TEXAS SOUTHERN UNIVERSITY
COLLEGE *of* SCIENCE *and* TECHNOLOGY
Department of Transportation Studies

Training Strategies and Materials

Product 0-6568-P1

Cooperative Research Program

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Texas Department of Transportation
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Training Strategies and Materials

Prepared for TxDOT Project 0-6568:

Use of Flashing Yellow Operations to Improve Safety at Signals with Protected-Permissive Left Turn (PPLT) Operations

By

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INTRODUCTION

TxDOT project 0-6568 "Use of Flashing Yellow Operations to Improve Safety at Signals with Protected-Permissive Left Turn (PPLT) Operations" has developed guidelines for implementation of FYA PPLT displays including general guidelines on the FYA PPLT operation and guidelines on the installation of FYA signals. To facilitate the implementation of the guidelines developed by this project, training strategies and materials have been developed for providing a training session for TxDOT signal operations and TMC personnel.

This document consists of two parts. Part I "Training Strategies" provides details on the purpose, method, scheduling and location for the training. Part II "Training Materials" provides a list of the developed training materials along with the printouts of these training materials.

TRAINING STRATEGIES

Training Objectives and Contents

The goals of the proposed training section are to introduce to traffic engineers the developed guidelines and the use of these guidelines for implementing FYA signal display under PPLT control mode. The training session will cover the following topics:

1. General guidelines on the FYA PPLT operation
2. Guidelines on the installation of FYA signals

Training Audience

The potential audience for the workshop will be the engineers who are in charge of traffic signal design and installations. It will include the personnel in TxDOT traffic operations sections in different districts and traffic engineers in local Transportation Management Centers (TMCs).

Training Method

Researchers suggest a half-day, two-hour workshop for the proposed training. It is our belief that a half-day course at a TxDOT host district will encourage better participation considering the busy schedules of those individuals targeted to attend.

The workshop will introduce the general guidelines on the FYA PPLT operation and guidelines on the installation of FYA signals. At the end of the workshop, workshop evaluation form will be distributed to all attendees and will be reviewed after the workshop. The workshop agenda and materials will be refined, as appropriate, to capitalize on comments and suggestions that will improve the workshop in the future.

Training Scheduling and Coordination

The scheduling of workshops will be coordinated between the university workshop team leader, TxDOT project director from the Traffic Operations Division and TxDOT project advisor from the Human Resources Division. The project director will be responsible for coordinating workshops scheduling with TxDOT district training coordinators to ensure that district training facilities will be available for conducting workshops.

Training Location

The workshops are planned to be held in a TxDOT facility within selected host district. Location selection will be coordinated between the workshop team leader, project director and project advisors.

TRAINING MATERIALS

PowerPoint materials include:

- A presentation for introducing the guidelines developed for the implementation of Flashing Yellow Arrow (FYA) under Protected/Permissive (PPLT) control mode.

Workbook materials include:

- Detailed guidelines for the implementation of FYA PPLT display.
  - General guidelines on the FYA PPLT operation
  - Guidelines on the installation of FYA signals

General Recommendations for Implementation of Flashing Yellow Arrow (FYA) Under Protected/Permissive (PPLT) Control Mode

PowerPoint Presentation for Workshop

General Guidelines for Implementation of Flashing Yellow Arrow under Protected/Permissive Operations

Texas Southern University

Outline

- General guidelines on the FYA PPLT operation
- Guidelines on the installation of FYA signals
- Two examples of field implementation of FYA PPLT

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General Guidelines for Use of FYA PPLT Display

Guideline 1: When FYA should be considered

Guideline 2: Typical positions and arrangements

Guideline 3: Signal display sequence

Guideline 4: Safety assessment for converting from protected-only to FYA PPLT

Guideline 5: Supplementary signs

Guideline 6: Unfavorable/adverse conditions

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Guideline 1-

When FYA Should Be Considered

- FYA shall be used in a separate left-turn signal face to indicate permissive left turns (MUTCD 2009, Sections 4D.18 and 4D.20)
- According to the MUTCD Team, all new design work should comply with the guideline. The existing signalized locations that don't comply can retain the non-compliant display until the end of the service life of the signal heads, signal reconstruction, or other major modifications.

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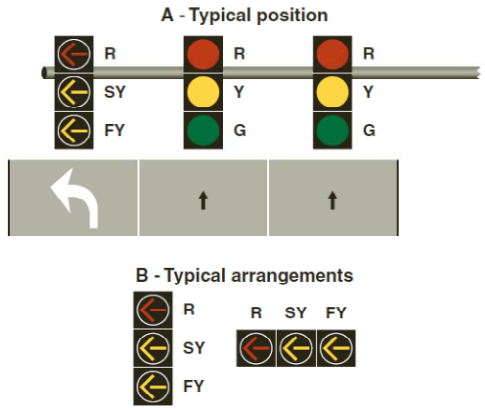
Guideline 2-

Typical Positions and Arrangements

- For Permissive-Only Mode

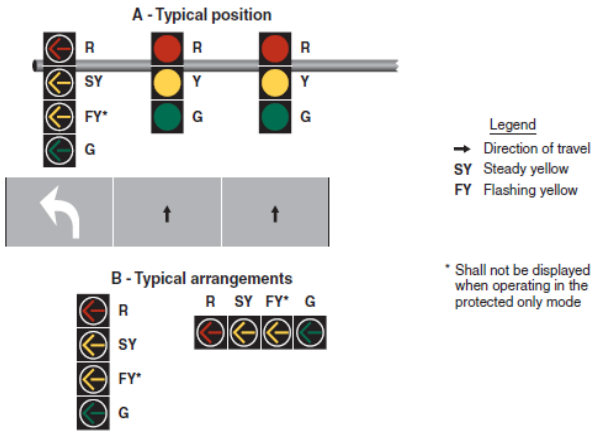


MUTCD (2009)

