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Evaluation of Flashing Yellow Arrow Traffic Signals in Indiana




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16. Abstract

The evaluation of flashing yellow arrow signals for widespread implementation was evaluated. Through the collection of field driver performance data, survey data, crash data, at two test sites in the state, it was concluded that this is a worthwhile practice to be considered for a larger scale deployment. The return on investment includes both increased safety, and improved mobility. Given Indiana's widespread usage of span and catenary signal supports, installation could be simplified to place a larger four section flashing yellow head in a horizontal orientation while leaving adjacent through lane three section signal heads in a vertical alignment, and not decrease the standard of care provided to the public, given proper engineering judgment.

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EXECUTIVE SUMMARY

EVALUATION OF FLASHING YELLOW ARROW TRAFFIC SIGNALS IN INDIANA

Introduction

The evaluation of the use of a flashing yellow arrow (FYA) for permissive left turns in Indiana was undertaken to provide guidance to the Indiana Department of Transportation on this topic. These signal types have been shown by other states and studies to reduce crashes and improve mobility at the same time. This win-win opportunity is the result of increased driver awareness during the permissive left-turn phase at a signal where a driver must yield the right-of-way to oncoming traffic. Increased mobility results from the elimination of the yellow trap, thus allowing lead/lag signal phasing. This can be particularly important for signal coordination projects along corridors so that green bands can be better aligned.

In the state of Indiana, most traffic signal support systems installed on the state highway system are span and catenary style instead of cantilevered mast arms. This is notable because typical FYA signal head arrangements consist of a vertical stack of four signal sections (from top to bottom: solid red arrow, solid yellow arrow, flashing yellow arrow, solid green arrow), instead of being three sections in the case of both a protected only signal, or a protected-permissive five-section "doghouse" style signal head. These signals only attach to the catenary wires at the ends of the signal head, and the addition of an extra section in vertical height could create a vertical clearance issue. The only way to resolve this clearance issue would be to then raise the catenary wires. However, not all vertical support poles have enough extra vertical space to permit such a raising, and this would require increased installation time. A possible solution for such a situation was evaluated in Vincennes, Indiana, whereby the four-section FYA signal head was installed in a horizontal orientation, while the other signal heads remained in a vertical orientation.

Findings

A comparative analysis was conducted between a typical installation in Centerville, Indiana, and the modified setup in Vincennes. Data was collected at both intersections to study driver behavior when a solo vehicle was approaching a flashing yellow arrow and would have to yield for the permissive left turn. Additional control locations at five section doghouse signals in each city were selected. The result was that there was not any statistical difference observed in driver acceleration/deceleration between any of the four sites.

To supplement the driver behavior data, surveys were conducted in both Vincennes and Richmond (neighboring city to Centerville). The survey participants were asked if they would go, yield, or stop when shown various images of left-turn scenarios. The result of the survey data showed that a majority of drivers surveyed understood what to do in various situations or did not give a fail-critical response. A fail-critical response was one that would likely lead to a crash, such as proceeding with the right-of-way on a red indication, or stopping on a solid green arrow. The only concerning case was when a vertical flashing yellow signal head displayed a solid yellow left-turn arrow while the adjacent through lanes had a solid circular green signal indication. In this case the fail-critical response rate was 11%.

A national review of media reports was also conducted, and it was identified that if proactive communications are not provided by INDOT, misinformation can be perpetuated by the media. Members of the Study Advisory Committee developed tools to help provide INDOT with tools ready to be deployed to local media outlets.

Crash data was requested for these intersections from 2009 through the present. It is first important to note that in the before condition, left turns were protected only, and then when the FYA signals were installed, this introduced a permissive left turn. The literature suggested that the crash rate would increase due to this increase in mobility. The actual crash data showed that when compared to previous trends, the flashing yellow signals did produce an increase in projected crash rates. However, the increase was either below or within guidance provided by the literature. The post-installation crashes at each site were carefully scrutinized, and eleven total had occurred through July 2014.

