signal face as a unit (assembly) that conveys the message to the driver. The display consists of the individual sections configured in any way. This term may be used in reference to the signal head.

**Display Face:** The part of a signal head provided for controlling traffic in a single direction. Same as “signal face” and “display.”
**Exclusive Display:** A third display (signal head) on a single approach for controlling the left-turn movement.

**FRA:** Flashing Red Arrow permissive indication.

**FYA:** Flashing Yellow Arrow permissive indication.

**GB:** Green Ball permissive indication.

**Horizontal Head:** A particular arrangement of signal indications in a horizontal position. This term is the same as MUTCD horizontal display face, and the same as a horizontal display arrangement.

**Interval:** A discrete portion of the signal cycle during which the signal indications remain unchanged.

**Lagging Left Turn:** A phase sequence in which a protected left-turn phase follows the opposing through-movement phase.

**Lead Left Turn:** Indicates a phase sequence in which a protected left-turn phase precedes the opposing through-movement phase.

**Lead-Lead Left Turn:** Indicates a phase sequence in which two left-turn movements from opposite directions of a street are both served by leading protected phases.

**Lead-Lag Left Turn:** Indicates a phase sequence in which one left-turn movement is served by a leading protected phase and the other left-turn movement (from the opposite direction of the same street) is served by a lagging protected phase.

**Lag-Lag Left Turn:** Indicates a phase sequence in which two left-turn movements from opposite directions of a street are both served by lagging protected phases.
**Permissive Mode** \(^{(1)}\): A mode of traffic control signal operation in which left or right turns may be made when a CIRCULAR GREEN indication is displayed after the motorist yields to oncoming traffic or pedestrians.

**Permitted Mode:** See permissive mode.

**Phase:** A part of the traffic signal time cycle allocated to any combination of traffic movements receiving right-of-way simultaneously during one or more intervals.

**Phase Sequence:** The order in which a controller cycles through all phases.

**Preemption:** The term used when the normal signal sequence at an intersection is interrupted or altered in deference to a special situation such as the passage of a train, bridge opening, or the granting of the right-of-way to an emergency vehicle.

**Protected Mode** \(^{(2)}\): A mode of traffic control signal operation in which left or right turns may be made only when a left or right GREEN ARROW indication is displayed.

**Protected/Permissive Mode** \(^{(1)}\): A mode of traffic signal operation in which the left-turn movement may be protected in the protected mode during part of the signal cycle and unprotected in the permissive mode during another part of the cycle.

In this report, the term protected/permissive does not infer a particular phasing order, i.e., protected/permissive or permissive/protected. In practice, the phase sequence is of major

\(^{(1)}\) The Traffic Signals Technical Committee of the National Committee on Uniform Traffic Control Devices recently revised and clarified this definition.

\(^{(2)}\) The Traffic Signals Technical Committee of the National Committee on Uniform Traffic Control Devices recently revised and clarified this definition.
importance. For this reason, where the phase sequence or order is known in this report, it is addressed specifically. In all other cases this term is interchangeable.

**Shared Display:** A signal display is considered to be a shared display (or head) when it constitutes one of the two required displays for the through movement and also provides the left-turn movement indication. This is the same as a shared indication.

**Signal Cycle:** The total time required to complete one sequence of signal phases at a signalized intersection with pretimed operation or a sequence of those phases with traffic demand at a signalized intersection with traffic-actuated operation.

**Signal Display Arrangement:** The signal arrangement as a unit (assembly) that conveys the message to the driver. The display arrangement consists of the individual sections configured in any way. This term may be used in reference to the signal head.

**Signal Face:** The part of a signal head provided for controlling traffic in a single direction. This is the same as a display face.

**Signal Head:** An assembly containing one or more signal faces that may be designated as one-way, two-way, etc. See also signal display or signal display arrangement.

**Signal Indications:** The illumination of a signal lens, such as the green ball. Same as “signal display.”

**Signal Lens:** The part of a signal section through which light from the light source or reflectors phases and, in doing so, is directed into a prescribed pattern, is filtered to a prescribed color, and, where necessary, is provided with a prescribed symbol or message.

**Signal Section:** The assembly of a housing, lens, and light source with necessary components and supporting hardware to be used for providing one signal indication.

**Signal System:** Two or more traffic control signals operating in coordination.
**Track Clearance**: An initial interval of the railroad preemption special control mode during which traffic stopped on the railroad tracks when preemption is initiated is given a signal indication, allowing that traffic to clear the tracks before the train reaches the crossing.

**Vertical Stack**: A particular arrangement of signal indications in a vertical position. Also called vertical display arrangement, or vertical display face.

**Yellow Trap**: The typical yellow trap occurs when a signal changes from the permissive left-turn intervals in both directions to a lagging protected movement in only one direction. A motorist attempting to make a left turn on the permissive green ball becomes trapped in the intersection when their green ball turns yellow for the change interval (both for the through heads and any left-turn heads). The motorist who is attempting to clear the intersection also sees the adjacent through lanes receive the yellow ball for their change interval. The left-turner mistakenly believes that the opposing traffic now has the yellow change interval and makes the left-turn, in effect becoming a sneaker left-turner. The yellow trap occurs because the opposing traffic does not in fact receive a yellow change interval, but instead has a green ball in the through lanes and a protected left-turn arrow. The potential for serious conflict occurs between the sneaker left-turning vehicle and the opposing, non-stopping through traffic.
SECTION 1
1.0 PROJECT OVERVIEW/FIRST PANEL MEETING

1.1 NCHRP 3-54 RESEARCH OBJECTIVE

The objective of the NCHRP 3-54 project is to evaluate the safety and effectiveness of different signal displays and phasing for protected/permissive left-turn control through laboratory and field studies. These studies will gather, analyze, and interpret data that will serve as the basis for protected/permissive control uniform display recommendations. The research will consider both leading and lagging operations associated with protected/permissive control, situations where the yellow trap occurs, and typical configurations.

The NCHRP 3-54 project will not develop any guidelines, warrants, or recommendations for the use of protected/permissive left-turn phasing. The underlying assumption is that the traffic engineer has decided that protected/permissive control is the most appropriate left-turn treatment. The goal of the NCHRP 3-54 project is to identify the most effective display(s).

1.2 THE NEED FOR MORE RESEARCH

There are several advantages of implementing the protected/permissive left-turn (PPLT) phasing, such as reduced delay, improved progression, reduced fuel consumption, and reduced air pollution. Many practicing agencies have found the advantages to outweigh the disadvantages. The disadvantages are potential motorist confusion and, if not implemented safely, the “yellow trap.” Many innovative signal displays and phase sequence patterns have been developed and used throughout the country that offer the advantages of PPLT phasing and diminish the disadvantages. At least four variations of the display to indicate the permissive phase are known to exist, including the flashing circular red, the flashing circular yellow, the flashing red arrow (FRA), and the flashing yellow arrow (FYA). Other
variations also exist in phasing, signal display, display face, signal placement, and use of supplemental signs.

The current PPLT standard allowed under the MUTCD provides uniformity in the left-turn treatment; however, the MUTCD is an evolving standard, and many displays used throughout the United States are not considered to be in conformity. Those displays continue to be used because of disagreement among practicing traffic professionals. The National Committee on Uniform Traffic Control Devices (NCUTCD) has expressed concern that the variety of protected/permisive left-turn controls currently used may confuse motorists traveling throughout the United States. In response to this concern, the National Committee has been the leading force behind this comprehensive national study to validate the operational advantages and safety aspects of the various left-turn control devices and signal display faces.

1.3 FIRST INTERIM REPORT

The first interim report for the NCHRP 3-54(02) project was submitted to the Research Panel in September of 1999. This document provided the Panel with factual information obtained from research efforts conducted in Tasks 1 through 6. The first interim report was divided into three sections, with Section 1 focusing on background information and the current state of practice with respect to PPLT use. Section 2 provided a brief summary of the specific tasks contained in the NCHRP 3-54(02) research project while Section 3 summarized the results of the first six individual working papers. Section 3 also identified the conclusions and recommendations regarding research efforts in the continuing tasks of this project.

1.4 SECOND INTERIM REPORT

This second interim report for the NCHRP 3-54(02) project presents a summary of the work and findings of the research project that have occurred since the first interim report was submitted in 1999. Similar to the first interim report, this second interim report is also
divided into three sections. Section 1 provides a summary of the results of the Research Panel meeting that was conducted upon completion of the first interim report. Section 2 provides a summary of Working Paper #7, *Driver Study Using Driver Simulation Technology (Confirmation Study)*, while Section 3 provides an overview of Working Paper #8, *Implementation Study Results*.

Interim Report #2 is published in two volumes with this report comprising Volume I. Volume II includes working papers #7 and #8 in their entirety, allowing the reader to review the full description of the methodology, results, and findings of individual work activities.

1.5 FIRST PANEL MEETING

A panel meeting was held between the Research Panel and the Research Team on October 26, 1999. The purpose of this panel meeting was to review the findings of the first six study tasks (documented in the first interim report) and to review the recommendations presented by the Research Team. Through the course of the day-long meeting, several major subject areas were discussed including the project objectives, what displays were to be further evaluated in the next phase of the project, alternative displays, how the displays should be evaluated, the confirmation study methodology, issues related to the use of simulators, and issues related to the field implementation study. Highlights from the first panel meeting are summarized below to provide context for the reader and understanding of the project’s direction between the first and second interim report.