Guideline 2-

Typical Positions and Arrangements (continued)

- For Protected/Permissive Mode



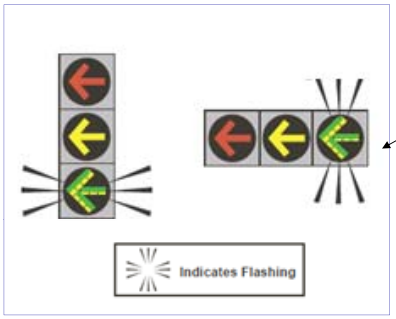
MUTCD (2009)

General Guidelines

Guideline 2-

Typical Positions and Arrangements (continued)

- Three-section signal face



MUTCD (2009)

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General Guidelines

Guideline 3-

Signal Display Sequence

	Opposing Left Turn (lead)	Opposing Through	**Subject Left Turn (lead)**	Subject Through	Description
1					All-red
2					Green arrow for subject approach
3					Steady yellow at the end of the protected subject LT phase
4					Red clearance at the end of the protected subject LT phase
5					Delay the start of subject FYA (Optional)
6					FYA permissive
7					Steady yellow arrow at the end of the permissive LT phase

Lead-Lead PPLT

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Lead-Lag PPLT

	Opposing Left Turn (lag)	Opposing Through	**Subject Left Turn (lead)**	Subject Through	Description
1					All-red
2					Green arrow for subject LT approach
3					Steady yellow at the end of the protected subject LT phase
4					Red clearance at the end of the protected subject LT phase
5					Delay the start of subject FYA (Optional)
6					FYA permissive
7					Yellow clearance for subject through
8					Red clearance for subject through
9					Steady yellow arrow at the end of the permissive LT phase

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General Guidelines

Lag-Lag PPLT

	Opposing Left Turn (lag)	Opposing Through	**Subject Left Turn (lag)**	Subject Through	Description
1					All-red
2					FYA permissive
3					Yellow clearance for through traffic
4					Red clearance for through traffic
5					Lag-lag protected phase for left-turns
6					Steady yellow clearance for left turns

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General Guidelines

Guideline 4-

Safety Assessment for Converting from Protected-Only to FYA PPLT

- Should evaluate whether it is safe to allow permissive left-turns/U-turn:
  - Left-turn accident history
  - Left-turn demand
  - Opposing traffic volume
  - Speed limit
  - Sight distance
  - No. of left-turn lanes and opposing through lanes
  - Geometry (i.e. whether turning paths conflict with each other)

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General Guidelines

Guideline 5-

Supplementary Signs

The use of a supplementary sign for FYA indications is optional and may be used where an engineering evaluation indicates it is necessary.

Sources: Deskins (2009), NCHRP Report 493 (2003)

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General Guidelines

Guideline 6-

Unfavorable/Adverse Conditions

- Special cautions are needed when installing FYA at intersections with:
  - Heavy traffic volume
  - High speed limit

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General Guidelines

Guideline 6-

Unfavorable/Adverse Conditions (continued)

- Heavy traffic volume or high speed limit may cause :
  - More “fail-to-yield” conflicts/crashes
  - More red-light runners for leading left-turns

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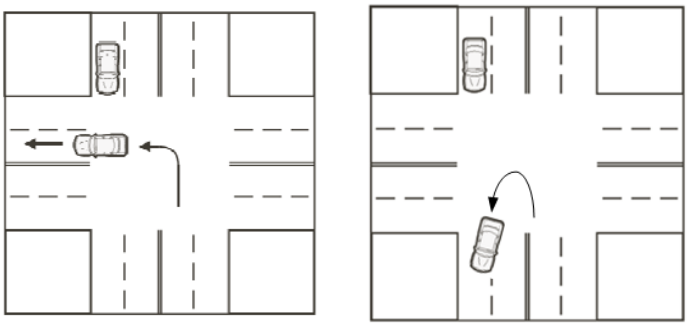
Guideline 6-

Unfavorable/Adverse Conditions (continued)

Problem 1: Increased "Fail-to-Yield" conflict/crashes



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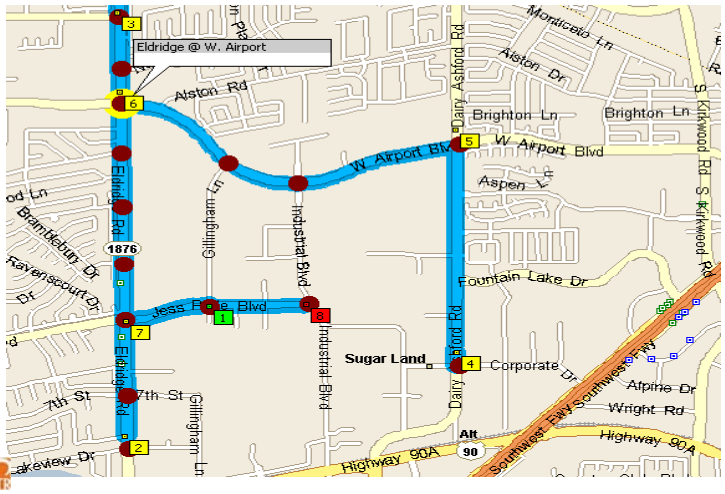
Guideline 6-

Unfavorable/Adverse Conditions (continued)

Problem 1: Increased Fail-to-Yield conflict/crashes



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Guideline 6-

Unfavorable/Adverse Conditions (continued)

Problem 1: Increased Fail-to-Yield conflict/crashes

- No safety issues except one intersection at W. Airport at Eldridge, which is the busiest intersection
  - Several complaint emails and phone calls received
  - 4 accidents due to failure to yield since its installation on 3/4/2011.
  - Disallowed the permissive left turn movement during the AM, noon, and PM peak periods on 4/6/2011. After that, the accident rate has decreased.

