

**EVALUATION OF TRAFFIC SIGNAL DISPLAYS FOR
PROTECTED-PERMITTED LEFT-TURN CONTROL
NCHRP PROJECT 3-54**

ENGINEERING ASSESSMENT REPORT

Working Paper 1

Prepared for:
National Cooperative Highway Research Program
Project Panel Members

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ENGINEERING ASSESSMENT

OVERVIEW

The research team, in concert with the Project Panel, developed a multitude of questions that were considered key to determining the “best” traffic signal indication for the PPLT control. Some of these questions would be answered through more traditional experimental procedures, where as other questions would be answered by applying engineering judgment based upon current practices. This working paper identifies the methodology and assumptions used to answer these questions.

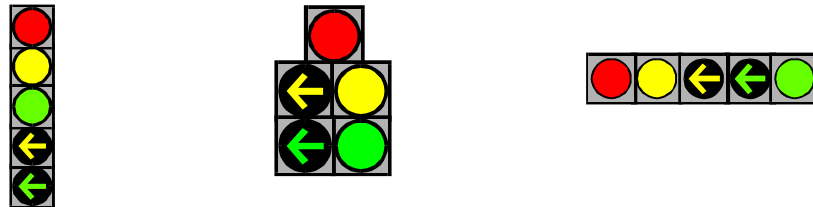
The research team developed an evaluation matrix as a method of relating the alternative indications to these questions. Table 1 presents the evaluation matrix completed for the engineering assessment phase of the project. The Research Team has used *Consumer Reports*-like figures (Ranking scale: ● = highest/best; ○ = lowest/worst) to provide a comparative score for each display in answering each question. Table 1 was updated from the August 1999 version based on current research findings – mostly from the confirmation study and implementation study. The Flashing Yellow Ball (FYB) and both red indications (FRA and FRB) were removed from Table 1 based on the direction provided by the Project Panel in October 1999.

Many of the questions in the evaluation matrix can only be addressed by an engineering assessment. The engineering assessment includes factual and judgmental information required to evaluate the proposed indications. A narrative discussion of the questions is included after Table 1.

INDICATION CONFIGURATIONS

The following diagrams illustrate the four indication configurations for which engineering assessment results are presented in this working paper. The four indication configurations are referred to here as:

Traditional Five Section (T5S) – This configuration consists of three balls (red, yellow and green) and two arrows (yellow and green). The five sections may be clustered or linear (vertical stack or horizontal). All sections are steady (not flashing) when on. One ball section is always On, and one of the two arrow sections may also be On. At all times, the state of the ball sections mirrors that of the adjacent through-only three-section head(s). It is assumed that this five-section head is observed by through traffic as well as turning traffic. The green ball provides the permissive indication.

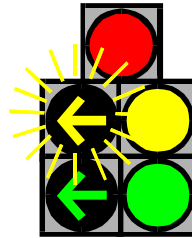


Permissive Lead/Lag (PLL) – This configuration is identical to the traditional five-section configuration, except that the green and yellow ball sections are shielded from the view of through drivers (e.g., optical programming or louvers) and that the state of the ball sections mirror that of the opposite-direction through-only three section heads. This configuration is often referred to as “Dallas phasing” or the “Dallas display”. The green ball provides the permissive indication.

Green Ball plus Flashing Arrow (GBFA) – This configuration is identical to the traditional five-section configuration, except that the yellow arrow section is flashing On when the following conditions are met:

- The green ball is On,
- The green arrow is not On, and
- The yellow arrow does not need to be steady On to provide yellow clearance following the green arrow.

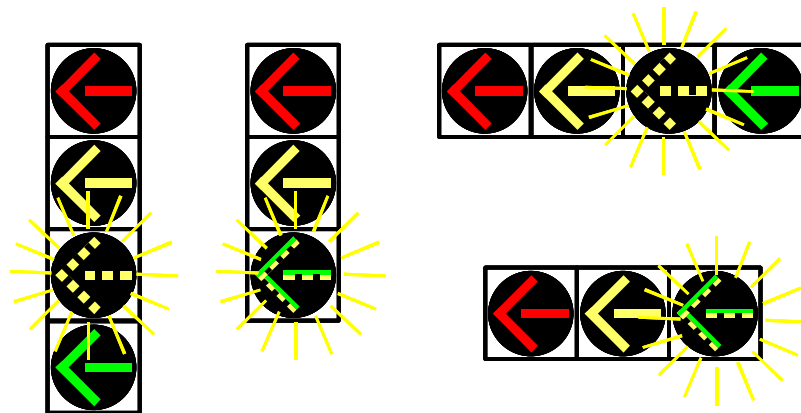
The green ball and flashing yellow arrow together provide the permissive indication.