1.5.1 Discussion of Project Objectives

The Research Panel reviewed and discussed the overall project objective, with the majority of panel members agreeing that the direction of the project to date was consistent with the stated project objective and that no changes would be made in either the project’s direction or project objective. The Research Panel members agreed that the research should support the (a) national standard, whatever that may be. The Research Panel also agreed that the
study should continue to focus on the permissive display that may be applied to any application. In addition, it was agreed that the final product of the project would be a display (or displays) supported by research that could be endorsed by the National Committee for use by an agency to indicate the permissive left-turn interval. The research project would not necessarily try to change the Manual on Uniform Traffic Control Devices (MUTCD) to universally change the fundamental permissive display.

1.5.2 Discussion of Displays to Be Further Evaluated

An initial straw pole of the panel members was conducted to identify whether members believed individual PPLT displays were viable candidates for inclusion in the MUTCD. The results of the straw pole are summarized in Table 1 below.

<table>
<thead>
<tr>
<th>Panel Member</th>
<th>Green ball</th>
<th>Yellow arrow</th>
<th>Yellow Ball</th>
<th>Red Arrow</th>
<th>Red Ball</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shared</td>
<td>MUTCD</td>
<td>Dallas</td>
<td>Shared</td>
<td>Separate</td>
</tr>
<tr>
<td>PM 1</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td></td>
</tr>
<tr>
<td>PM 2</td>
<td>No</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM 3</td>
<td>No</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>PM 4</td>
<td>No</td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>PM 5</td>
<td>No</td>
<td></td>
<td>Transition</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM 6</td>
<td>No</td>
<td>Transition</td>
<td></td>
<td>No</td>
<td>No</td>
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<tr>
<td>PM 7</td>
<td>No</td>
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<td>No</td>
<td>No</td>
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<td>PM 8</td>
<td>No</td>
<td></td>
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<td>No</td>
<td>No</td>
</tr>
<tr>
<td>PM 9</td>
<td>No</td>
<td></td>
<td></td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>

1. Choose red arrow based on study results
2. Choose the red ball because it gives flexibility for complex intersections, such as wide medians

The straw pole vote and subsequent discussion ultimately resulted in the panel members agreeing that the flashing red indications would be dropped from further evaluation by the NCHRP 3-54 research project. The Research Panel members agreed that the flashing red indications would continue to be needed, but only in special (restrictive) circumstances.
Based on the straw vote and panel discussion, it was also agreed that the FYA display was a definite candidate for further study.

To further refine the list of study displays, each panel member was asked to cast two votes for two additional displays to be carried into the next phase of the project. Each panel member could cast their vote on two separate displays or place two votes for a single display. The results of this second vote are presented in Table 2 below.

### Table 2
Results of Final Vote for Three Displays to be Further Studied

<table>
<thead>
<tr>
<th>Panel Member</th>
<th>Green Ball</th>
<th></th>
<th></th>
<th>Yellow Arrow</th>
<th></th>
<th></th>
<th>Red Arrow</th>
<th></th>
<th></th>
<th>Red Ball</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Shared</td>
<td>MUTCD</td>
<td>Dallas</td>
<td>Shared</td>
<td>Separate</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM 1</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM 2</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
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<tr>
<td>PM 3</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
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<td></td>
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<tr>
<td>PM 4</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>PM 5</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Unanimous inclusion for further study</td>
</tr>
<tr>
<td>PM 6</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
<td>Yes + Yes</td>
<td></td>
<td></td>
<td>Removed from further study</td>
<td></td>
<td></td>
<td>Removed from further study</td>
</tr>
<tr>
<td>PM 7</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>PM 8</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>PM 9</td>
<td>Yes</td>
<td></td>
<td></td>
<td>Yes</td>
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</tbody>
</table>

As shown in Table 2, the shared green ball, Dallas [Display] green ball, and the separate FYA displays received the most votes to be included in the next phase of the research project. The red arrow and red ball displays were removed from further study.

### 1.5.3 Display Evaluation Methodology Discussion

In an effort to outline potential next steps, the Research Team presented a recommended study plan describing how a focus group work activity would be conducted and the purpose of a confirmation study. In addition, University of Massachusetts – Amherst (UMass) and
Texas Transportation Institute (TTI) staff presented their capabilities in conducting the confirmation study through the use of driving simulators. The Research Team then presented a recommended study approach towards a field implementation plan in response to panel comments on the value of the focus group.

1.5.4 Simulator Use Discussion

The research panel deliberated the value of the potential use of simulator technology in the research project. Ultimately, most of the panel members indicated a preference for simulator use over the focus group concept. The panel indicated a general belief that the simulator would provide the desired sample for a confirmation study and at the same time provide the opportunity to inquire with each participant their interpretations of various displays.

Completing the simulator discussion, the research panel members directed the Research Team to proceed with the confirmation study using the simulators located at UMass and TTI. The Research Team was further directed to provide a statement of work to the NCHRP for approval prior to commencing the simulation studies. The panel members also directed that the horizontal head was to be excluded from the simulation studies in an effort to reduce the number of variables and that the cluster head was to be used.

1.5.5 Field Implementation Discussion

While the panel members supported the use of a driver simulation testing environment as part of the confirmation study, several panel members also stated their belief that the projected needed a field implementation study.

The panel members indicated their preference that all implementation changes be kept as simple as possible while still conforming to the MUTCD. The panel concluded by directing the Research Team to proceed with a field implementation study. As part of the initial efforts, the Research Team was directed to prepare the necessary documents to receive experimental approval from the Federal Highway Administration for all volunteer agencies using the FYA display.
1.5.6 Field Implementation Study Display Schemes

Having agreed to move forward with a field implementation study, the panel members discussed potential options for testing the FYA display. From the discussion, it was unanimously agreed that some positional change from the FYA interval to the yellow arrow (YA) clearance was preferred. The panel directed that specific options to be considered for the Field Implementation Study should include:

- For shared green ball (GB) locations with the doghouse: use of a bi-modal green arrow/yellow arrow (GA/YA) in the lower left section. The desired display would be the 5-section doghouse with the GA/YA in the lower left section mounted over the left-turn lane as a separate display.

- For Dallas phasing locations, consider replacing the GB with the FYA as an option. It was noted that issues of indication location are a problem with horizontal heads.

- For separate left turn heads, use a red arrow (RA), YA, and GA/YA in a 3-section vertical display or, alternatively, a RA, YA, FYA, and GA in a 4-section vertical display.

1.5.7 Research Team Action Items

Prior to adjourning, the Research Team identified several action items requiring further efforts by the Research Team. Those action items included:

- Establishing an E-group for the purpose of sharing ideas related to the implementation study and what should be included.

- Developing a work statement for conducting the confirmation study using the simulator.

- Updating Working Paper 1 to reflect panel comments.
• Updating Working Paper 3 to reflect revisions suggested by the panel related to the interpretation of the photographic driver survey results.

• Proceeding with the Field Implementation Study, beginning with preparation of an implementation study work plan and budget for approval by the Research Panel members and NCHRP.

• Preparing the documents necessary to receive experimental approval from the Federal Highway Administration for all volunteer agencies using the FYA display.

1.6 INTERIM FINDINGS

Since the October 1999 Panel Meeting, the Research Team has been focused on the completion of the confirmation and implementation studies. Two additional working papers and an update to an existing working paper have now been prepared to report on the findings resulting from the continuing research activities. The working papers, which are summarized in the next three sections of this report, are contained in their entirety in Volume II of this report and consist of the following:

- Working Paper 1: Engineering Assessment
- Working Paper 7: Driver Study Using Driver Simulation Technology
- Working Paper 8: Implementation Study Results
2.0 WORKING PAPER 1: ENGINEERING ASSESSMENT

2.1 ENGINEERING ASSESSMENT

As part of the Interim Report #1, the Research Team provided an engineering assessment that was intended to explore the many judgmental elements that affect the use of traffic signal displays that are not measured through some scientific experiment. To perform the Engineering Assessment, the Research Team considered practical issues related to how an agency would actually implement a particular signal display or indication. This section presents an update of the assessment based on the studies completed since the first interim report was issued.

2.2 OBJECTIVE

The objective of the engineering assessment was to include consideration of scientific and non-scientific implementation issues in the following areas: safety, operations, implementability, human factors, and versatility. The updated engineering assessment identified factual and judgmental information required to evaluate the signal displays, or indications. The assessment provided a thorough evaluation based upon sound engineering practice and the latest findings of the on-going research effort.

2.3 METHODOLOGY

The Research Team identified questions related to each of the major areas identified above and included additional questions that were identified subsequent to the issuance of the first interim report. Each question was responded to based upon factual and judgmental information as well as on results obtained from one or more of the individual study tasks.
2.4 RESULTS

There are two significant tables that were developed in the engineering assessment. The first table, Table 2-1, lists each of the major categories (safety, operations, etc.) and each question within each category. Each question was rated from highest to lowest in a “Consumer Reports”-like grading scale. By design, there were not quantitative scores associated with any display and/or indication (individual questions are not weighted equally). Therefore, judgment was used to assess which displays and/or indications performed better than others. Many of the questions in Table 1 require further explanation or clarification of intent and/or meaning. An evaluation of each of the questions in Table 1 is explored in more detail in the update to Working Paper 1.