Implementation

In looking at costs to install FYA at intersections, there are several key parameters. The first is the signal control cabinet hardware. For this hardware expense, as long as the malfunction management units are of the MMU2 specification, they can be upgraded for little to no cost by means of a firmware update. This could be done as part of the routine annual recertification process. If a controller is not compliant with the MMU2 specification, then a possibly significant expense may be incurred. The second cost is that for an extra section to be added to a signal head. The third cost would be to upgrade existing field wires to have a minimum of eight conductor wires. The cost of pulling additional wires through the signal conduit would be dwarfed by any costs related to collapsed or damaged conduit needing replacement. Based on the AASHTO 2010 *Highway Safety Manual,* the comprehensive cost of a signal property damage only crash is $7,400 and $44,900 for a possible injury crash. The reduction of at least one possible injury crash or a combination of several property damage only crashes is all that would be required to have a positive return on investment in the first year alone. Continued crash reductions into the future would significantly increase the benefit received by the State.

Therefore, as a result of this research, it is clear that a larger scale implementation of FYA signal heads should be considered. There was also no reason to believe that, given proper engineering judgment, the placement of a FYA signal head in a horizontal configuration adjacent to vertical through lane signal heads would reduce the safety and mobility benefits provided by the FYA signal head.

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1. INTRODUCTION

Providing a consistent driver expectation has been a fundamental principal of modern traffic engineering, and is the foundation for the *Manual on Uniform Traffic Control Devices* (MUTCD). However, traffic signals routinely provide mixed messages at locations having permissive left turns. At such locations, the through lanes are allowed to proceed with the right-of-way on a solid circular green (CG) ball signal phase, however when the same solid green ball is displayed for a permissive left turn it no longer indicates an assignment of right-of-way as shown in Figure 1.1. Thus a "Left Turn Yield on Green" sign is typically added to the mast arm of the signal to clarity this uncertainty to drivers. One of the solutions for this inconsistency is to substitute a flashing yellow arrow in place of a solid green ball to indicate a permissive left turn. By its very definition the color yellow (amber), when displayed by a traffic signal, indicates a cautionary condition, which is consistent with how a driver should respond to a permissive left-turn situation. Beginning in March 2006, the Federal Highway Administration provided interim approval for the flashing yellow arrow to be used, and it was then subsequently incorporated into the 2009 MUTCD.

The flashing yellow arrow (FYA) traffic signal is a specialized signal display for protected/permissive left-turn control (PPLT). It utilizes a flashing yellow arrow to instead of a traditional solid circular green ball indication during the permissive phase with the intent to improve the safety performance of the intersection. Figure 1.2 shows the most common PPLT display arrangements used in the United States. Figure 1.3 illustrates other unique traffic signal displays that have been used in recent times (Brehmer, Kacir Noyce, & Manser, 2003).

The yellow trap is one of the major problems of the traditional PPLT control displays. The 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, as shown in Figure 1.4. A driver attempting to make a left turn on the permissive circular green indication becomes trapped in the intersection when their circular green indication turns yellow for the change interval (for the through traffic). During the change interval, the left-turn driver who is attempting to clear the intersection sees the

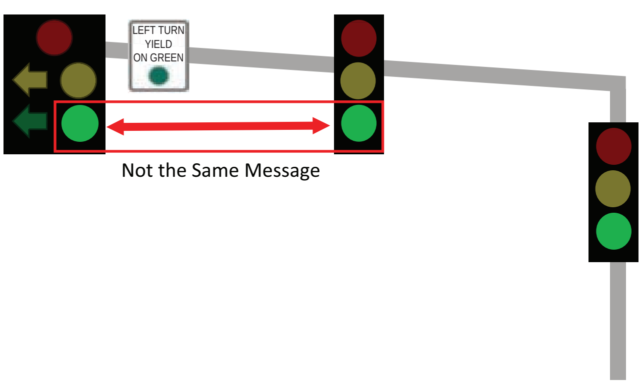


Figure 1.1 Comparison of a protected/permitted left-turn lane signal to a through lane signal.