Flashing Yellow Arrow (FYA) – This configuration consists of four arrow sections arranged linearly, as either a vertical stack or horizontal. The four arrows in order from top to bottom are red, steady yellow, flashing yellow, and green. An optional variation has only three sections with the bottom section being a bi-modal section able to display either a steady green arrow or a flashing yellow arrow. One, and only one, arrow is On at all times. The flashing yellow arrow provides the permissive indication. This configuration can be used for left or right turns. When used for a left turn, the flashing yellow arrow is On when the following conditions are met:

- The green arrow is not On,
- The steady yellow arrow is not On, and
- The opposite-direction through-only heads are green.

The steady yellow arrow is used to provide yellow clearance following both the protected turn indication (green arrow) and the permissive turn indication (flashing yellow arrow).



However, it is acceptable (and desirable) to not provide yellow clearance when changing from a permissive indication to a protected indication, in which case the flashing yellow arrow remains flashing until the green arrow goes On.

Within the signal head, the flashing yellow arrow indications will be located in the signal head at the typical location of the current green ball indication, with the exception in the use of the flashing yellow indication as a shared indication. When the flashing yellow indication is used as a shared indication, the flashing yellow arrow section will flash for the left-turning permitted interval and be solid for the left-turn protected clearance interval. One alternative is to use a standard 5-section head (cluster, vertical, or horizontal) and replace the green arrow section with a bi-modal green/yellow left arrow. The yellow arrow in this bi-modal section would be flashing to indicate the permissive interval. The yellow arrow above the bi-modal section would just be used to clear the protected left-turning phase. (Question to the Panel: Do we want to allow the 3-Section All-Arrow display as used in Jackson County?)

Based on the panel meeting in 1999, it was agreed by the Panel Members that the identified alternative display would not require any changes to existing two-phase signal operations. Therefore, the indications evaluated are assumed to not be used on signal approaches that have no protected left-turn phase. This assumption does not preclude the use of a suitable PPLT display in a situation where a protected phase is used at some times, but not at others.

Table 1. Engineering Assessment Evaluation Matrix - Page 1 of 4

#	Questions to be answered	Solid Green Ball			Flashing Yellow Arrow	Comments
		Traditional Five Section	Green Ball plus Flashing Arrow	Dallas Display		
SAFETY						
S-1	Does it fail safe? Is a misunderstanding of the indication likely to result in a safe action?	○	○	○	◐	The driver simulation/confirmation study has shown safer operation for the FYA
S-2	Can the indication eliminate the yellow trap under all operational and field conditions?	○	○	◑	●	
S-3	Can a red clearance be displayed after leading left?	○	○	●	●	
S-4	Can the start of permissive indication be delayed?	○	○	●	●	
S-5	Does it avoid dilution of the safety or meaning of other indications?	◑	◑	◑	◑	
S-6	Are traffic violations minimized?					
S-7	Are accident costs reduced?					
S-8	Are conflicts reduced?	○	○	○	◑	This ranking will be revisited with the completion of WP 8 conflict results
OPERATIONS						
O-1	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?	◑	◑	◑	●	
O-2	Does the indication impact pedestrian movements?	◐	◐	◐	◐	All indications mean yield to LT driver
O-3	Can the indication be used with lead/lag operation?	○	◐	●	●	
O-4	Does the indication impact opposing left-turning traffic?	◐	◐	●	●	
O-5	Does the indication allow the skipping of all side-street phases?	○	○	●	●	
O-6	Is the indication consistent with flashing indications?	●	●	●	●	
O-7	Does operating the intersection in flashing mode provide negative consequences?	●	●	●	●	
O-8	Does the indication lead to false starts or related driver errors?	◐	◑	◐	◑	Confirm w/ WP7

Ranking scale: ● = highest/best; ○ = lowest/worst

Table 1. Engineering Assessment Evaluation Matrix - Page 2 of 4

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

Ranking scale: ● = highest/best; ○ = lowest/worst

Table 1. Engineering Assessment Evaluation Matrix - Page 3 of 4

#	Questions to be answered	Solid Green Ball			Flashing Yellow Arrow	Comments
		Traditional Five Section	Green Ball plus Flashing Arrow	Dallas Display		
VERSATILITY						
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 1. Engineering Assessment Evaluation Matrix - Page 4 of 4