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Guideline 6-

Unfavorable/adverse Conditions (continued)

Problem 1: Increased Fail-to-Yield conflict/crashes

Intersection	Direction	Avg. LT Volume (vph)	Avg. Thru Volume (vph)	After Conflicts Counts – Before Conflicts Counts
FM 2244 & Walsh Tarlton, Austin	NB	192	72	+
	EB	216	1422	
	WB			
FM 620 & Great Oaks, Austin	NB	152	1594	-
	SB			
US 84 & Hogan, Bellmead	WB	26	1036	-
	EB			
US 84 & Ashleman, Bellmead	WB	23	897	-
	EB			
US 84 & Maxfield, Bellmead	WB	10	893	-
	EB			

- In the 5 field conflict study intersections, only 1 intersection had a increased fail to yield traffic conflict.
  - Heavy LT volume AND heavy opposing thru volume

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Guideline 6-

Unfavorable/adverse Conditions (continued)

- Problem 2: Increased red-light runners for leading left-turns
  - Drivers may be less sensitive to steady yellow arrow when using FYA → Be trapped at the end of permissive left-turn phase (FYA → Solid Yellow Arrow →Red Arrow)

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Guidelines on the Installation of FYA Signals

Guideline 7: General Installation Procedure

Guideline 8: Load Switch Output Options

Guideline 9: Overlap Programming Method for FYA PPLT

Guideline 10: Checklist for Setting up FYA PPLT

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Guideline 7 –
General Installation Procedure

- Step 1 - Set up traffic control plan determined by the engineer. To include warning signs, reflective cones, vehicle mounted arrow boards, temporary stop signs or police for controlling the intersection if needed, etc.
- Step 2 - Modify left-turn signal heads and install supplemental signs

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Guideline 7 –
General Installation Procedure (continued)

- Step 3 - Transmit signal timing plans to controller replacement, replace the controller and MMU, may modify MMU program card and /or add load switches
- Step 4 - Re-wire and check every signal lens for proper display
- Step 5 – Test and confirm proper signal operations

Guideline 8 –

Load Switch Output Options

Two optional modes for driving the controller and load switch outputs for displaying FYA indication

Ped Mode – use the unused "yellow" outputs of pedestrian load switches

Allows an FYA signal to be implemented without using a second full load switch socket or cumbersome cabinet re-wiring

Overlap Mode – add overlap load switches

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Guideline 8 –

Decisions on which mode should be used (to be continued)

- **Cabinet conditions**
  - Availability of unused load switch sockets
    - Overlap Mode may not be feasible when there are not enough number of unused load switch sockets
  - Presence of pedestrian load switches
  - 16-channel cabinet preferred for both modes
- **Internal programming of controller**
  - E.g. Naztec suggests the use of Ped Mode and the controllers are programmed accordingly
  - For a better decision, contact the manufacturer of controllers and MMUs to confirm

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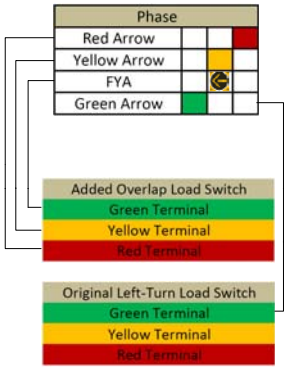
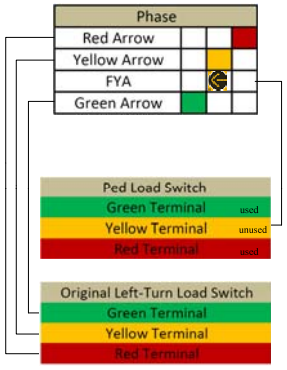
Guideline 9 –
Overlap Programming Method for FYA

- Based on information from signal controller manufacturers.

  Verified through the field tests in Waco and Austin District.



Overlap Mode



Ped Mode

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Guideline 10 –
Checklist before Setting up FYA (to be continued)

- **Check replacement head size/mounting**
  - 12-inch lens typically required
  - 4-section vertical signal head (to replace 5-section doghouse) may need to raise wire spans
- **Check # of cabinet channels and unoccupied load switch sockets**
- **Check if the mast arm is long enough to center the FYA signal head over the exclusive left-turn lane**

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Guideline 10 –
Checklist before Setting up FYA (continued)

- **Check status of signal equipment**
  - A malfunctioned load switch or a bad load switch socket may lead to problems
- **Check if # of available cables is sufficient to enable FYA**
  - Due to the flashing indication, additional cabling may be necessary for the FYA to be controlled by its own circuit.

Southbound Approach, FM 2244 & Walsh Tarleton, Austin, Less cables (6) available than needed (7)

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Guideline 10 –
Checklist before Setting up FYA (continued)

- **Confirm with signal equipment manufacturers about the applicability and programming method of the controller and MMU**

Some MMUs Supporting FYA Displays

Make	MMU	Type of Standard
EDI	SSM-6LE, SSM-12LE, 16LE SmartMonitor	NEMA TS-1
	MMU-16LE SmartMonitor	NEMA TS-2
	2010ECL, 2018KCL, 2018ECL	170/2070
Naztec	516 MMU LCD w/Ethernet	NEMA TS2
Reno A&E	MMU-1600D Series	NEMA TS-1 and TS-2
	MMU-1600G Series	NEMA TS-1 and TS-2
	2018 Series	170/2070
Econolite	MMU-16LE	NEMA TS-1 and TS-2

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Guideline 10 –
Checklist before Setting up FYA (continued)