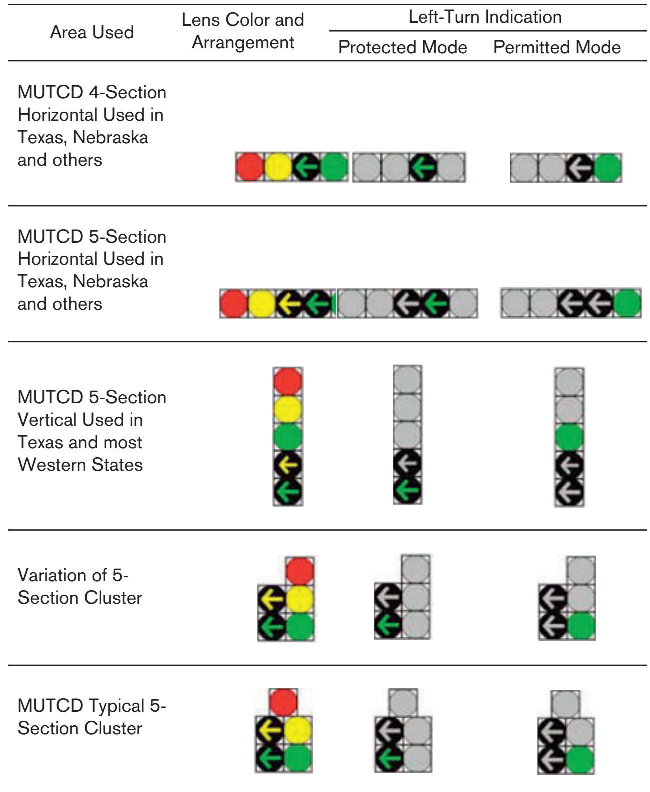


Figure 1.2 Typical PPLT displays used in the United States (Brehmer et al., 2003).

adjacent through lanes receive the circular yellow indication for their change interval. Because of the change in signal indication, the left-turner mistakenly believes that the opposing traffic also has the yellow change interval also and so attempts to make the left turn, resulting in a dangerous condition at the intersection in these situations. The yellow trap occurs because the opposing traffic does not, in fact, receive a yellow change interval but instead has a circular green indication in the through lanes and a protected left-turn arrow indication. This condition creates the potential for conflict between an unsuspecting left-turning vehicle and opposing, non-stopping, through traffic (Brehmer et al., 2003).

There is a business case for considering the implementation of flashing yellow PPLT signals. According to page 21 of the Indiana 2010 Strategic Highway Safety Plan "Crashes at the intersection of two or more roadways in Indiana produce one in four of all severe outcome crashes and about one in five fatal crashes" (Brehmer et al., 2003). Implementation of the flashing yellow arrow in Indiana represents an opportunity to reduce such crashes and save lives. It also improves operational flexibility by permitting lagging left turns. Such lagging left turns would otherwise create a yellow trap, and thus opens up many additional opportunities to improve mobility through intersection coordination along corridors. Implementation of the flashing yellow arrow may be done as part of signal visibility improvement projects with highway safety improvement program (HSIP) funds from the Federal Highway