The second table, Table 2-2, identified allowable combinations of placement, display faces, and left-turn phasing. This table identified the practical considerations regarding display or indication, based on 1) whether it could be used in a shared display face or a separate display, and 2) whether the display or indication could be used in a lead-lead, lag-lag, or lead-lag left-turn signal operation.
<table>
<thead>
<tr>
<th>#</th>
<th>Questions to be answered</th>
<th>Solid Green Ball</th>
<th>Flashing Yellow Arrow</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Traditional Five Section</td>
<td>Green Ball plus Flashing Arrow</td>
<td>Dallas Display</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>4</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>5</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>6</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>7</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>8</td>
<td></td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

**OPERATIONS**

<table>
<thead>
<tr>
<th>#</th>
<th>Questions to be answered</th>
<th>Solid Green Ball</th>
<th>Flashing Yellow Arrow</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Traditional Five Section</td>
<td>Green Ball plus Flashing Arrow</td>
<td>Dallas Display</td>
</tr>
<tr>
<td>1</td>
<td>Does the indication increase total delay to the driver due to indecision, increased start-up lost times, reduced travel speeds, and/or lower saturation flow rates?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>2</td>
<td>Does the indication impact pedestrian movements?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>3</td>
<td>Can the indication be used with lead/lag operation?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>4</td>
<td>Does the indication impact opposing left-turning traffic?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>5</td>
<td>Does the indication allow the skipping of all side-street phases?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>6</td>
<td>Is the indication consistent with flashing indications?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>7</td>
<td>Does operating the intersection in flashing mode provide negative consequences?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
<tr>
<td>8</td>
<td>Does the indication lead to false starts or related driver errors?</td>
<td>○</td>
<td>○</td>
<td>○</td>
</tr>
</tbody>
</table>

Ranking scale: ● = highest/best; ○ = lowest/worst
### Table 2-1. Engineering Assessment Evaluation Matrix - Page 2 of 4

<table>
<thead>
<tr>
<th>#</th>
<th>Questions to be answered</th>
<th>Solid Green Ball</th>
<th></th>
<th></th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td><strong>IMPLEMENTABILITY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I-1</td>
<td>Are there significant issues with installation? Can the indication be placed to meet with the current MUTCD requirements?</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td>GBFA and FYA will require amendment of MUTCD</td>
</tr>
<tr>
<td>I-2</td>
<td>Are there issues with conversion of existing indications?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Convert a signal currently using traditional 5-section indication?</td>
<td>●</td>
<td>○</td>
<td>○</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Convert a signal currently using permissive-only?</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Convert a signal currently using protected-only?</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>I-3</td>
<td>Are there legal issues to consider including the Uniform Vehicle Code and state and local laws?</td>
<td>●</td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>I-4</td>
<td>Does the signal indication permit maximum number of signal phasing strategies?</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td></td>
<td><strong>HUMAN FACTORS</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H-1</td>
<td>Is the indication universally understood? Does the indication meet both priori and ad hoc driver expectancies?</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td>See WP 7</td>
</tr>
<tr>
<td>H-2</td>
<td>Do drivers respond correctly to the information presented?</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>H-3</td>
<td>Do drivers accept the indication? Does the indication increase driver workload, reduce conspicuity, or increase driver error?</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>H-4</td>
<td>Are supplemental signs required for understanding?</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>H-5</td>
<td>Do drivers exposed to the &quot;new&quot; indication easily learn the meaning?</td>
<td>○</td>
<td>●</td>
<td>●</td>
<td></td>
</tr>
<tr>
<td>H-6</td>
<td>Does the signal indication fail safe? What are the consequences of a driver misinterpreting the signal indication message?</td>
<td>○</td>
<td>○</td>
<td>●</td>
<td></td>
</tr>
</tbody>
</table>

**Ranking scale:** ● = highest/best; ○ = lowest/worst
### Table 2-1. Engineering Assessment Evaluation Matrix

| #   | Questions to be answered                                                                 | Solid Green Ball                           |  |  |  |
|-----|-----------------------------------------------------------------------------------------|--------------------------------------------|--|--|--
|     |                                                                                         | Traditional Five Section | Green Ball plus Flashing Arrow | Dallas Display | Flashing Yellow Arrow | Comment |
| V-1 | Does it allow permissive-only operation?                                                 | ●                                          | ●                            | ●              | ●              |         |
| V-2 | Does it allow protected-only operation?                                                 | ○                                          | ○                            | ●              | ●              |         |
| V-3 | Does it allow change between mode of operation by time of day?                          | ○                                          | ○                            | ●              | ●              |         |
| V-4 | Can it be used on curved approaches?                                                    | ●                                          | ●                            | ○              | ●              |         |
| V-5 | Does it allow two far-side LT heads in customary locations?                            | ●                                          | ●                            | ○              | ●              |         |
| V-6 | Does it allow use of any phase sequence?                                                | ○                                          | ○                            | ●              | ●              |         |
| V-7 | Is it applicable to right turns as well as left?                                        | ○                                          | ●                            | ●              | ●              |         |
| V-8 | Can it be used with span wire-mounted signals?                                          | ●                                          | ●                            | ○              | ●              |         |
| V-9 | Can heads be in same location as permanent protected-only heads for easy conversion?    | ○                                          | ○                            | ●              | ●              |         |
| V-10| Can heads be in same location as permanent permissive-only heads for easy conversion?   | ●                                          | ●                            | ○              | ●              |         |
| V-11| Does it allow use of all of the opposing through green time for permissive turns?       | ○                                          | ○                            | ●              | ●              |         |
| V-12| Can it be used when the left-turn lane is shared with through traffic?                  | ●                                          | ●                            | ○              | ●              |         |
| V-13| Can permissive, turning traffic proceed legally without stopping?                        | ●                                          | ●                            | ●              | ●              |         |
| V-14| Could it replace all current standard and non-standard PPLT indications?                 | ○                                          | ○                            | ●              | ●              |         |
| V-15| Can it be used where there is no adjacent through movement?                             | ○                                          | ○                            | ●              | ●              |         |
| V-16| Can it be used where the adjacent through movement is unsignalized?                    | ○                                          | ○                            | ●              | ●              |         |

**Ranking scale:**
- ● = highest/best; ○ = lowest/worst
<table>
<thead>
<tr>
<th>#</th>
<th>Questions to be answered</th>
<th>Solid Green Ball</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Traditional Five</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Section</td>
</tr>
<tr>
<td>V-17</td>
<td>Can it be used when the left-turn slot is physically separated or on different alignment</td>
<td>⬜</td>
</tr>
<tr>
<td></td>
<td>than through lane (wide median, etc.)?</td>
<td>⬜</td>
</tr>
<tr>
<td>V-18</td>
<td>Can the signal indication be placed horizontally or vertically in the same arrangement?</td>
<td>⬜</td>
</tr>
<tr>
<td>V-19</td>
<td>Does it work under all preemption scenarios?</td>
<td>⬜</td>
</tr>
<tr>
<td>V-20</td>
<td>Does it avoid the yellow trap situation under all circumstances?</td>
<td>⬜</td>
</tr>
<tr>
<td>V-21</td>
<td>Can the permissive indication be easily applied to other than PPLT situations?</td>
<td>⬜</td>
</tr>
<tr>
<td>V-22</td>
<td>Will practitioners likely use the indication if made the standard, or allowed alternate?</td>
<td>⬜</td>
</tr>
</tbody>
</table>

Ranking scale: ⬜ = highest/best; ⬜ = lowest/worst
### Table 2. Allowable Combinations of Placement, Display Face, and Phasing for Potential Display Type

<table>
<thead>
<tr>
<th>Placement</th>
<th>Indication Arrangement</th>
<th>Phasing</th>
<th>Display Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Traditional Five Section Green Ball</td>
</tr>
<tr>
<td>Shared Indication with Through</td>
<td>5-Section Cluster</td>
<td>Lead-lead Lefts</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lag-Lag Lefts</td>
<td>Y²</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lead-Lag Lefts</td>
<td>N</td>
</tr>
<tr>
<td>5-Section Vertical</td>
<td>Lead-Lead Lefts</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Lag-Lag Lefts</td>
<td>Y²</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Lead-Lag Lefts</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>5-Section Horizontal</td>
<td>Lead-Lead Lefts</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Lag-Lag Lefts</td>
<td>Y²</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>Lead-Lag Lefts</td>
<td>N</td>
<td>N</td>
</tr>
<tr>
<td>Separate Indication</td>
<td>5-Section Cluster</td>
<td>Lead-Lead Lefts</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Lag-Lag Lefts</td>
<td>Y²</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Lead-Lag Lefts</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>5-Section Vertical</td>
<td>Lead-Lead Lefts</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Lag-Lag Lefts</td>
<td>Y²</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Lead-Lag Lefts</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td>5-Section Horizontal</td>
<td>Lead-Lead Lefts</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Lag-Lag Lefts</td>
<td>Y²</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>Lead-Lag Lefts</td>
<td>N</td>
<td>Y</td>
</tr>
</tbody>
</table>

Footnotes:
1. Assumes that the yellow arrow serves to both clear the green arrow and flash for the permitted interval. Use the bi-modal in the bottom and use the yellow for the clearance.
2. Works only if serve both lagging lefts at the same time, otherwise a yellow trap may be created.
2.5 ENGINEERING ASSESSMENT FINDINGS

The Engineering Assessment material presented in Table 2-1 focused on key issues surrounding safety, operations, implementability, human factors, and versatility. The findings of this assessment are highlighted below:

- Within the category of safety, the assessment findings suggest that the FYA display offered the highest level of safety, followed by the green ball display using Dallas phasing.