Some controllers Supporting FYA Displays

Vendor	Controller Type	Model of Controllers Enabling FYA	Min. Firmware Requirement	User Manual Collected*
Econolite	NEMA TS 2	ASC3-2100 ASC3-1000	Version 2.48.00	• Econolite controller programming method
Naztec	NEMA TS 2	TS2 Type 1 TS2 Type 2	Version 61.x	• Naztec controller programming method
McCain	170	All McCain 170 controllers	Version 233MC1	• 2070 controller programming method
	2070	All McCain 2070 controllers	Version 2033RV	
Peek	NEMA TS1 and TS 2	3000E	Version 3.7.3 BD420	• 3000E controller programming method
Northwest Signal	NEMA TS1 and TS 2	M1 Controller	NWSCentral**	• M1 controller programming method

* Documents are available at the website for the research project: http://itri.tsu.edu/TXDOT6568/d.htm

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FYA PPLT Field Implementation

- FM 620 & Great Oaks in Austin, TX
- US 84 & Hogan, Bellmead, TX

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Field Implementation in FM 620 & Great Oaks

- **Before conditions**
  - 16-channel cabinet (Ped channels in use)
  - MMU: EDI-16E
  - Controller: Econolite ASC/3 1000
  - Signal head: 5-section horizontal GB PPLT

(to be continued)

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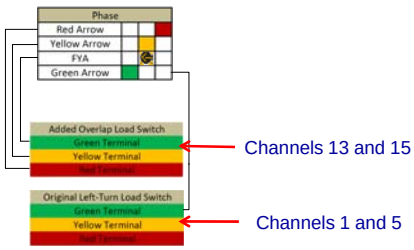
Field Implementation in FM 620 & Great Oaks (Continued)

- **Overlap Mode or Ped Mode**
  - Unused load switch sockets available
  - Use of Ped Mode may create needs for program card jumpers that are not correct
  - → **Overlap Mode was chosen**
- **Overlap Programming Method**
  - Two additional load switches added to Channels 13 and 15



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(to be continued)

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Field Implementation in FM 620 & Great Oaks (Continued)

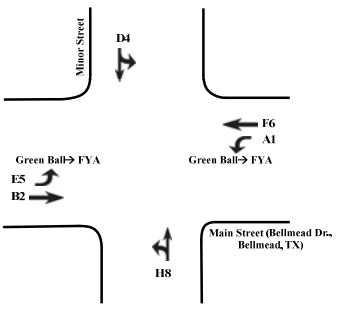
- **Signal head**

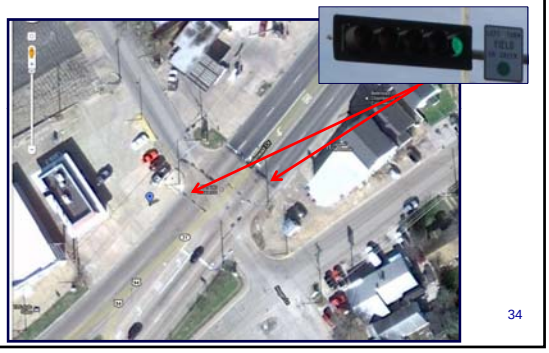
Before	red	yellow	solid yellow	green	green
After	red		flashing yellow	solid yellow	green

- **Upgrade for Controller and MMU**
  - Controller: Econolite ASC/3 1000 Controllers
  - MMU: EDI-16L → EDI 16LE SmartMonitor

Field Implementation in US 84 & Hogan

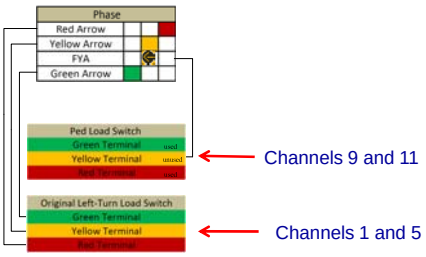
- **Before conditions**
  - 12-channel cabinet (6 load switches in use in the cabinet)
  - MMU: EDI-16; Controller: Naztec 900 Series TS 2
  - Signal head: 5-section horizontal GB PPLT
  - No pedestrian channels, no pedestrians signal heads

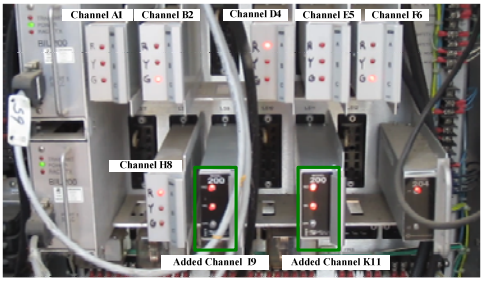




Field Implementation in US 84 & Hogan (Continued)

- **Overlap Mode or Ped Mode**
  - Waco District uses Naztec controller, which suggests the use of Ped Mode for FYA with the corresponding internal programs
  - → **Ped Mode was chosen**
- **Overlap Programming Method**
  - FYA mapped to Channels 9 and 11 (Virtual Ped LS)

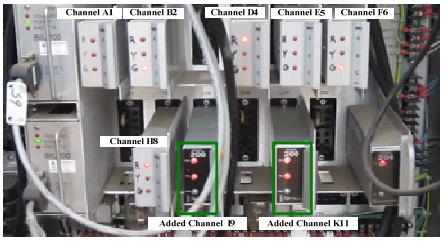




Examples of Field Implementation

Field Implementation in US 84 & Hogan (Continued)

- **Particular Problem with US 84 & Hogan**
  - No "Walk" signal inputs for the Virtual Ped LS → "**Red fail**" detected by MMU



Solution 1: Add new jumpers on MMU program card

Solution 2: Install Load Resistors on the unused Walk (Green) Field Terminals for Load Switches 9 and 11 (suggested solutions)

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Field Implementation in US 84 & Hogan (Continued)