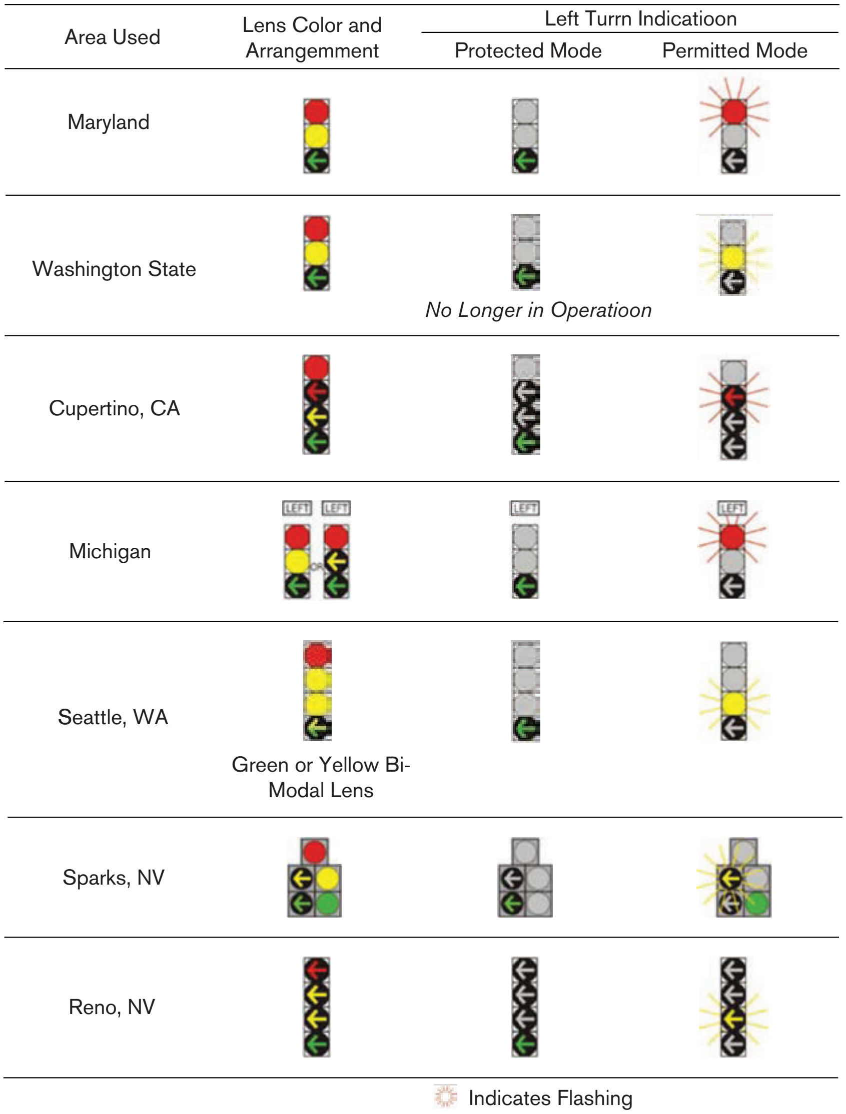


Figure 1.3 Unique PPLT displays used in the United States (Brehmer et al., 2003).

Administration. Additionally, in time it may also possibly lead to elimination of supplemental left-turn signal signs and thus reduce the number of maintenance items in the field. A reduction in the number of maintenance items would be expected to yield a cost savings over a period of years into the future. Thus Indiana stands to gain substantially from this research, by saving lives, and creating opportunities to integrate external (federal) funding; truly a win-win for the state.

As previously mentioned, the *2010 Strategic Highway Safety Plan* for Indiana states that intersection crashes account for 25% of injury crashes and 20% of all fatal crashes in the state. Specifically at signalized intersections these crashes have remained relatively steady for the period between 2004 and 2009 as seen in Figure 1.5, with an average of just under 463 injury crashes per year and 55 fatalities per year (Brehmer et al., 2003). This steady pattern of crashes raises the question of how can the State seek to proactively decrease such crashes.

Recognizing that each crash has real costs, directly and indirectly to the State, reducing these numbers holds the potential for real gains in economic output. At injury and fatal crashes, there are direct costs for law enforcement, damaged roadside hardware, and clean up. Indirect costs include congestion, decreased worker productivity, and decreased earnings which results in a decrease in taxes to be collected.

In searching for methods to reduce these crashes, one such possibility is the flashing yellow arrow. However, there are a number of possible combinations for how this could be implemented, with varying implications. For example, the NCHRP report 493 (project 3-65) entitled "Evaluation of Traffic Signal Displays for Protected/Permissive Left-Turn Control" identified eight different protected permitted phasing schemes and 21 various hardware mounting combinations options (Brehmer et al., 2003).

As indicated in TRB web-only circular #123 the typical crash reduction observed at signalized intersections