#	Questions to be answered	Solid Green Ball			Flashing Yellow Arrow	Comments
		Traditional Five Section	Green Ball plus Flashing Arrow	Dallas Display		
VERSATILITY (continued)						
V-17	Can it be used when the left-turn slot is physically separated or on different alignment than through lane (wide median, etc.)?	○	○	◐	●	
V-18	Can the signal indication be placed horizontally or vertically in the same arrangement?	◐	◐	◐	●	
V-19	Does it work under all preemption scenarios?	○	◐	●	●	
V-20	Does it avoid the yellow trap situation under all circumstances?	○	○	◐	●	
V-21	Can the permissive indication be easily applied to other than PPLT situations?	○	○	○	●	
V-22	Will practitioners likely use the indication if made the standard, <u>or allowed alternate</u> ?	●	◐	◐	●	

Ranking scale: ● = highest/best; ○ = lowest/worst

NARRATIVE DISCUSSION OF THE QUESTIONS

Many of the questions in Table 1 require further explanation or clarification of intent and/or meaning. Each of the questions in Table 1 are listed below and includes a brief discussion about that question. The following abbreviations are used to refer to the permitted indications:

SAFETY

S-1 / Does it fail safe? Is a misunderstanding of the indication likely to result in a safe action?

The results of the photographic driver survey (see Working Paper 3) and confirmation study (Working Paper 7) identified a fail safe and fail critical responses for the various permitted indications tested.

S-2 / Can the indication eliminate the yellow trap under all operational and field conditions?

The yellow trap is a problem associated with the green ball indications. PLL solves the yellow trap issue for the green ball indication for those sites that allow the indication to be shielded from the view of adjacent through movement drivers. This is not feasible, for example, at many span wire signals, on curved approaches, where there is no adjacent through movement, etc. The FYA indication always eliminates the yellow trap because the permitted indication will stay illuminated as long as the opposing through is green. In addition, the FYA can be installed at any intersection, regardless of geometry and type of construction (span wire, mast arm, poles only).

S-3 / Can a red clearance be displayed?

A red clearance can be displayed after the protected green indication for the Dallas display and the flashing yellow arrow display. In the other displays, the green ball may be On while the green arrow is On, and therefore cannot be relied on to provide red clearance.

S-4 / Can the start of permissive indication be delayed?

Some agencies like to delay the start of the permissive display for at least a few seconds after the opposing through movement starts up, to ensure permissive turners are aware that the opposing

through has a green display, before the permissive display begins. As for red clearance, this can be done only with the Dallas and FYA displays.

S-5 / Does it avoid dilution of the safety or meaning of other indications?

This question was of most concern for some of the already-eliminated displays (e.g., flashing red) and is not a discriminator for the remaining candidates.

S-6 / Are traffic violations minimized?

The Engineering Assessment cannot answer this question. It is difficult to determine by any scientific study if the number of violations will be reduced because it is difficult to determine whether the “violation” was deliberate, or if it is the result of not understanding the meaning of the indication. This question is better answered based on the conflict analysis (Working Papers 5 and 8).

S-7 / Are accident costs reduced?

The Engineering Assessment cannot answer this question. The crash analysis indicates that all non-green permissive indications have a relatively low crash rate. Therefore, the crash cost should be reduced with more uniform use of one of the non-green indications.

S-8 / Are conflicts reduced?

See working paper 8.

OPERATIONS

O-1 / 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?

The dual-display indications (all except the FYA) have shown some hesitation by motorists due to the red ball and green arrow shown at the same time.

O-2 / Does the indication impact pedestrian movements?

The Engineering Assessment cannot answer this question specifically. Typically, the GB and FYA permissive indications have the same affect on pedestrian movements. The lower number of fail critical errors with the FYA makes it safer for pedestrians crossing the left-turn path.

O-3 / Can the indication be used with lead/lag operation?

The traditional green ball five section and indications cannot operate safely under a lead/lag phasing because it would create the yellow trap. The operation with these indications would need to be either lead-lead or lag-lag turn phasing. The FYA and PLL permitted indications can operate under lead/lag turn phasing. See similar question in the safety section.

O-4 / Does the indication impact opposing left-turning traffic?