- **Signal head**

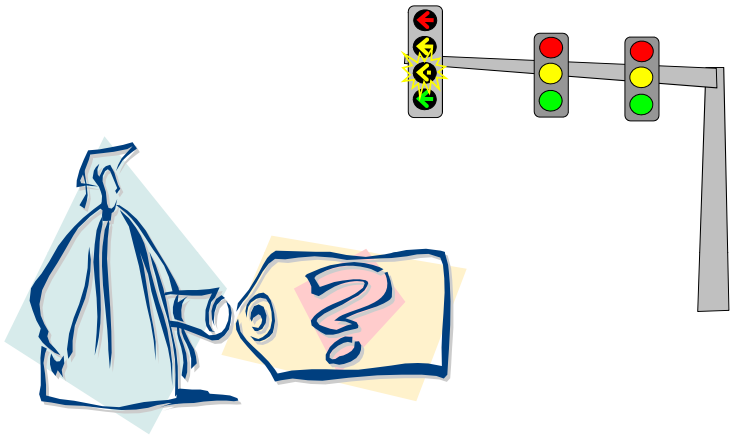
Before	red	yellow	solid yellow	green	green
After	red	red	flashing yellow	solid yellow	green

- **Upgrade for Controller and MMU**
  - Controller: Naztec 900 Series TS 2 → Naztec 900 Series TS 2
  - MMU: EDI-16 → Naztec 516

Summary

- This session introduced:
  - General guidelines for use of FYA PPLT display
  - Guidelines on hardware and software associated with implementing FYA signals
- Two examples of field implementation

Thanks and Questions?



General Guidelines for Implementation of Flashing Yellow Arrow (FYA) Under Protected/Permissive (PPLT) Control Mode

Workbook Materials for Workshop

GENERAL GUIDELINES FOR IMPLEMENTATION OF FYA PPLT

The purpose of this document is to present general guidelines for future implementation of the FYA PPLT display in Texas. These guidelines were developed based on the results of a thorough literature review, a nationwide survey of traffic engineers, field tests in Waco and Austin Districts, crash data analysis and field conflict studies conducted throughout the TxDOT research project 0-6568.

1 FRAMEWORK OF DEVELOPED GUIDELINES

The proposed guidelines include two parts: 1) general guidelines on the FYA PPLT operation, and 2) guidelines on the installation of FYA signals. The recommended guidelines were highlighted in shaded text boxes for easy reference.

2 GENERAL GUIDELINES ON THE FYA PPLT OPERATION

This part of guidelines aims to provide general guidelines regarding the situations under which the use of FYA indications should be suggested. The guidelines also aim to address other issues that need to be considered during the implementation of FYA signals.

Guideline 1 – When FYA Should Be Considered:

FYA signal indication is suggested for the permissive-only or permissive-protected left-turn operations if a separate left-turn signal face is being operated.

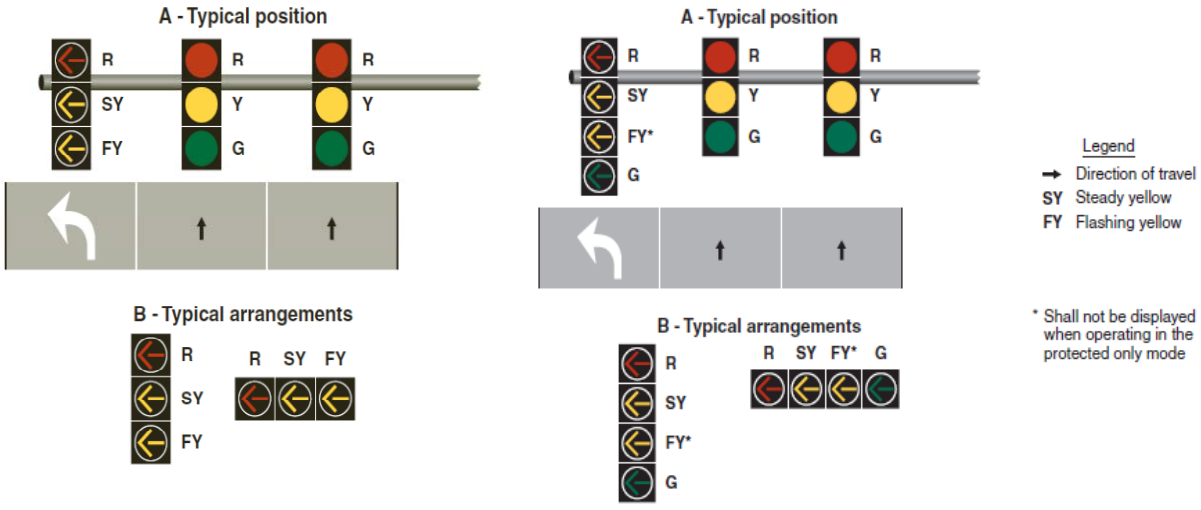
This guideline is based on the provision in Section 4D.18 and Section 4D.20, the 2009 Edition MUTCD. According to this manual, circular green signal indications shall not be used in a separate left-turn signal face to indicate permissive left turns. According to a highway engineer with the MUTCD Team, all new design work shall comply with this guideline. The existing signalized locations that don't comply can retain the non-compliant display until the end of the service life of the signal heads, signal reconstruction, or other major modifications.

In addition, the 2009 Edition MUTCD also suggests that for unusual geometric conditions, such as wide medians with offset left-turn lanes, a flashing left-turn red arrow signal indication

instead of an FYA should be used in a separate left-turn signal face to indicate that each vehicle must successively come to a full stop before making a permissive left turn. Note that, this option is used only when it is proven by engineering studies.