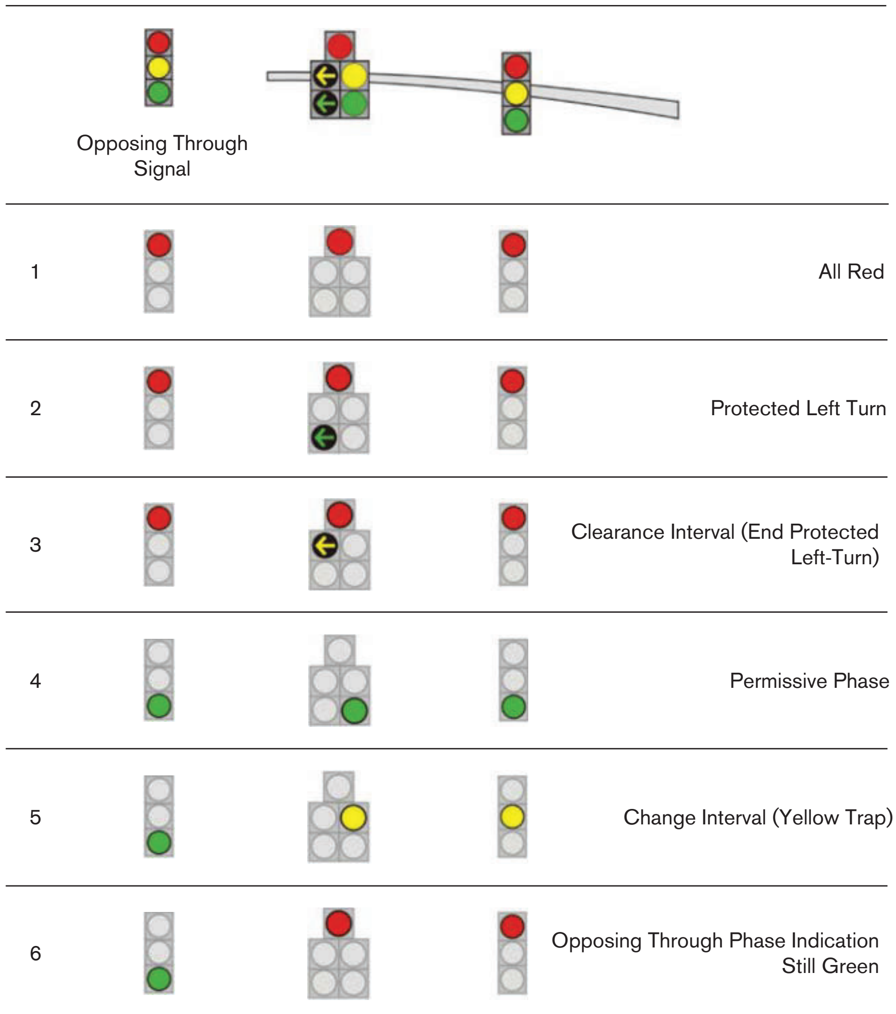


Figure 1.4 Typical yellow trap (Brehmer et al., 2003).

implementing the flashing yellow arrow was approximately 30% at the study sites (as shown in Figure 1.6) (Brehmer et al., 2003). If one applies this reduction factor to the statewide total of injury and fatal crashes (463+55=518) there could be a potential for preventing 155 crashes across the state per year with this technology.

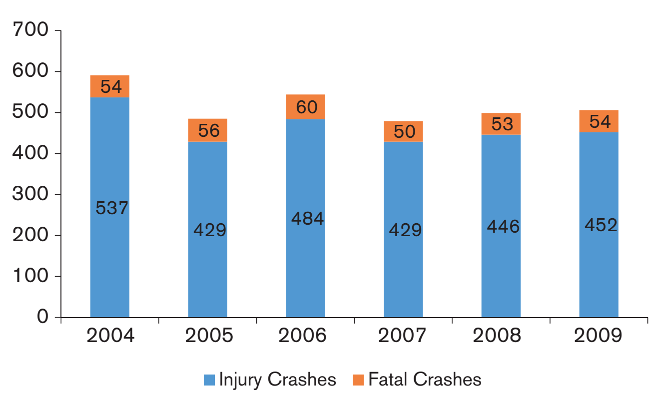


Figure 1.5 Fatal and injury crashes at signal controlled intersections in Indiana (Indiana Department of Transportation, 2010).

The safety and mobility benefits that are inherent with FYA are only possible if drivers correctly understand the meaning of the signal displays. Kerrie L. Shattler et al. prepared a study addressing this issue. In her study Shattler created a driver comprehension survey to evaluate driver responses to various combinations of supplemental signage and adjacent signal indications for both PPLT five section signal heads and vertical four section FYA signal heads. The results of this survey included

- "No significant differences were found in correct driver responses of the FYA and CG, regardless of whether or not a supplemental sign was used at the FYA approach. However, the analysis of the fail-critical responses revealed significantly higher incorrect "go" responses for the CG scenario, compared to the FYA with supplemental sign." (Schattler, Rietgraf, Burdett, & Lorton, 2013)
- "Regardless of the color of the adjacent through traffic signal (green or red), the provision of the supplemental sign at the FYA approaches significantly improved drivers' understanding of the correct "Yield"message. This finding was further confirmed by the fail-critical responses, which showed that the FYA with supplemental sign has significantly lower fail-critical "go" responses than the FYA without a supplemental sign." (Schattler et al., 2013)

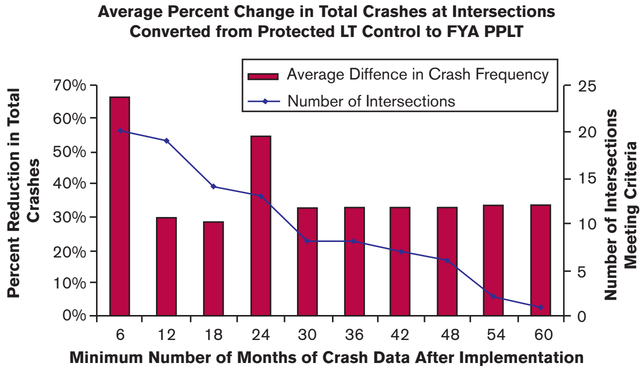


Figure 1.6 Crash reductions observed at intersection after implementing the flashing yellow arrow (Brehmer et al., 2003).