- Within the category of operations, the green ball display using Dallas phasing performed at very similar overall ranking levels, with the remaining green ball displays performing at lesser levels.

- Within the category of implementability, the green ball indication was identified as being the most implementable. This finding reflects the status of the green ball indication as being the current standard for most agencies. By comparison, the FYA display was found to be more implementable than a standard green ball display in a separate left-turn head and overall near equal to the implementability of a green ball display using Dallas phasing.

- Within the category of human factors, the FYA display was shown to rank the best.

- Within the category of versatility, the FYA display clearly was shown to offer the most versatility while the standard green ball display shared with a through lane offered the least.

- Table 2-2 identified allowable combinations of placement, display face, and left-turn phasing and highlights the fact that only the green ball indication and the FYA can be used in both the shared head placement and in the separate left turn head placement. The green ball has some limitations in the shared head placement (e.g., it can’t be used
for lead-lag phasing; must serve both lagging lefts at the same time; has other yellow trap potential). Consequently, the comparison provided in Table 2-2 points out that the flashing yellow arrow appears to be the most universal option.
SECTION 3
3.0 WORKING PAPER 7: CONFIRMATION STUDY

3.1 SIMULATION TASK OVERVIEW

The objective of NCHRP 3-54(2) research Task 10 was to evaluate driver’s comprehension of the most promising types of PPLT signal displays using full-scale driving simulators. The driver evaluation was conducted as part of the research project were completed using fully-interactive dynamic driving simulators located in the Human Performance Laboratory on the University of Massachusetts – Amherst (UMass) campus and at the Texas Transportation Institute (TTI). An evaluation of the same PPLT signal displays in a static environment was also completed at both locations to provide comparison data to the simulator experiment as well as to previous research efforts.

The following sections provide a summary of the development and administration of the driving simulation experiment and the follow-up static evaluation completed at both universities. A detailed review of the study methodology and findings is presented in Working Paper #7.

3.2 SIGNAL DISPLAYS STUDIED

Based on the Phase I research results presented in previous working papers, the Research Team and Research Panel identified 12 different PPLT signal displays for further evaluation. The selected displays differ in permitted indication, display face, location, and through movement indication. Each of the PPLT signal displays include only the green ball and/or FYA permitted indications. The flashing red permitted indications were not evaluated in this task. The green ball permitted indication represents the current state-of-the practice and the FYA permitted indication represents the most promising alternative based on research findings to date. Figure 1 illustrates the PPLT displays evaluated in the driving simulation experiment.
Figure 1. PPLT Displays Evaluated in Driver Simulator Experiment

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Lens Color and Arrangement</th>
<th>Left-Turn Indication</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Protected Mode</td>
</tr>
<tr>
<td>1, 2</td>
<td>R</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>Y &lt;-&gt; Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G &lt;-&gt; G</td>
<td></td>
</tr>
<tr>
<td>3, 4</td>
<td>R</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>Y &lt;-&gt; Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G &lt;-&gt; G</td>
<td></td>
</tr>
<tr>
<td>5, 6</td>
<td>R</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>Y &lt;-&gt; Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G &lt;-&gt; G</td>
<td></td>
</tr>
<tr>
<td>7, 8</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>Y &lt;-&gt; Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Y &lt;-&gt; Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G &lt;-&gt; G</td>
<td></td>
</tr>
<tr>
<td>9, 10</td>
<td>R</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G</td>
<td></td>
</tr>
<tr>
<td>11, 12</td>
<td>R</td>
<td>G</td>
</tr>
<tr>
<td></td>
<td>Y</td>
<td></td>
</tr>
<tr>
<td></td>
<td>G</td>
<td></td>
</tr>
</tbody>
</table>

R = RED  Y = YELLOW  G = GREEN  Y = FLASHING YELLOW

<sup>a</sup>1, 3, 5, 7, 9, 11 – GB through indication; 2, 4, 6, 8, 10, 12 – RB through indication

<sup>b</sup>The indication illuminated for the given mode is identified by the color letter
3.3 SIMULATION STUDY METHODOLOGY

After completing a practice course to provide familiarization with the simulator environment, drivers completed the experimental modules. To avoid the need for verbal communication during the experiment, drivers were navigated through the modules by guide signs provided on each intersection approach. In addition, drivers were asked to observe speed limit signs (30 mph), providing a higher level of realism and speed control during the experiment. The driving portion of the experiment, including the practice module, required between 15 and 20 minutes to complete.

Drivers’ responses to each PPLT signal display scenario were manually recorded as correct or incorrect. Incorrect responses were further classified as being fail-safe or fail-critical. A fail-safe response was one in which the driver did not correctly respond to PPLT signal display, but did not infringe on the right-of-way of the opposing traffic. A fail-critical response was an incorrect response in which the driver incorrectly responded to PPLT signal display and impeded the right-of-way of opposing traffic, creating the potential for a crash.

Throughout the study, drivers were asked to think out loud and verbally express their thoughts about anything they observed. Research team members were present to record the results of the simulation, including the responses at each intersection and other driving related factors such as indecision, unnecessary braking, or any pertinent verbal comments made. Each experiment was recorded on videotape allowing the researchers to verify and review the manually collected data.

3.4 VIDEO-BASED STATIC EVALUATION

After completing the driving portion of the study drivers were asked to participate in a static evaluation of PPLT signal displays. The static evaluation was administered using videocassette recordings of the screen captures for the 12 PPLT displays. Each display was shown for 30 seconds during which time the driver was verbally asked to choose one of four
responses to the traffic signal lights shown. Similar to the Phase I research, the four potential responses were:

- Go, you have the right-of-way;
- Yield, then go if a gap in the opposing traffic exists;
- Stop first, then go if a gap in the opposing traffic exists; or,
- Stop and wait for the appropriate signal.

Once drivers responded with one of the four possible choices they were asked to indicate their confidence in the answer. Additionally, any comments made by the drivers regarding the displays were manually recorded.

### 3.5 CONFIRMATION STUDY SAMPLE SIZE

Based on the approved research plan, 400 drivers were sought to complete the driving simulator experiment; 200 at UMass and 200 at TTI. In an attempt to represent the general driving population, four age groups of drivers were identified. In addition, an attempt was made to include an equal number of male and female drivers and a range of educational and ethnic backgrounds. A total of 464 drivers participated in the experiment, yielding 4,613 individual evaluated PPLT scenarios (5,230 PPLT scenarios with the static evaluation).

### 3.6 CONFIRMATION STUDY FINDINGS

Driver comprehension was determined from the distribution of correct and incorrect responses for each of the selected PPLT signal displays. Several categories of incorrect responses were used to further evaluate this data. Standard analysis of variance (ANOVA) techniques were used on all collected data to compare driver comprehension related to the 12 selected PPLT signal displays.
3.6.1 Driving Simulator

Based on analysis of 348 driver evaluations (3,402 displays), the findings of the driving simulator experiment include:

- In the aggregate, the data also 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.

- The data showed no statistical difference in driver compression when the data was cross analyzed by permitted indication, display face, through indication, and location of the display.

- There was no statistical difference in permitted indication (GB, FYA, GB/FYA), signal head display face (five-section cluster, four-section vertical, or five-section vertical), PPLT display location (shared or exclusive), or adjacent through indication (GB or RB). Additionally, there were no significant differences by the various PPLT display components in terms of the percentage of fail critical responses.

- The data showed no statistical difference between in driver compression when the data was analyzed by sex, age, number of miles driven annually, or education.

- The data showed that there is a statistical difference in driver compression by sex and age. The data was further cross analyzed for the combined effect of age and sex. In this analysis, there was a statistically significant difference between the three age groups within the female drivers.

- The data showed that TTI drivers had a slightly higher level of understanding (overall) as compared to UMass drivers.
The data was cross analyzed between data from TTI and data from UMass. This analysis would suggest differences by geographic location. The data shows that the TTI drivers responded correctly 93 percent of the observations, compared to UMass drivers responding correctly 90 percent of the time. The data supports a statistically significant difference; however when the data were expanded across the 12 experimental PPLT signal displays, there were no statistically significant differences.

Males and females had statistically equivalent levels of comprehension. There were no statistically significant differences in the percentage of correct or fail critical responses across the 12 PPLT signal displays evaluated.

The age demographic resulted in statistically significant differences. Drivers in the over 45 age category had significantly fewer fail critical responses. Overall older drivers were more cautious in the driving simulator experiment, often opting to wait for all opposing vehicles to pass before completing the permitted left-turn maneuver.

Drivers that had driven between 10,000 and 20,000 miles in the previous year had significantly more correct responses and significantly fewer fail critical responses than drivers with less than 10,000 miles driven in the previous year.