This question is a follow-up to the question in O-3. For the reasons identified previously, the traditional green ball and green ball plus FYA indications will restrict the use of lead/lag left-turn phasing. Otherwise, none of the indications really impact opposing left-turning traffic.

O-5 / Does the indication allow the skipping of phases?

All indications allow the protected turn phase to be skipped. However, if all side street phases are skipped, a normally-leading left-turn can immediately follow the conflicting through movement, and thereby introduce the left-turn trap. Therefore, scoring on this issue is the same as for the lead/lag question.

O-6 / Is the indication consistent with flashing indications?

All of the remaining candidate displays are consistent with other displays that use flashing outputs (e.g., whole signal flashes red, or yellow in one direction and red in other).

O-7 / Does operating the intersection in flashing mode provide negative consequences?

The green ball indications flash the yellow or red ball only when the intersection is operated in flashing mode, and this presents no problems. The FYA indication flashes the red arrow, and presents no problems.

O-8 / Does the indication lead to false starts or related driver errors?

See Conflicts Study and Photographic survey results.

IMPLEMENTABILITY

I-1 / Are there significant issues with installation? Can the indication be placed to meet with the current MUTCD requirements?

The two options involving flashing yellow arrows do not meet current MUTCD requirements, and will require a modification to the MUTCD. The FHWA issued an interpretation in 1993 that stated “Dallas Phasing” is permitted provided that the left-turn signal indications are not seen by the through-movement driver.

I-2 / Are there issues with conversion of existing indications?

The conversion from a permissive indication to any type of protected movement will require an additional or modified signal head. Converting from a protected-only indication to a PPLT indication will require a head change, and for all but the FYA will most likely need a head relocation. The Dallas Display will require a bit more effort due to visibility-limiting requirements.

I-3 / Are there legal issues to consider including the Uniform Vehicle Code and state and local laws?

Both the UVC and state/local laws would have to be changed to define the use of flashing yellow arrows.

I-4 / Does the signal indication permit maximum number of signal phasing strategies?

The FYA indication provides the most flexibility relative to the left-turn phase sequence, even if there is no adjacent through movement. Left-turn trap considerations, and the inability to operate protected-only phasing limit the flexibility of the traditional five-section display and the green ball plan flashing arrow display.

HUMAN FACTORS

H-1 / Is the indication universally understood? Does the indication meet both the priori and ad hoc driver expectancies?

The Engineering Assessment cannot answer this question. The Photographic Driver Survey and the Conflict Study addresses this question in more detail.

H-2 / Do drivers respond correctly to the information presented?

The Engineering Assessment cannot answer this question. The Photographic Driver Survey and the Conflict Study addresses this question in more detail.

H-3 / Do drivers accept the indication? Does the indication increase driver workload, reduce conspicuity, or increase driver error?

The Engineering Assessment cannot answer this question.

H-4 / Are supplemental signs required for understanding?

For green ball indications, some agencies use the "left-turn yield on green ball" signal, many do not. For the FYA, no supplemental sign was used in the Implementation Study and motorist reaction was good.

H-5 / Do drivers exposed to the "new" indication easily learn the meaning?

The Engineering Assessment cannot answer this question. None of the project tasks addressed this issue. Discussions with practitioners indicated that driver understanding is high.

H-6 / Does the signal indication fail safe? What are the consequences of a driver misinterpreting the signal indication message?

Question S-1 answers the issue of fail safe for each of the permissive indications. The consequences of a wrong interpretation the green ball indications have the highest consequence if a driver misinterprets the indication message. The Driver Survey analyzed fail critical responses to various permitted indications. The Driver Survey indicated a fail critical response of

24.9 percent for the green ball indication and 16.6 percent for the flashing yellow arrow indication.

VERSATILITY

V-1 / Does it allow permitted-only operation?

All candidate displays allow the protected turn phase to be omitted.

V-2 / Does it allow protected-only operation?

Only the Dallas display and the FYA display allow protected-only operation.

V-3 / Does it allow change between mode of operation by time of day?

Same answer as question V-2 above.

V-4 / Can it be used on curved approaches?

In general, optical shielding of the green and yellow ball indications is not feasible on curved approaches.

V-5 / Does it allow two far-side LT heads in customary locations?

Some agencies (e.g., Caltrans) require two left-turn heads, and these are often placed on the far side of the intersection – usually with one on the end of a mast arm or on a median pole, and the other on the far left quadrant pole. Due to its optical shielding requirements, the Dallas display usually cannot be placed in both these locations.