- "Drivers have a significantly higher comprehension of the FYA when the adjacent through traffic has a green signal, as compared to a red signal, regardless of the presence or absence of the supplemental sign. However, this finding was not confirmed in the fail-critical responses because there was no significant difference between the two scenarios with respect to the incorrect and unsafe "go" responses." (Schattler et al., 2013)

2. BACKGROUND

Since the National Cooperative Highway Research Program (NCHRP) Report 493 was published more than a decade ago in 2003 it has become a foundational text for flashing yellow turning arrows. The flashing yellow arrow indication/display were found to result in a high level of understanding and to have a lower misunderstanding rate as compared with other PPLT indications. The flashing yellow arrow display offers more versatile field application features (e.g., the display can be operated in various operational modes by time of day and implemented on any signal mount at any intersection configuration) as compared with traditional PPLT indication (Indiana Department of Transportation, 2010).

The advantages of FYA display explained in the paper were as follows:

- The display eliminates the yellow trap. By tying the flashing yellow arrow indication to the opposing through movement display, the yellow trap is completely eliminated. The flashing yellow arrow indication becomes an overlap capable of running with the compatible and opposing through phases.
- The display eliminates the need for louvers or optically shielded display faces for the left-turn lanes.
- The display requires no supplemental signing. The flashing yellow arrow indication was shown in the laboratory and field implementation studies to be understood without the need of additional signing. However for motorist educational purposes, supplementary signs may be needed with initial deployments.
- The display provides flexibility in signal phasing operation. There are many reasons some modes of left-turn operation (permissive only, protected only, protected permissive, lead/lag, etc.) are chosen or the mode is changed during the day. In most cases, however, 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 (Brehmer et al., 2003).

TABLE 2.1
Benefits of Flashing Yellow Ball Permitted Indications—Washington (Brehmer et al., 2003)

Measure of Effectiveness	Flashing Yellow	Green Ball
Average Number of Left-Turn Conflicts (per day)	3.14	5.00
Collisions per Million Vehicles	0.49	0.89
Percent of Drivers Who Consider the Display Safer	66%	34%

Human factors are an important factor that cannot be ignored in evaluating a traffic signal indication's design. Signal color is the issue to be perceived and understood by the human eye. And based on research by Kittelson & Associates, Inc. in conjunction with the Texas Transportation Institute, the percentage of the yellow color deficiencies is lower than the red-green color deficiencies. The research stated, "[T]here is no evidence to suggest that drivers with red-green deficiencies have worse driving records that those without color deficiencies." These authors also stated, "In Washington, the change to a flashing yellow ball permitted indication was started in 1966. The objective of the flashing yellow ball was to create an indication that was intuitively obvious, conveying the left-turn driver's obligation to yield." Table 2.1 below shows the result between 1978 and 1985 of this changing (Brehmer et al., 2003).

In addition to color perception, another human factor to consider is motorist awareness of the meaning of the device. As driver familiarity with each new FYA installation cannot be universally assumed, instructional supplemental signs have been noted with many implementations. Some signs are clearly intended to be temporary, others are intended to be phased out over time, and perhaps others intended to be permanent. One clearly temporary sign, shown in Figure 2.1, uses text exclusively, however other variations are also known to exist. These include more permanently mounted instructional signs such as the one shown in Figure 2.2 include an image of a yellow arrow, and Figure 2.3 showing a text only variation. Related research into this was conducted

Figure 2.1 Temporary flashing yellow advisory sign. (Source: https://www.flickr.com/photos/formerwmdriver/6841448535/)

Figure 2.2 Auxiliary sign type 1.

Figure 2.3 Auxiliary sign type 2.

by Schattler, Rietgraf, Burdett, and Lorton that aimed to answer questions and others surrounding driver psychology. Through a survey of 363 drivers they found driver understanding of a FYA indication was in excess of 90%, except when a FYA was utilized in a split phasing signal system (73% correct understanding) displaying a red signal for adjacent through lanes. Additionally it was found that the presence of a supplemental sign, while improving driver understanding, did not do so in a statically significant manner. The survey questions were also staged to evaluate acceptance of FYA supplemental signage compared to no signage, and no statistically significant difference was found (Schattler et al., 2013).