Guideline 2 - Typical Positions and Arrangements for FYA Signal Head:

- Figure 1 (a) is for permissive-only mode
- Figure 1 (b) is for PPLT mode



(a) Permissive-Only Mode Left Turns (b) PPLT Mode Left Turns

Source: MUTCD (2009)

Figure 1: Typical Position and Arrangement for Separate Signal Faces with FYAs

This guideline is based on the provision in 4D.18 and Section 4D.20, the MUTCD (2009).

Furthermore, according to the 2009 Edition MUTCD, a three-section signal face (shown in Figure 2) containing a dual-arrow signal section is also permitted where signal head height or wind loading limit the use of a four-section signal face. However, based on the nationwide survey of traffic engineers conducted during this research, the three-section signal face is not recommended for implementing FYA signals because dual-arrow signal section which is used to

display both green arrow and FYA may confuse drivers especially who are green-yellow color blind.

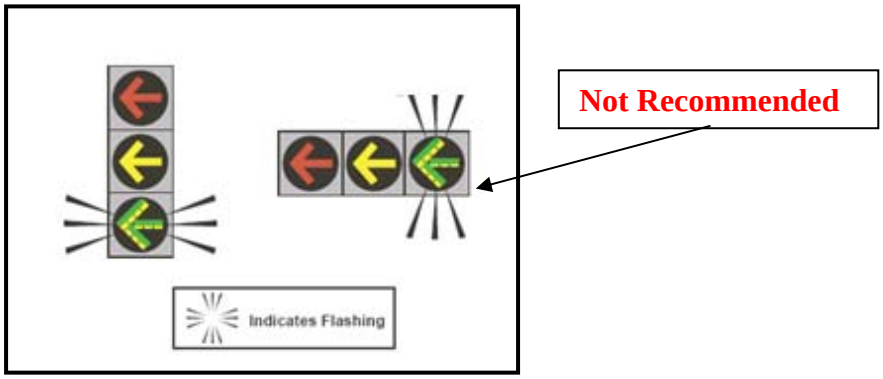


Figure 2: Three-Section Signal Face

Guideline 3 – Signal Display Sequence:

The suggested FYA display sequences for different types of signal left-turn phasing (lead-lead, lead-lag, lag-lag) are illustrated in Figures 3, 4 and 5.

This guideline is suggested based on NCHRP Report 493, the MUTCD, and the results of this research.

	Opposing Left Turn (lead)	Opposing Through	**Subject Left Turn (lead)**	Subject Through	Description
1					All-red
2					Green arrow for subject approach
3					Steady yellow at the end of the protected subject LT phase
4					Red clearance at the end of the protected subject LT phase
5					Delay the start of subject FYA (Optional)
6					FYA permissive
7					Steady yellow arrow at the end of the permissive LT phase

Figure 3: FYA Displays for Lead-Lead PPLT Operations

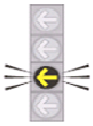
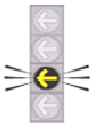
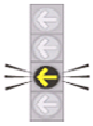
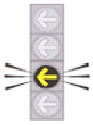
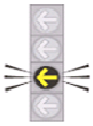
	Opposing Left Turn (lag)	Opposing Through	**Subject Left Turn (lead)**	Subject Through	Description
1					All-red
2					Green arrow for subject LT approach
3					Steady yellow at the end of the protected subject LT phase
4					Red clearance at the end of the protected subject LT phase
5					Delay the start of subject FYA (Optional)
6					FYA permissive
7					Yellow clearance for subject through
8					Red clearance for subject through
9					Steady yellow arrow at the end of the permissive LT phase

Figure 4: FYA Displays for Lead-Lag PPLT Operations

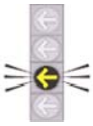
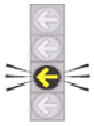
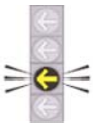
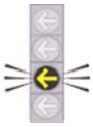
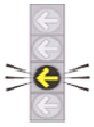
	Opposing Left Turn (lag)	Opposing Through	**Subject Left Turn (lag)**	Subject Through	Description
1					All-red
2					FYA permissive
3					Yellow clearance for through traffic
4					Red clearance for through traffic
5					Lag-lag protected phase for left-turns
6					Steady yellow clearance for left turns

Figure 5: FYA Displays for Lag-Lag PPLT Operations

For leading-phased left turns, the MUTCD suggests that a steady left-turn yellow arrow signal indication should be displayed following the left-turn green arrow signal display, as shown in interval 3 in Figures 3 and 4. The MUTCD does not provide recommendations about whether a steady red arrow should be displayed after the steady yellow arrow, as shown in interval 4 in Figure 3. According to the literature reviewed, a steady red arrow is recommended to clearly indicate the end of the protected left-turn interval. In addition, in the field study, a delay of the start of FYA (interval 5 in Figures 3 and 4) has been set to prevent the left-turn vehicles from failing to yield to the opposing vehicles at the beginning of permissive left-turn interval, which worked well from the observation by the researchers.

The crash analysis in this research also showed that issues that may result in crashes were associated with leading protected left-turn interval, i.e., "steady yellow arrow confusion". To address the issue, we suggest the use of a little longer red arrow (e.g. 3-4 seconds for interval 4 in Figures 3 and 4) between the steady yellow arrow and FYA, because this red clearance interval can better warn the left-turn drivers of the end of the protected left-turn, and better clear the confused left-turn drivers who have already entered the intersection.

For lagging phased left-turns, the MUTCD suggests that FYA should be followed directly by the steady green arrow signal indication, as shown in Figure 4 (the lagging left-turn movement in the blue box) and Figure 5. A steady yellow arrow should not be displayed in between (provision G in section 4D.20).