V-6 / Does it allow use of any phase sequence?

Only the Dallas display and FYA can accommodate any left-turn phase sequence, including lead/lag without introducing the left-turn trap.

V-7 / Is it applicable to right turns as well as left?

The green ball indications have been used for right-turn applications as a common application, but the traditional five section displays cannot provide a permissive turn display while the

adjacent through movement is stopped. The FYA is the only option for a right turn through pedestrians where a two way street changes to one-way towards the intersection and a green ball cannot be displayed. The FYA has been used for right turn displays in Tucson for approximately ten years with no problems.

V-8 / Can it be used with span wire-mounted signals?

It is often difficult to provide adequate optical shielding for the Dallas display when the head is mounted on a span wire.

V-9 / Can heads be in same location as permanent protected-only heads for easy conversion?

The FYA provides the most flexibility in head placement.

V-10 / Can heads be in same location as permanent (thru) permissive-only heads for easy conversion?

Only the traditional five section and green ball plus FYA.

V-11 / Does it allow use of all of the opposing through green time for permissive turns?

Only the Dallas display and FYA display do this.

V-12 / Can it be used when the left-turn lane is shared with through traffic?

The Dallas display requires optical shielding from through traffic, and therefore cannot be used where turning and through traffic share a lane.

V-13 / Can permissive, turning traffic proceed legally without stopping?

This question was of concern only for some of the displays of already eliminated.

V-14 / Could it replace all current standard and non-standard PPLT indications?

Only the FYA has universal application. The Dallas Display could not be applied to an intersection with span wire, shared lanes, no through movement, or on curved approaches. The traditional five section display, and the “green ball plus flashing arrow” display cannot replace

installations using experimental heads to deal with the yellow trap, and cannot be used in some other situations, such as where a green ball cannot be displayed (e.g., where a two-way street changes to one-way).

V-15 / Can it be used where there is no adjacent through movement?

Lane control can be used for applications using the green ball displays. The FYA is more apt to apply to these situations.

V-16 / Can it be used where the adjacent through movement is unsignalized?

The unshielded green ball options cannot be used in this situation.

V-17 / Can it be used when the left-turn slot is physically separated or on different alignment than through lane (wide median, etc.)?

The green ball displays are more likely to be misinterpreted as a protected display in this situation.

V-18 / Can the signal indication be placed horizontally or vertically in the same arrangement?

Since the FYA involves only four (or optionally three) sections, it is more easily accommodated in situations where space is limited for a horizontal arrangement.

V-19 / Does it work under all preemption scenarios?

Some preemption scenarios, such as limited service during adjacent parallel railroad operation, require the left-turn to be held on red while the through movement is allowed to proceed. Only the FYA has a red arrow that can be used in such situations.

V-20 / Does it avoid the yellow trap situation under all circumstances?

See question S-2.

V-21 / Can the permissive indication be easily applied to other than PPLT situations?

For example,

- Left and right turns through pedestrians where a two-way street changes to one-way towards the intersection (consider the left-turn from the two-way leg) need a permissive indication other than a green ball, since it is not safe to show a green ball at these locations.
- The northbound right turn simultaneously with the westbound left-turn needs a permissive indication to avoid the need to ban the westbound U-turn.
- A permissive-only left-turn movement from a left-turn lane physically separated from the through movement (e.g., in a wide median) requires a permissive indication other than a green ball.
- A permissive-only left-turn at an intersection without an adjacent through movement may require a permissive indication other than a green ball.
- During railroad preemption, the permissive-only left-turn can proceed permissively, but the through movement must be held on red.

V-22 / Will practitioners accept the indication as the standard?

The implementation study has showed that approximately 8 out of 10 practitioners favor an alternative display. There are a few engineers that believe the Dallas Display fixes the safety and operational problems experienced with the traditional display.

IMPLEMENTATION ISSUES

Contractor's note to the Panel Members: The following discussion is offered as outstanding issues regarding implementation of various permissive displays. Quite frankly, the contractor was not able to make a definitive stand on these issues and will be looking for feedback from the Panel Members and Technical Advisors. The basic question to be answered is whether to allow shared green ball FYA indication.

The Dallas display is included in the MUTCD and is under active deployment in some jurisdictions. Further deployment of the Dallas display or the flashing yellow arrow (FYA) display, if it were adopted as a new alternative for PPLT, could be limited to new PPLT installations, without any need to retrofit existing PPLT installations. However, many agencies are likely to want to upgrade existing PPLT installations to take advantage of the new display. This section discusses some of the issues that are involved in upgrading existing traditional PPLT displays to the Dallas display or the FYA.