Education level of the drivers was not statistically significant in determining comprehension levels. However, PPLT scenario three (five-section cluster in a shared location with a FYA permitted indication and GB through indication) was comprehended significantly more by drivers with only a high school diploma than drivers with a higher education level.

Analyzing the first observed PPLT display encountered by each of the 316 drivers resulted in some significant differences in comprehension.
The percent of correct responses was not significantly different across the 12 PPLT signal displays. However, when reviewing driver responses to the first observed PPLT signal display, there were significantly more fail critical responses when using the five-section cluster in a shared location with a FYA permitted indication and GB through indication than when using a five-section cluster in a shared location with a GB permitted indication and GB through indication. It should be noted that the five-section cluster with GB permitted indication and GB through indication is commonly used in both Massachusetts and Texas, and it is reasonable to assume that drivers had encountered this display prior to participating in the experiment.

A violation of driver expectancy may have resulted in a higher level of incorrect responses at displays with alternative permitted indications as they were initially observed in the simulator experiment. For example, drivers from Massachusetts and Texas have typically only encountered the GB permitted indication and green arrow protected indication. Based on several drivers’ comments as they approached the first displays containing the FYA permitted indication, they initially assumed the indication to be a protected green arrow and assumed the right-of-way. Only after making a fail-critical error did they correctly determine that the display was indeed not a green arrow.

3.6.2 Static Evaluation

Based on analysis of 436 driver evaluations (5,230 displays), the findings of the video-based static evaluation experiment include:

- Overall the comprehension was high as 83 percent of 5,230 scenarios were evaluated correctly.

- A significant amount of fail critical responses are generated from three scenarios, each of which contain the GB permitted indication.
• The permitted indication resulted in statistically significant differences of correct and fail critical responses. Displays with the FYA permitted indication and the GB/FYA simultaneous permitted indication had significantly more correct responses than displays with the GB permitted indication. Displays with the GB permitted indication were associated with significantly more fail critical responses than displays with either the FYA or GB/FYA permitted indications.

• PPLT displays with the four-section vertical display face had a significant amount of correct responses. However, it is important to note that only the FYA permitted indication was evaluated in this display face, and it is likely this combination that attributes for the increased percentage of correct responses.

• Displays with the RB through indication resulted in a significantly lower percent correct response rate than displays with the GB through indication. PPLT displays with the RB through indication also resulted in significantly more fail critical responses. This may be attributed to the fact that the practice of using RB through with a permitted left-turn indication is not used in Massachusetts or most of Texas.

• The location of the PPLT signal display did not result in statistically significant differences. Consistent with the static evaluation, drivers participating in the experiment at TTI had significantly more correct responses than drivers participating at UMass.

• Demographically statistically significant differences were observed within age, education, and driving experience demographics. Drivers over the age of 45 had a significantly lower comprehension of the PPLT signal displays. Drivers with only a high school diploma had a significantly lower comprehension than driver with a higher education level. Interestingly, drivers with between 10,000 and 20,000 miles driven in the previous year had significantly more correct responses than both
drivers with fewer than 10,000 miles driven and drivers with over 20,000 miles driven in the previous year.

3.6.3 Driving Simulator and Static Evaluation

Combining the results of both the driving simulator experiment and video-based static evaluation has led to the following conclusions:

- Driver comprehension in the simulator experiment was significantly higher than the static evaluation. The results indicate that what drivers say they will do and what they actually do in the driving environment are not always consistent. The biggest inconsistencies occurred for displays with the GB permitted indication. In the simulator experiment, the four scenarios with the GB permitted indication resulted in fail critical responses six percent of the time. By contrast the same four scenarios in the static evaluation resulted in fail critical responses 19 percent of the time.

- Inconsistencies between responses in the driving simulator and static evaluation for displays with the GB permitted indication are cause for concern. Although drivers provided with dynamic cues, which are present in the simulation, are correctly able to interpret the GB permitted indication, there is reason to believe drivers do not have a good understanding of the GB permitted indication. Specifically, drivers observing the GB permitted indication in the static evaluation were more likely to make fail-critical responses. Evidence suggests that the PPLT indication is only one of many elements that the driver takes into account when making left-turn decisions. This result also explains why low level of comprehension related to the green ball permitted indication is not consistent with left-turn crash frequencies.

- In the simulator experiment, the through indication had little effect on driver comprehension, while in the static evaluation the RB through indication resulted in lower comprehension levels. Based on driver comments throughout the entire
experiment, drivers often did not observe the through indication in the simulator, but noticed the through indication in the static evaluation.

- Comparing all types of responses in both of the experiments, it can be said that many drivers base their left-turn decision on surrounding traffic, specifically the opposing traffic, instead of the signal indication. This may be due to a lack of driver understanding of the indication.
4.0 WORKING PAPER 8: IMPLEMENTATION STUDY

4.1 IMPLEMENTATION TASK OVERVIEW

To address the lack of field applications of the FYA PPLT display, the project panel approved the study of this display in the field as part of the NCHRP 3-54 (02) amended study. The objective of NCHRP 3-54(2) research Task 14 was to document how the FYA display can be implemented, including documentation of any technical or political issues as well as safety and cost implications associated with implementing this display. The Research Panel felt strongly that this task was needed before such a display, if deemed “best” understood, could be recommended to the National Committee on Uniform Traffic Control Devices.

The following sections provide a summary of the development and administration of the implementation study, field data that was collected, and preliminary results. The implementation study has been delayed as a result of complications with volunteer agency participation and is currently on-going. As a result, the detailed review of the study methodology and findings documented in Working Paper #8 is still evolving.

It should be noted that the Research Panel is not recommending the implementation of the FYA display at this time. Instead, the panel is seeking further evidence and support that the FYA display is a safer and better-understood display than what is currently allowed in the MUTCD.

4.2 IMPLEMENTATION STUDY METHODOLOGY

The field implementation study was initiated at the request of the Research Panel to collect actual field data on the FYA display. The implementation study collected before and after implementation of a FYA PPLT display (including crash data and conflict data) to record the safety performance associated with the FYA display. The implementation study also
collected field operational data, such as start-up lost time and saturation flow rate data, to quantify the operational impacts. The implementation study monitored field installation by the operating agency and documented techniques and issues resolved (e.g., control logic) for successful implementation to be achieved. In addition, agency assistance was sought to help quantify other implementation issues such as field personnel reaction, as well as labor, hardware, and software costs.

4.2.1 Characteristics of Study Intersections

The study intersections selected for evaluation currently operated PPLT and were considered typical intersections containing no unique geometric or operational features. Specific features sought in study intersections included:

- right angle intersections with four approaches;
- exclusive left-turn lane(s) on the study approach;
- current use of the green arrow indication for the protected left-turn movement and the green ball indication for the permitted left-turn indication;
- relatively flat approach grades;
- 12-foot lane widths;
- no on-street parking; and
- no other variables that directly impact the left-turn movement being evaluated.

Each agency that volunteered to participate in the study was asked to identify at least three intersections for improvement (i.e., installation of the new FYA PPLT signal display). An additional three intersections were identified within each study region that did not receive any improvements during the study period. These intersections served as control sites. Therefore, a minimum of six study sites was requested at each study region (study regions sometimes involved multiple agencies).
4.2.2 Proposed FYA Display Face

The Research Team, in partnership with Research Panel and technical advisory group members, identified several display faces that demonstrated good motorist understanding. There were four possible PPLT signal displays that were recommended for installation of the FYA display at locations where there was an exclusive left-turn lane and the left-turn display was a separate display (not used by the adjacent through movements). Those alternative displays are shown in Figure 2 below. As shown in Figure 2, the display can be implemented in four different head configurations, using three or four sections and horizontal or vertical alignments. The three-section head options involve shared use of a bi-modal section by the green and flashing yellow arrows. The three-section display face may be desired for clearance purposes or for ease of implementation if an existing three-section display face is available. The signal display face can be mounted either vertically or horizontally.

![Figure 2. Exclusive FYA Display Faces](image)

In the exclusive display application, one, and only one, of the four arrows is illuminated at all times. The FYA is illuminated when traffic can safely turn by yielding to opposing through traffic and/or pedestrians (permissive operation). The other three arrows are used just as in the normal three-color exclusive left turn display. The red arrow is displayed when it is unsafe to make a left turn movement. The green arrow is displayed when the left turn movement can be made with no conflicting simultaneous vehicle or pedestrian movement.
(protected operation). The steady yellow arrow is illuminated for a few seconds as a clearance indication following both the green arrow and the FYA.

4.3 PARTICIPATING AGENCIES

The Research Team sought the participation of volunteer agencies on a national basis. In August 2000, the Research Team issued an Implementation Plan for submittal to volunteer agencies identifying the project goals and objectives, project requirements, and the responsibilities of both the volunteer agencies and the Research Team. Each volunteer agency implementing the FYA display was required to first request (and receive) approval for experimentation of a traffic control device though the Federal Highway Administration (FHWA).

Since August 2000, the contractor has contacted over 35 agencies from across the United States. Of those 35 agencies, a total of nine agencies submitted a request to FHWA for experimentation of the FYA display. Two of those nine study implementation locations were subsequently “withdrawn” due to controller logic issues or implementation procedures not consistent with the project objectives.