Guideline 4 – Safety Assessment for Converting Signal Operation from Protected-Only Mode to FYA PPLT Mode:

Before implementation of the FYA PPLT operations at intersections that were previously operated under protected-only mode, following factors need to be checked to evaluate whether it is safe to allow permissive left-turns/U-turn at the intersection:

- Left-turn volume
- Opposing traffic volume
- Speed limit
- Sight distance
- Number of left-turn lanes and opposing through lanes
- U-turn volume
- Crash history
- Geometry (i.e., whether turning paths conflict with each other)

This guideline is based on the results of this research project. Among the 51 intersections under study, 7 intersections were converted directly from traditional four-section protected-only signal operation to four-section FYA PPLT operation. The left-turn related crash rates at 5 intersections out of the 7 intersections increased. By analyzing the crash data at these intersections, it was found that the major causes for the increased crash rates is that the locations are not safe to allow permissive left turns due to some traffic and geometric conditions, such as heavy traffic volume, high speed, and presence of multiple turning lanes.

Guideline 5 – Supplementary Signs

An optional supplementary sign for FYA indications may be used where necessary.

"LEFT-TURN YIELD ON FLASHING YELLOW" without graphic

Source: Deskins (2009) and NCHRP Report 493 (2003)

Figure 6: Optional Supplementary Sign for FYA PPLT

Guideline 6 – Unfavorable/Adverse Conditions for FYA PPLT Operation:

Special cautions are needed to install FYA signal indication at intersections with following traffic conditions:

- Heavy traffic volume
- High speed limit

If the installation of FYA is required at such intersections, the use of lead-lead signal phasing sequence should be avoided.

This guideline is based on the results of this study. The "steady yellow confusion" problems related to the use of FYA may occur and the number of "red-light runners" may increase at intersections with high traffic volumes and/or high speed limit, especially when the subject left-turn movements are operated under leading left-turn phases. Therefore, if the installation of the FYA display is used at such intersections, for example, to comply with the requirement of

Sections 4D.18 and 4D.20 of the 2009 Edition MUTCD, a lag-lag signal phasing sequence would be preferable to minimize the occurrence of the above issues.

3 GUIDELINES ON THE INSTALLATION OF FYA SIGNALS

This part of guidelines is focused on providing guidelines on hardware and software issues associated with installing FYA signals. These guidelines were developed based on the literature review, the survey of equipment manufacturers/vendors, and the field tests conducted in Waco and Austin Districts.

Guideline 7 – General Installation Procedure:

The installation procedure can be generalized as the following steps:

- Step 1 Set up traffic control plan determined by the engineer. To include warning signs, reflective cones, vehicle mounted arrow boards, temporary stop signs or police for controlling the intersection if needed, etc.
- Step 2 Modify or replace left-turn signal heads and install supplemental signs;
- Step 3 Transmit signal timing plans to the controller replacement, replace the existing controller and MMU with the replacements which has been programmed, modify MMU program card, load switches may be added;
- Step 4 Re-wire and check every signal lens for proper display;
- Step 5 Confirm proper signal operations.

This procedure is generalized based on the practices of TxDOT district traffic engineers during the field tests conducted in Bellmead and Austin, TX.

Guideline 8 – Load Switch Output Options:

Generally, there are two optional modes for driving the controller and load switch outputs for displaying FYA indications:

- Ped Mode – use the unused "yellow" outputs of pedestrian load switches

  Generally, Ped Mode allows an FYA signal to be implemented without using a second full load switch socket or cumbersome cabinet re-wiring.

- Overlap Mode – add overlap load switches

This guideline is based on information collected from signal equipment manufacturers/vendors and the experiences of the field tests. During Stage I field test in Waco District, Ped Mode was used to drive controller and load switch outputs; while during Stage II field test in Austin District, Overlap Mode was used.

The decisions associated with which mode should be used largely depend on the existing hardware conditions and preferred level of system flexibility, e.g., availability of unused load switch sockets and presence of pedestrian load switches. It is critically important to refer to relevant instructions from the equipment providers, since the internal controller programming may vary with different manufacturers.

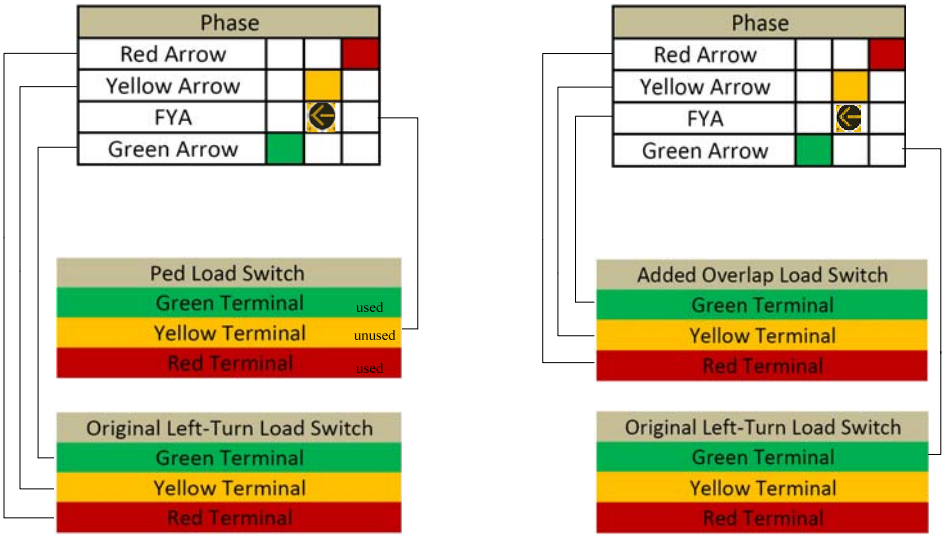
Guideline 9 – Typical Overlap Programming Method for FYA PPLT:

Typically, different overlap programming methods are used for Ped Mode and Overlap Mode:

- Under Ped Mode, the output of FYA should be mapped to the pedestrian yellow output on the pedestrian load switches. The green arrow, steady yellow arrow, and red arrow outputs are commonly mapped to the load switch driving the corresponding protected left-turn phases (Figure 8 (a)).
- Under Overlap Mode, the output of FYA, steady yellow arrow, and red arrow are commonly mapped to the added load switches. The FYA should be outputted through the green field terminals. The green arrow should be mapped to the load switch driving the corresponding protected left-turn phases (Figure 8 (b)).