Results from the Project's Agency Survey noted that 52% of the existing protected-permitted locations used a traditional five-section head as one of the two required far side through heads. Since both the Dallas display and the FYA display require the PPLT head to be separate from any through movements' heads, these 52% of existing installations would need an additional head installed if they are to take advantage of the new display.

If the existing PPLT head is in a location suitable for replacement with the new display, and if spacing permits, then the simplest solution is to make this replacement and then add a new through-only three-section head somewhere in front of the through lane(s). If the new display must be at a different location than the existing PPLT display, it may be feasible to convert the existing head to a three-section through-only head, but likely, it will need to be relocated to the right to provide sufficient separation. Also, it may be necessary to install a longer mast arm to locate the new display farther to the left of the current PPLT head location.

The FYA is more flexible in its location requirements than the Dallas display, due to the latter's need for optical shielding, but both are likely to involve significant costs for upgrades to existing PPLT installations where the PPLT head serves as one of the required through-movement heads.

As discussed above, the Dallas display is not an option for replacement of an existing traditional PPLT display if the approach is curved or the head is mounted on a span wire that provides insufficient stability for optical shielding.

Of course the flashing arrow add-on to the traditional five-section display can be added to any existing PPLT head, but as can be seen from the above table, this option is not attractive in terms of the engineering assessment.

The Dallas display requires optical shielding, which adds to the cost and requires careful maintenance. The FYA requires modifications to the controller and conflict monitor for a full-featured implementation, which adds to its cost. Costs are likely similar for both options.

Adoption of the FYA as a new standard would require modifications to the MUTCD and vehicle codes. The Dallas display would not. This would be a one-time event, and would not involve costs for each installation or upgrade.

The research team developed Table 2 to show if the different permitted indication types can be used with various combinations of:

- Placement (shared head with through traffic or separate left-turn head)
- Indication arrangement (5-section cluster, 5-section vertical, or 5-section horizontal)
- Phasing (leading lefts, lead-lag, or lagging lefts)

TABLE 2. ALLOWABLE COMBINATIONS OF PLACEMENT, INDICATION ARRANGEMENT, AND PHASING FOR POTENTIAL INDICATION TYPE

Placement	Indication Arrangement	Phasing	DISPLAY TYPE		
			Traditional Five Section Green Ball	Solid Green Ball – Dallas Display	Flashing Yellow Arrow
Shared Indication with Through	5-Section Cluster	Lead-lead Lefts	Y	N	Y ¹
		Lag-Lag Lefts	Y ²	N	Y ¹
		Lead-Lag Lefts	N	N	Y ¹
	5-Section Vertical	Lead-Lead Lefts	Y	N	Y ¹
		Lag-Lag Lefts	Y ²	N	Y ¹
		Lead-Lag Lefts	N	N	Y ¹
	5-Section Horizontal	Lead-Lead Lefts	Y	N	Y ¹
		Lag-Lag Lefts	Y ²	N	Y ¹
		Lead-Lag Lefts	N	N	Y ¹
Separate Indication	5-Section Cluster	Lead-Lead Lefts	Y	Y	Y
		Lag-Lag Lefts	Y ²	Y	Y
		Lead-Lag Lefts	N	Y	Y
	5-Section Vertical	Lead-Lead Lefts	Y	Y	Y
		Lag-Lag Lefts	Y ²	Y	Y
		Lead-Lag Lefts	N	Y	Y
	5-Section Horizontal	Lead-Lead Lefts	Y	Y	Y
		Lag-Lag Lefts	Y ²	Y	Y
		Lead-Lag Lefts	N	Y	Y

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.

Table 2 highlights the fact that only the green ball indication and the yellow flashing arrow 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 (can't be used for lead-lag phasing; must serve both lagging lefts at the same time; has other yellow trap potential). This exercise points out that the flashing yellow arrow appears to be the most universal option.

REACHING AN ENGINEERING ASSESSMENT CONCLUSION

The "Safety" Section of Table 1 generally shows the FYA as being ranked higher than other candidate indications, with the Dallas Display being ranked close behind. However, the elimination of the yellow trap most distinctly separates the FYA from the other indications.

The "Operations" Section of Table 1 generally shows the FYA and the Dallas Display being equally ranked.