The first agency to respond to the volunteer solicitation was Montgomery County, Maryland. In September 2000, Montgomery County implemented the FYA display at three intersections. Maryland’s participation in the implementation study was subsequently followed by other agencies as chronologically summarized below in Table 3 (as of the time this report was printed).
### Table 3
Implementation Study Sites to Date

<table>
<thead>
<tr>
<th>Agency</th>
<th>Implementation Date</th>
<th>Number of Implementation Sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Montgomery County, Maryland</td>
<td>September 2000</td>
<td>3</td>
</tr>
<tr>
<td>City of Tucson, Arizona</td>
<td>May 2001</td>
<td>3</td>
</tr>
<tr>
<td>Jackson County, Oregon</td>
<td>May 2001</td>
<td>1*</td>
</tr>
<tr>
<td>Oregon Department of Transportation</td>
<td>June 2001</td>
<td>2</td>
</tr>
<tr>
<td>City of Beaverton, Oregon</td>
<td>April 2002</td>
<td>3</td>
</tr>
<tr>
<td>Broward County, Florida</td>
<td>June 2002</td>
<td>3</td>
</tr>
</tbody>
</table>

*One site in Jackson County meets the NCHRP 3-54 study requirements, though non-conforming displays have been implemented as other locations in the County as well with FHWA approval.

### 4.3.1 Other Agency Participation

In addition to the agencies listed in Table 3 that have implemented the experimental FYA display, three other agencies requested and received FHWA approval to participate in the study. Two of the agency’s were ultimately unable to participate in implementation and one agency’s participation is still pending as described below.

- The City of Kennewick, Washington received FHWA approval to implement and planned to do so by October 2001 but then withdrew from the study due to signal controller complications that could not be resolved to the City Traffic Engineer’s satisfaction. The specific circumstances experienced by Kennewick are detailed in Working Paper #8.

- The City of Carson City, Nevada has submitted their request for implementation to FHWA; however, their proposed implementation included a supplemental sign explaining the meaning of the FYA display. After discussions with the Research Team, it was decided that FHWA would approve the installation if the supplemental sign was dropped from the implementation. Carson City has not responded to FHWA and it is unclear how or if the City will proceed with implementation.
Snohomish County, Washington has received FHWA approval for implementation and plans to implement at one intersection. Implementation in Snohomish County has also been delayed by traffic signal controller software issues that have not yet been resolved by the software manufacturer.

4.4 POST SURVEY OF VOLUNTEER AGENCIES

A post implementation survey was administered to the agencies that participated in the implementation study. The survey was aimed at identifying what issues had to be dealt with in order to implement the FYA display, the cost to the agency to implement the FYA display and whether there was support within the agency and outside the agency for the FYA display.

Overall, each of the participating volunteer agency experienced favorable results with the FYA display implementation. The most commonly reported problem was overcoming the current design of controllers and conflict monitors. In all cases, the participating agencies had to use either internal logic (e.g., command box in the Wapiti firmware for the Type 170 controller) or some type of external logic or relay device to implement the FYA display.

The cost to implement the FYA display has been relatively low (approximately $750 for new signal heads and about 200 man-hours total). All agencies have received significantly more positive support (internal and external) than any negative support.

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1 In a typical PPLT situation, it is possible for the green ball (GB) display and green arrow (GA) display to illuminate simultaneously. However, by converting to the FYA display, the FYA and GA displays cannot illuminate simultaneously. In unusual situations, additional or different phases could serve as parent phases to drive the FYA overlap. The same overlap logic can also be used to drive right turn arrows where appropriate. In those cases where existing controller software could not be modified to provide this functionality, the same effect could be achieved using external logic, although with less flexibility It is assumed that new controller software and any significant upgrade of existing controller software will include this functionality, so that over time, external logic will no longer be needed. The special logic described above can be implemented using a "logic box" external to the signal controller, or with software enhancements in the signal controller.
4.4.1 Agency Feedback

In addition to the formal written survey response comments, there is a fair amount of anecdotal evidence that provides preliminary insight into the agencies’ perspective on use of the FYA display. The overall response to the FYA display from traffic engineers around the county has been positive. In general, traffic engineers have expressed their approval of the FYA display because:

- It is a separate signal head for the left-turn control;
- The indication is flashing, which attracts more attention; and
- They have more operational control.

In general, local law enforcement agencies have been supportive of the FYA display. There has been some hesitation from city councils or county commissioners over the FYA display. Their concern has been largely focused on the issue of trying something new that is not formally part of the MUTCD.

In addition to the anecdotal data presented above, a brief summary of equipment and performance feedback shared by each of the agencies participating in the FYA field implementation is provided below. Further details are provided in Working Paper 8.

4.4.1.1 Montgomery County, MD

Montgomery County implemented the FYA display in September 2000 at three intersections. The signal head used was a 4-Section vertical all-arrows display. The FYA indication was tied to the opposing through green indication. The County uses Econolite NEMA controllers and implementation required special external logic. The County did not use any media press release prior to implementation but did use VMS’s in advance of the intersections for a period of 48 hours. The County has had minimal citizen feedback for the near two years of deployment.
4.4.1.2 Tucson, AZ

The City of Tucson, Arizona has been the only agency to implement and then discontinue use of the FYA display. The City implemented FYA on May 30, 2001 at two intersections, replacing PPLT displays with a 5-section vertical display face. The City of Tucson has been using the FYA for their right-turn overlaps for over 10 years without any problems. The City’s local traffic management is with Econolite ASC/2 controllers. The City used an external flashing circuit tied to the FYA indication, which did not conflict with the controller’s conflict monitor.

Within one week of implementation of the FYA, there was a crash at one of the study intersections. Due to a lack of communication between the city traffic engineer and city manager (about participating in this study), the city manager directed the city traffic engineer to rescind participation in the implementation study. Nevertheless, based on feedback from the operations engineer, the intersection operations performed well during the time that the FYA display was in effect. The FYA display continues to be used for the right-turn overlap movements.

4.4.1.3 Jackson County, OR

Jackson County, Oregon has pursued a somewhat unique path with their implementation of the FYA display that is addressed below. The county traffic engineer for Jackson County, Oregon approached the contractor to implement the FYA display in their county. They only had one (1) intersection that could be converted over from existing PPLT to the FYA display. The single intersection met the project requirements. The county subsequently submitted the FHWA request and it was approved by FHWA. The single intersection is currently operating with a FYA display using a 4-section all-arrow vertical display face.

Since initial implementation in 2001, Jackson County has converted five existing exclusive (protected only) left turn operations to PPLT with a FYA display. However, in these installations, the County used a 3-section vertical display face – the center indication is used for the yellow arrow clearance (following the green ball) and the FYA (permissive period).
The County has received FHWA approval for this display face, which was pursued in an effort in by Jackson County to save on the cost of a new display face (4-section) and running additional wire cable to address vertical clearance issues.

The County has had very positive feedback from the local police department and local citizens. The County’s local traffic management is a Type 170 controller with Wapiti firmware. Special command box logic was required in order to implement the FYA indication. Additional details regarding the Jackson County experience, including documentation of how the three-section displays were implemented, are provided in Working Paper 8.

### 4.4.1.4 Woodburn, OR

The Oregon Department of Transportation (ODOT) implemented the FYA display in June 2001 at two intersections located in Woodburn, Oregon. The signal head used was a 4-Section vertical all-arrows display. The local intersection management is a Type 170 controller with Wapiti firmware. Special command box logic was required in order to implement the FYA indication. ODOT and the local City government (City of Woodburn) staff report receiving minimal public feedback regarding the FYA displays.

### 4.4.1.5 Beaverton, OR

The City of Beaverton, Oregon implemented the FYA display at three study locations in April 2002 after having been granted authority to implement the FYA display from the City Traffic Commission and the Mayor’s office. The signal head used is 4-Section all-arrows display face. The local intersection management is controlled by a Type 170 controller with Wapiti firmware. Special command box logic was required in order to implement the FYA indication. The City was able to use the same basic logic developed by ODOT for the Woodburn site in their implementation. The implementation has been in operation for approximately four months at the time this report was published and had not experienced any problems.
4.4.1.6 Broward County, FL

Broward County was first approached by the contractor to implement the FYA display in May 2000. It was not until May 2002 that the County implemented the experimental display. This two-year relationship between the contractor and implementing agency is an example of why Task 14 took so long to complete and the subsequent delay in completing this study. The delay in implementation was due to a multitude of factors, most of which could be attributed to limited County staff resources (time), and the desire to implement a different display from that requested by the research project (which required an additional FHWA approval process).

Ultimately, the County implemented a 5-Section Vertical Display, with the top two indications being a red ball and a yellow ball. It was the desire of the County to clear the approach with all yellow balls, rather than clearing the left-turn movement with a yellow arrow as the research team proposed. The bottom three indications are all arrows.

Broward County issued a press release, which was received by one newspaper agency with negative press coverage (the opening line was “Broward County residents are guinea pigs”). At the time this report was prepared, the FYA operation had been in place for over a month and the County received no citizen calls. Additional details regarding the Broward County experience, including illustrations of how the five-section displays were implemented, are provided in Working Paper 8.

4.4.2 Public Reaction

Public comments from citizens that have experienced the FYA display in the field have generally been positive. Several volunteer agencies have reported receiving e-mails or written letters from the motoring public with most, if not all, having been in support of the FYA display.