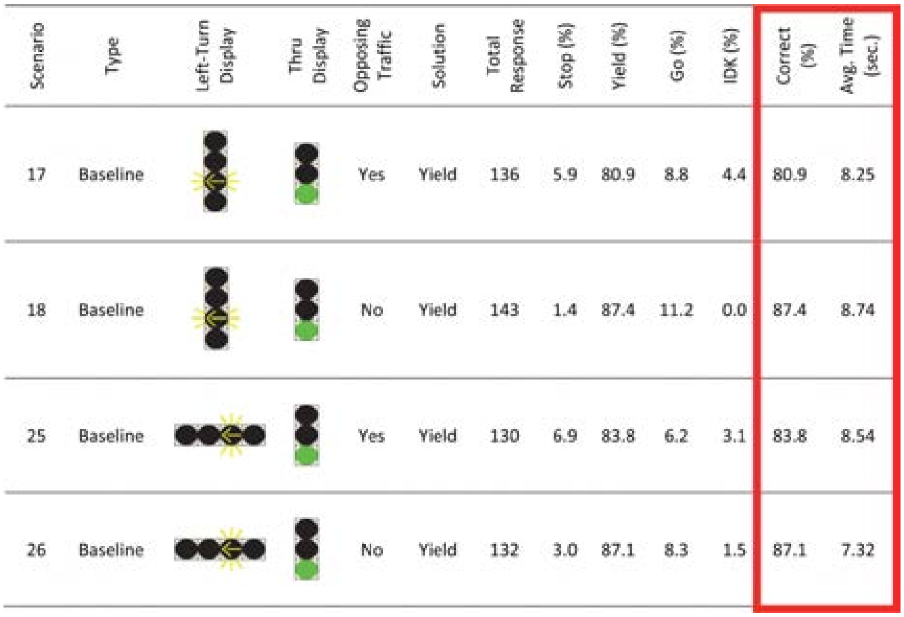
A third human factor to consider is the effect, if any, that the placement or orientation of the FYA indication has on a driver. A study similar to that conducted by Schattler et. al was commissioned by the National Cooperative Highway Research Program (NCHRP) and led by David A. Noyce. In Noyce's NCHRP study, the research team analyzed driver behavior and driver comprehension impacts of retrofitting existing three- and five-section signal displays with the FYA indication. A computer-based static study and a dynamic driving simulator study was conducted at several locations in Madison, Wisconsin and Amherst, Massachusetts. The stated objective was "to determine if the location of the FYA indication within any given signal display arrangement had a significant impact on driver comprehension." This NCHRP report concluded that the FYA on the left-turn display was less confusing leading than CG on the left-turn display for drivers to understand. The study relied heavily on a driving simulator to collect this data. This enabled the evaluation of non-standard head configurations (Noyce, Bill, & Knobler, 2014).

For the results of where the FYA section was located (middle or bottom of the signal display), the study found that "in Wisconsin, scenarios involving a FYA indication in the middle section had a correct response rate of 77.4%, while scenarios involving a FYA indication in the bottom section had a correct response rate of 78.1%. In Massachusetts, the correct response rates were 68.1% and 70.0%, respectively," and "there were no significant differences identified." This means the location of the FYA in the signal display does not make any difference to the drivers (Noyce et al., 2014).

Regarding the impacts of the adjacent through indication on driver comprehension of the FYA in both Massachusetts and Wisconsin, the author stated: "Left-turn signal displays with the FYA indication with a CG thru movement indication had the highest correct response rate at 89.7%, followed by the CY indication with a correct response rate of 74.6%. When the adjacent indication was a CR indication, the lowest correct response rate at 66.9% was observed. The difference between each of these adjacent thru indications was statistically significant. Massachusetts had similar results with correct response rates of 79.1% with a thru CG indication, 69.9% with a thru CY indication, and 60.8% with a thru CR indication, respectively. Results show that the thru indication is considered in left-turn decision making and has a large impact on driver comprehension" (Noyce et al., 2014).