The "Implementability" Section of Table 1 generally shows the FYA and Dallas Display as being equally ranked.

The "Human Factors" Section of Table 1 generally shows the FYA as being ranked higher on more questions than other candidate indications. The demonstrated success of the FYA display being understood without the use of a supplemental sign separates the FYA indication from other candidate indications.

The "Versatility" Section of Table 1 clearly shows the FYA as being ranked higher on almost all questions as compared to other candidate indications.

Table 2 shows that the FYA is the only display that can be universally used in both a shared and Separate indication application for all modes of left-turn signal operation.

Having summarized the five key sections of Table 1 and the assessment conducted in Table 2, one could come to the conclusion that the engineering assessment supports the FYA indications as the "better" indication.

However, before such a conclusion can be made, the engineering assessment should consider a "shortlist" of key questions that were previously identified by the Research Panel to help focus

the engineering assessment to a logical conclusion. The following five questions were identified as Primary questions:

- Is the proposed indication as safe as other candidate indications?
- Does the proposed indication avoid dilution of the safety of other signal indications?
- Can it be used for protected/permissive left-turns (avoid the left-turn trap) in all situations?
- Can it be used for any left-or right-turn where a green ball is not appropriate?
- Is the proposed indication as efficient as other candidate indications?

Assuming for a moment that the “proposed” indication is the FYA indication, the following responses are arrived at:

The answer to the first Primary question can be found in the “Safety” and “Human Factors” Sections of Table 1, which as stated above identified the FYA as a “safer” indication due large in part to the avoidance of the yellow trap in all situations, and generally better understood.

For the second Primary question the answer would be “YES.” The FYA maintains the current definitions of the UVC and MUTCD.

For the third Primary question the answer would be “YES.” The FYA can be used for protected/permissive left-turn in all situations.

For the fourth Primary question, the answer would be “YES.” The FYA can be applied to both left and right turn applications.

For the fifth Primary question asks whether the proposed indication [the FYA] is AS efficient as other candidate indications. The answer to this primary question could be arrived at considering the “Operations” Section of Table 1, which generally identified the FYA and the Dallas Display as being equally ranked. However, the FYA can be universally applied in more circumstances than can the Dallas Display. So, the clear answer to this question is “YES” the FYA is (at least) AS efficient as other candidate displays.

So for the FYA, the answer to all five questions is YES.

Similar analysis of the Dallas display yields answers of YES, YES, NO, NO, YES.

The answering of the primary questions identifies the FYA indication as a solid candidate display.

The direction by the Research Panel was that if a clear indication choice was not evident by answering the primary questions, then a second set, or Secondary set of questions should be answered. So all issues are considered, the research team will answer the Secondary questions with, again, the assumption being made that the FYA indication is the “proposed” indication. The Secondary Questions were:

- Is the average cost of installation and conversion less than the other displays?
- Is a supplemental sign necessary?
- Will the display require changes to the UVC, MUTCD, or other standards and laws?
- Are there any other advantages over other short listed displays?

The average cost of conversion reported by the volunteer agencies that implemented the FYA indication as part of the Implementation Study (reported in Working Paper 8) was \$750 per intersection approach. This cost was primarily for new or retrofitted signal heads, flasher circuits, and in some cases external logic units. It is fair to assume that this order of cost would be equal to any alternative display if an agency was converting from a permissive-only operation as a before condition.

For the second – Secondary question, the answer is clearly “NO.” The FYA indication has been proven in the lab and in the field that it does not warrant a supplemental sign.

For the third Secondary question, the answer is “YES.” Changes would be required, al biet minor changes, to the MUTCD. Some state laws may need to be changed as well.

For the forth Secondary Question, the answer is also “YES,” the FYA indication does posses other advantages over other short listed displays. See below.

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 limited to leading-left-turn signal operation (protected-permissive) because there is no possible means to shield the green ball from the adjacent through lane cone of vision. The FYA indication fully supports supplemental signal heads.

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 to a one-way opposite approach, or because of the adjacent left turn from the stem of a T-intersection can not proceed at the same time (e.g., a pedestrian conflict for dual left-turn lanes).

OVERALL ENGINEERING ASSESSMENT CONCLUSION

Based on the findings of Tables 1 and 2, and the results of going through the Primary and Secondary questions, the FYA indication is supported by this Engineering Assessment and Evaluation study task as the “best” indication for the protected-permissive left-turn operation.