As part of the on-going research activities, the consultant team has observed motorist reaction to the FYA display immediately upon implementation in the field. The drivers’
responses to the new displays suggest there has been very little confusion, with most motorists driving through the intersection as if nothing was changed.

Interestingly, many agencies that have implemented the FYA display have reported that drivers waiting to make a permitted left turn now stop behind the stop bar and wait for a gap in opposing traffic (as opposed to entering the intersection and then stopping).

### 4.5 AGENCIES DECLINING PARTICIPATION

One of the single greatest challenges encountered by the Research Team was the recruitment of volunteer agencies to participate in the field implementation study. Multiple agencies were contacted and assistance solicited; however many agencies lacked the resources to participate in the study. Table 4 provides a listing of agencies that declined participation in the study and the primary reasons cited for not participating based on phone calls and e-mail correspondence.
<table>
<thead>
<tr>
<th>ID #</th>
<th>Agency</th>
<th>Stated Reason for Not Participating in Field Implementation Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>City of Dallas, Texas</td>
<td>Interested but declined due to resources limitations</td>
</tr>
<tr>
<td>2</td>
<td>City of Peoria, Illinois</td>
<td>Initially interested in participation, but declined after considering their current use of the FRA indication and control logic issues associated with the FYA indication.</td>
</tr>
<tr>
<td>3</td>
<td>City of Kent, Washington</td>
<td>Interested but declined due to resources limitations</td>
</tr>
<tr>
<td>4</td>
<td>City of Redmond, Washington</td>
<td>Declined to participate due to other high-priority projects and limited funding.</td>
</tr>
<tr>
<td>5</td>
<td>Monroe County, New York</td>
<td>Initially interested but cautious about getting involved due to changes in management staff.</td>
</tr>
<tr>
<td>6</td>
<td>North Carolina DOT</td>
<td>Interested but declined to participate due to differences of opinion of PPLT operation among the various state districts, and changes in management staff.</td>
</tr>
<tr>
<td>7</td>
<td>City of Boulder, Colorado</td>
<td>Initially interested but declined to participate</td>
</tr>
<tr>
<td>8</td>
<td>City of San Jose, California</td>
<td>Interested but declined to participate due to resources limitations</td>
</tr>
<tr>
<td>9</td>
<td>City of Waco, Texas</td>
<td>Interested but declined to participate due to resources limitations and changes in management staff.</td>
</tr>
<tr>
<td>10</td>
<td>City of Everett, Washington</td>
<td>City traffic engineer interested but City Council declined to participate due to previous use of the FYB indication, which may lead to driver confusion.</td>
</tr>
<tr>
<td>11</td>
<td>City of Springfield, Missouri</td>
<td>Initially interested but declined to participate due to changes in management staff.</td>
</tr>
<tr>
<td>12</td>
<td>City of Lafayette, Louisiana</td>
<td>Initially interested but declined to participate because signal maintenance staff did not support the need to change.</td>
</tr>
<tr>
<td>13</td>
<td>Vermont Agency of Transport</td>
<td>Initially interested but will not participate</td>
</tr>
<tr>
<td>14</td>
<td>Mississippi DOT</td>
<td>Initially interested but will not participate</td>
</tr>
<tr>
<td>15</td>
<td>Milwaukee, Wisconsin</td>
<td>Interested but declined due to resources limitations</td>
</tr>
<tr>
<td>16</td>
<td>City of Anaheim, California</td>
<td>City traffic engineer interested but upper management was concerned about the tourist population understanding a unique traffic control device.</td>
</tr>
<tr>
<td>17</td>
<td>City of Anchorage, Alaska</td>
<td>Interested but signal controller equipment not compatible and there was a change in management staff.</td>
</tr>
<tr>
<td>18</td>
<td>City of Wyoming, Michigan</td>
<td>City traffic engineer interested but City Council declined participation</td>
</tr>
<tr>
<td>19</td>
<td>Athens-Clark County Georgia</td>
<td>City traffic engineer interested but declined due to resources limitations</td>
</tr>
<tr>
<td>20</td>
<td>City of Juneau, Alaska</td>
<td>*****</td>
</tr>
<tr>
<td>21</td>
<td>Georgia DOT</td>
<td>The state traffic engineer and several district engineers expressed interest in participation, but could not respond within the time constraints of the project.</td>
</tr>
<tr>
<td>22</td>
<td>Cobb County, Georgia</td>
<td>*****</td>
</tr>
</tbody>
</table>
### Table 4
Summary of Volunteer Agencies Declining Study Participation (Continued)

<table>
<thead>
<tr>
<th>ID #</th>
<th>Agency</th>
<th>Stated Reason for Not Participating in Field Implementation Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>23</td>
<td>Washington County, Oregon</td>
<td>Interested but declined due to driver confusion concerns</td>
</tr>
<tr>
<td>24</td>
<td>City of Los Angeles, California</td>
<td>City has implemented the Dallas Display to their satisfaction and do not see the need for a change.</td>
</tr>
<tr>
<td>25</td>
<td>City of Lewisville, Texas</td>
<td>City interested but declined to participate.</td>
</tr>
<tr>
<td>26</td>
<td>Ada County, Idaho</td>
<td>The county (region) traffic engineer very interested, selected sites for implementation, but due to limited resources did not participate.</td>
</tr>
<tr>
<td>27</td>
<td>Florida State DOT</td>
<td>State traffic engineer support the experiment and co-implemented with Broward County.</td>
</tr>
<tr>
<td>28</td>
<td>Texas DOT</td>
<td>State Traffic engineer ultimately supported the City of Waco's interest in implementation</td>
</tr>
</tbody>
</table>

### 4.5.1 Non-Participating Agency Survey

A survey was sent to all agencies that were contacted through the course of the implementation task (as summarized in Table 4) for the purpose of formally identifying why they chose not to participate. Surveys not returned are a reflection of the lack of time by many of the agencies contacted. As noted in Table 4, in many cases the agencies contacted by telephone to participate in the study chose not to participate because their responsibilities were too great and time was too scarce to commit themselves to participating in the study.

Of the follow-up surveys sent to the agencies, six surveys were returned. Table 5 summarizes the reasons offered for not participating in the study as documented in the returned surveys.

Although not captured by the follow-up surveys (since follow-up surveys were only returned by six non-participating agencies), those agencies that have verbally indicated to the Research Team that they do not support the FYA display cited reasons including:

- They see nothing wrong with the normal green ball operation;
- The FYA display requires additional equipment (another signal head); and
• There are techniques available today that satisfy their concerns (the Dallas Display, or other displays, such as the FRA).
Table 5
Summary of Volunteer Agencies Responses to Follow-Up Surveys

<table>
<thead>
<tr>
<th>Agency</th>
<th>State Reason For Not Participating In The Implementation Study</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Anaheim, CA</td>
<td>Local upper management felt there were too high a number of visitors (Disney Land, Rose Bowl, etc.) and that unfamiliar motorists would have difficulty understanding the new display.</td>
</tr>
<tr>
<td>City of Athens, GA</td>
<td>Too little time to commit to the project.</td>
</tr>
<tr>
<td>City of Dallas, TX</td>
<td>Too short on staff to commit the resources needed.</td>
</tr>
<tr>
<td>City of Everett, WA</td>
<td>The City participated in the flashing yellow ball experiment several years ago. The City upper management did not want to appear that they were “ping-ponging” between displays for PPLT operation.</td>
</tr>
<tr>
<td>City of Kennewick, WA</td>
<td>Irreconcilable problems with controller and conflict monitor (risk).</td>
</tr>
<tr>
<td>City of Peoria, IL</td>
<td>The flashing red arrow has performed well for their needs and they did not want to expend resources needed for the FYA display to work (controller and conflict monitor issue).</td>
</tr>
</tbody>
</table>

4.6 PRELIMINARY IMPLEMENTATION STUDY FINDINGS

The field implementation study is on-going at this time, with before-and-after study data collection still in process and agency surveys being circulated to solicit review and feedback. While this process is continuing, some preliminary trends and qualitative findings can be made as discussed below. In reviewing the remainder of this section, it should be understood that the results of the study are not complete and the findings presented are subject to additional review and may change pending the data and response that is ultimately received.

4.7 NEXT STEPS

The Research Team will be continuing “before” and “after” studies for the implementation sites as well as solicitation of agency feedback through surveys. The results of this
information will be made available to the Research Panel through an update to Working Paper 8 as the information is received.
5.0 RECOMMENDATIONS

Through the course of this study, the individual research tasks such as the Agency Survey, Photographic Driver Survey, Traffic Operations Study, Traffic Conflict Study, Crash Analysis, Driver Simulation Study, Field Implementation Study, and Engineering Assessment have provided the Research Team with a tremendous amount of data. The various working papers have presented this data and captured key findings derived from the research task activities. This section of the interim report provides the Research Team’s recommendation based on the collective project findings to date.

5.1 STUDY RECOMMENDATIONS

Based on the findings of this project, the Research Team is offering several recommendations as summarized below.

5.1.1 Recommendation #1: Incorporate FYA Display into the MUTCD

It is recommended that the FYA display be included in the MUTCD as an allowable alternative display to the green ball when used in protected-permissive left-turn control/operation. Additional recommendations relating to display type, location, and supplemental signing are presented below.