This guideline is based on information collected from signal equipment manufacturers/vendors and has been verified through the field tests conducted in Waco District and Austin District. It should be noted that the choice of programming method for FYA outputs may also be restricted by the internal programs of controllers and MMUs.

Based on the experience in the field test in Waco District, a Red-Fail problem will occur with the Ped Mode if the Green (or Walk) field terminals for a load switch is unused. This problem can be resolved by installing load resistors or capacitors on the unused Green (Walk) field terminals for the load switches.



(a) Ped Mode (b) Overlap Mode

Figure 7: Typical Overlap Programming Methods for FYA PPLT

Guideline 10 – Checklist for Setting up FYA PPLT:

Before FYA signal is set up in the field, the proposed checklist can be used to examine the existing hardware conditions at the intersections.

This guideline is based on the literature review and field tests. Full awareness of the existing hardware conditions can facilitate a smooth implementation of FYA PPLT. The following checklist can be used before FYA PPLT is set up in the field.

☑ Check replacement head size/mounting

The implementation of the FYA indication typically requires a 12-inch lens. If the current green ball display has an 8-inch lens, replacement of the complete head will likely be necessary. Sometimes, installation of four-section vertical signal head (to replace five-section doghouse) may need to raise wire spans.

☑ Check the number of cabinet channels and unoccupied load switch sockets

The number of cabinet channels has effects on how to program the controller and MMU (e.g., MMU program card), and the number of unoccupied load switch sockets

may determine which option, Ped Mode or Overlap Mode, will be more suitable.

☑ Check if the number of available cables is sufficient to enable FYA signals

A common installation of PPLT phasing using a green ball for the permissive interval makes use of the green through phase to illuminate the green ball. Due to the flashing indication, additional cabling may be necessary in order for the flashing display to be controlled by its own circuit.

For example, at FM 2244 & Walsh Tarlton, Austin, TX, there were only 6 cables available for the signal lens for southbound approach on Walsh Tarlton Ln. Before the installation of FYA, the signals for the side street (Walsh Tarlton Ln) were operated by PPLT. The permissive left-turn green ball had the same indication with the adjacent through movement. To enable FYA, one more cable was needed (7 in total).

☑ Check if the mast arm is long enough to center the FYA signal head over the exclusive left-turn lane

☑ Check status of signal equipment

Before implementing FYA signals, the equipment to be used should be checked, e.g., a malfunctioned load switch or a bad load switch socket may lead to problems during the implementation of FYA.

☑ Confirm with signal equipment manufacturers about the applicability and programming method of the controller and MMU

Most leading signal equipment manufacturers have developed new models of controllers and MMUs that support FYA signal operations. Controllers must have the correct firmware to enable FYA operations.

TSU research team has contacted major signal equipment manufacturers. The team has collected information about the types of controllers that support FYA operations, the minimum firmware requirement, as well as the user manuals collected, as summarized in Table 1 and Table 2.

While manufacturers and users will often devise different solutions that may result in inter-changeability and inter-operability problems, according to the interview with a member of NEMA Standards Approval Associate, the recent development of the NEMA TS-2 amendment

No. 4 for FYA will provide an equipment based standard that will ensure compatibility between the controller and MMU that are conformant to the new standard. The Standard will provide a way for these issues to be mitigated.

Table 1: Some Controllers and Firmware Supporting FYA Displays

Vendor	Controller Type	Model of Controllers Enabling FYA	Min. Firmware Requirement	User Manual Collected*
Econolite	NEMA TS 2	ASC3-2100	Version 2.48.00	• Econolite controller programming method
		ASC3-1000		
Naztec	NEMA TS 2	TS2 Type 1	Version 61.x	• Naztec controller programming method
		TS2 Type 2		
McCain	170	All McCain 170 controllers	Version 233MC1	• 2070 controller programming method
	2070	All McCain 2070 controllers	Version 2033RV	
Peek	NEMA TS1 and TS 2	3000E	Version 3.7.3 BD420	• 3000E controller programming method
Northwest Signal	NEMA TS1 and TS 2	M1 Controller	NWSCentral**	• M1 controller programming method

* Documents are available at the website for the research project: http://itri.tsu.edu/TXDOT6568/d.htm

** Version unspecified

Table 2: Some MMUs Supporting FYA Displays

Make	MMU	Type of Standard
EDI	SSM-6LE, SSM-12LE, 16LE SmartMonitor	NEMA TS-1
	MMU-16LE SmartMonitor	NEMA TS-2
	2010ECL, 2018KCL, 2018ECL	170/2070
Naztec	516 MMU LCD w/Ethernet	NEMA TS2
Reno A&E	MMU-1600D Series	NEMA TS-1 and TS-2
	MMU-1600G Series	NEMA TS-1 and TS-2
	2018 Series	170/2070
Econolite	MMU-16LE	NEMA TS-1 and TS-2

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Kacir, K.C., Brehmer, C.L., Noyce, D.A., and Manser, M.P. *NCHRP Report 493: Evaluation of Traffic Signal Displays for PPLT Control*. Transportation Research Board, National Research Council, Washington, D.C., 2003.

Deskins, J. *Five Years of Observations of the Flashing Yellow Arrow Display*. ITE Meeting, 2009.