5.1.1.1 Displays

The 4-Section, all arrow display face should be the only display allowed. The only display that justifies an exception to this recommendation is the 3-Section display face with bi-modal lens. The 3-Section display face with bi-modal lens should also be allowed since it operates the same as the 4-Section display face. (Note to Panel: A discussion needs to take place that addresses the 3-section all-arrow display used in Jackson County that seems to be working without any problems.)
5.1.1.2 Location

The left-turn signal should be an exclusive display for the left-turn movement. As such, the FYA should be logically tied to the opposing through green indication/display. The left-turn signal head can be placed over the lane line between the left-turn lane and the adjacent through lane, or over the left-turn lane.

5.1.1.3 Supplemental Signs

Supplemental signing is not warranted with FYA, but use of supplemental signing is optional.

5.1.2 Recommendation 2: Conduct Follow-Up Study

It is recommended that a follow-up study be conducted in five years. The follow-up study should:

1) Analyze the crash data currently being collected for the experimental FYA displays implemented as part of this study;

2) Identify whether the FYA display should become the only display allowed in the MUTCD for a protected-permissive left-turn operation; and

3) Identify an implementation plan.

5.1.3 Recommendation 3: Restrict Use of Flashing Red Indications

It is recommended that use of flashing red indications be limited such that they are allowed in rare and restrictive implementations. The restrictive application would be left to a traffic engineering analysis conducted by a qualified professional.

This recommendation is supported by the findings of Tasks 3, 4, 5, and 6, and the findings reported in various working papers. It is acknowledged that the flashing red indications have a high level of understanding and a low fail-critical response. However, the flashing red indications dilute the meaning of the red indication used for exclusive stop conditions.
5.2 BASIS FOR RECOMMENDATIONS

The remainder of this section details the Research Team’s basis for the recommendations made.

5.2.1 Findings and Implications of Working Paper 7

The results of Working Paper 7 showed:

- The FYA display is equally understood (measured in terms of correct responses to questions presented) as the green ball;

- There is no significant difference of the motoring public correctly interpreting the meaning the FYA indication compared to the green ball (see Working Paper 7 results);

- The FYA display showed a higher fail-safe response compared to the green ball; and

- The conflict studies have shown that motorists interpret the FYA display correctly.

5.2.2 Findings and Implications of Working Paper 8

The results of Working Paper 8 showed:

- The FYA display has been successfully implemented in the field with relatively little or no technical or political issues;

- The majority of practicing traffic engineers accept the FYA display; and

- The field data support high understanding of the FYA display.

The research team has demonstrated a solid research approach to studying all permissive displays, of which all research efforts have been fully documented in the eight working papers. Putting the technical results of the research findings aside, and remembering that the panel selected this Research Team because the team brought a balanced approach to the
project that combined research and practical application. It is, therefore, appropriate to now focus on the practical element of why the FYA display is recommended for inclusion into the national manual.

5.2.3. The Yellow Trap

The original research problem statement addressed the yellow trap issue as a major concern of the panel. Additionally, the research team has fully discussed the left-turn yellow trap in previous reports. For these reasons, the description of the yellow trap will not be, therefore, repeated here. But, it must be recognized that the yellow trap issue is fundamental to why this research project got started in the first place. The FYA display, when tied to the opposing through green indication, eliminates the yellow trap from occurring, under all circumstances.

5.2.4 Operational Advantages

Likewise, the research team has previously discussed the various modes of left-turn operation, including permissive only, protected only, protected permissive, lead/lag, etc. There are many reasons why some modes of left turn operation are chosen, or why the mode is changed during the day, but in most cases it is for operational efficiency, such as to increase the left turn capacity, improve traffic progression through coordinated signals, or to reduce the duration required for the protected phase including full suppression of the protected phase. The research team has discussed the operational advantages that various modes of left-turn operation provide and that the current MUTCD standard green ball display presents safety problems. As a result, traffic engineers operate their intersections with less than optimum efficiency for the trade-off of intersection safety. Creative and aggressive traffic engineers are searching for ways to maintain intersection safety and improve intersection operations. If this were not true, then there would not be over five non-standard PPLT displays being used now just within the United States. Given this discussion
as a pre-amble, the flashing yellow arrow display supports the following modes of left-turn operations:

5.2.4.1 Protected-only Operation

The FYA does not require the permissive display to be used at all if desired. In this mode, it operates the same as a protected-only display.

5.2.4.2 Protected-Permissive Operation

The FYA display is “logically tied” to the green output of the opposing through movement to avoid the yellow left-turn trap. Logically tying a phase means that the traffic signal control software only outputs the flashing yellow arrow indication (permissive turn) during the green interval of the opposing through phase. This assures that when the permissive display terminate, the opposing through phase will terminate simultaneously. This completely eliminates the yellow trap, even when lead/lag phasing is used, or when side street phases are skipped and the leading left turn phase now follows the through phase.

5.2.4.3 Permissive-Protected Operation

Historically, most traffic engineers with lagging protected operations serve both left-turn phases for the same duration so as to not create the yellow trap. Because the FYA display is tied to the opposing through movement thus eliminating the yellow trap, this operation becomes much more efficient. This operation is especially useful for skipping the protected-only sequence when there is inadequate vehicular demand.

5.2.4.4 Permitted-only Operation

The permitted left-turn operation allows the drivers to execute left turns when gaps occur within the opposing through movement.

The FYA allows a signal to change modes in any way during the day, or for longer periods of time if desired. A key advantage to this operation is that a signal could, for example, change from an eight-phase protected-only operation during peak hours, to an eight-phase protected/permissive operation during the day, to a simple two-phase permissive-only signal
operation during low volume conditions. It is also feasible for one direction to operation protected-permissive while the opposite approach uses a different mode. All combinations are feasible and can be selected to optimize the operational efficiency as conditions change.

5.2.5 Other Considerations

5.2.5.1 Supplemental Display Arrangements

The FYA display supports all of the modes of left-turn operation as identified above and can be implemented in states that require supplemental signal heads. States such as California use supplemental signal heads normally located on the far side of the intersection. This type of operation is not possible with the Dallas display due to its need for optical shielding.

5.2.5.2 Right-Turn Overlap Display

The FYA display would solve the problem of having to prohibit the conflicting U-turn when operating a right turn overlap during a side street left turn phase. Similarly, the FYA display could be used for right turns – that have to yield to pedestrians – from approaches with no through movement and where a circular green indication can not be displayed due, for example, to a one-way opposite approach.

5.2.6 Universal Application

The FYA display is the only display that provides a universal solution. It can be used at every intersection, no matter how unusual. Others cannot be used in some situations, such as if the heads are mounted on span wires, if dual far side heads are needed (e.g., in California), if there is no adjacent through movement, if the approach is curved, if the turn must be held (not even permissive) during railroad preempt although both through movements can proceed, etc.
5.2.7 The Glenn Grigg Hypothesis:

We cannot forget the pioneers in the industry that have developed solid engineering principals that should be considered here. One such pioneer is Glenn Grigg, the retired traffic engineer from the City of Cupertino, California. It was the proposal of Glenn Griggs several years ago that a new display was needed that improved efficiency of left turns at traffic signals without depreciating the safety of protected left-turn phasing. It was Grigg’s hypothesis that the permissive left-turn display should have the following characteristics:

- Change in Color
- Change in Mode
- Change in Position
- Change in Shape

The FYA display provides a change in color (green to yellow), a change in mode (steady to flashing), change in position (lateral change is display placement and vertical change in the signal display arrangement), and a change in shape (circle to arrow).

5.2.8 Public Support for the Display

The reaction from the public about the FYA has been good. Working Paper 8 identified all seven implementing agencies as receiving positive feedback from local citizens. Yes, it is true, that there are some negative feelings about changing to the FYA display, but that type of response is expected anytime there is change.

Outside of the auspices of the NCHRP 3-54 project, public reaction has been overwhelmingly good.

The City of Reno, Nevada received tremendous public response immediately upon converting several intersections to using the FYA display. Sixty-six percent of the callers favored the new display, 27 percent were neutral (asked for information), and seven percent were negative (they did not see a reason for the change). As found in Jackson County, most
of those in favor of the FYA display wanted the displays retro-fitted to other intersections where protected-only left turn phasing was in operation.

The FYA has been in use in Europe for many years.

5.2.9 Disadvantages to the FYA display:

The FYA display has the following disadvantages:

- The MUTCD and vehicle codes will need to be amended.
- There will need to be software modifications in both controller firmware and conflict monitors to achieve the full flexibility of the FYA display.

5.2.10 Remarks:

The key to overcoming the yellow trap appears to be tying the permissive turn movement’s proceed indication to the opposing movement’s green interval. The FYA display prevents the adjacent through traffic from being mislead or confused by the permitted movement’s signal display. The proposed use of the FYA display solves many safety and operational problems associated with permitted turns display/indication, including the problem of motorists misinterpreting the circular green indication as a protected phase green indication.

The FYA display meets all of the functional requirements for both left and right turn permitted movements, while being safe and readily understood by motorists, and universally implementable. The FYA display also provides an alternative with simpler and more flexible signal hardware than is now required for those situations where the current MUTCD provides a solution.
6.0 REFERENCES