One element in particular that was investigated in the report was the concept of mixed orientation signals. The mixed orientation signal heads were the combination of vertically orientated heads for though traffic, and a horizontally placed head for left-turning traffic. The data presented by the author indicated that there was an improved (decreased) response time when oncoming traffic was present for all vertical signals compared to mixed orientation signals. Without opposing traffic present, however, the result was the opposite. When considering reaction time to the signal displays, mixed orientation signals showed improved (decreased) reaction time in the absence of opposing traffic. This is seen in Figure 2.4.

The four most common traffic signal displays for protected permissive left-turn (PPLT) control, are the Traditional Five Section (T5S), Permissive Lead/Lag (PLL, also known as "Dallas phasing" or "Dallas display"), Green Ball plus Flashing Arrow (GBFA) and Flashing Yellow Arrow (FYA). To find the best indication for PPLT control, this paper rated several aspects of each of the indication for PPLT. Table 2.2, Table 2.3, and Table 2.4 present the



Scenario	Type	Left-Turn Display	Thru Display	Opposing Traffic	Solution	Total Response	Stop (%)	Yield (%)	Go (%)	IDK (%)	Correct (%)	Avg. Time (sec.)
17	Baseline			Yes	Yield	136	5.9	80.9	8.8	4.4	80.9	8.25
18	Baseline			No	Yield	143	1.4	87.4	11.2	0.0	87.4	8.74
25	Baseline			Yes	Yield	130	6.9	83.8	6.2	3.1	83.8	8.54
26	Baseline			No	Yield	132	3.0	87.1	8.3	1.5	87.1	7.32

Figure 2.4 NCHRP 20-07 table of results for driver response at FYA signals.

TABLE 2.2
Engineering Assessment Evaluation Matrix—Safety and Operations (Noyce et al., 2007)

Engineering Assessment Evaluation Matrix						
		Solid Green Ball				
#	Questions to Be Answered	Traditional Five Section	Green Ball plus Flashing Arrow	Dallas Display	Flashing Yellow Arrow	Comments
SAFETY						
S-1	Does it fail safe? Is a misunderstanding of the indication likely to result in a safe action?	1	1	1	3	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?	1	1	4	5	
S-3	Can a red clearance be displayed after leading left?	1	1	5	5	
S-4	Can the start of permissive indication be delayed?	1	1	5	5	
S-5	Does it avoid dilution of the safety or meaning of other indications?	4	4	4	4	
S-6	Are traffic violations minimized?					
S-7	Are accident costs reduced?					
S-8	Are conflicts reduced?	1	1	1	2	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?	4	4	4	5	
O-2	Does the indication impact pedestrian movements?	3	3	3	3	All indications mean yield to LT driver
O-3	Can the indication be used with lead/lag operation?	1	3	5	5	
O-4	Does the indication impact opposing left-turning traffic?	2	2	5	5	
O-5	Does the indication allow the skipping of all side-street phases?	1	1	5	5	
O-6	Is the indication consistent with flashing indications?	5	5	5	5	
O-7	Does operating the intersection in flashing mode provide negative consequences?	5	5	5	5	
O-8	Does the indication lead to false starts or related driver errors?	2	4	3	4	

TABLE 2.3
Engineering Assessment Evaluation Matrix—Implementability and Human Factors (Noyce et al., 2007)

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

evaluation matrix completed for the engineering assessment phase of the project. (Ranking scale: 5 = highest/best; 1 = lowest/worst) to provide a comparative score for each display in answering each question. Table 2.5 shows 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), and
- Phasing (leading lefts, lead-lag, or lagging lefts) (Noyce, Bergh, & Chapman, 2007).

The crash data is the most obvious way to understand the improvement of safety by using FYA indication displays compared to other options. A Kittelson & Associates, Inc. and Texas Transportation Institute study team evaluated 24 intersections from around the country (Schattler et al., 2013). Table 2.6 shows the summary of average crash rates observed. The research team also analyzed the crash data using methods established by Kenneth Agent. Agent calculated crash rates based on the number of left-turn crashes per 100,000 left-turn vehicles multiplied by the opposing flow. The equation used by Agent was: Average Crash Rate = Left-turn Crashes per 100,000 left-turns opposing flow (Schattler et al., 2013); results are shown in Table 2.7. Evaluating the data using yet another crash statistic, average left-turn crashes per year, also

TABLE 2.4
Engineering Assessment Evaluation Matrix—Versatility (Noyce et al., 2007)

Engineering Assessment Evaluation Matrix						
		Solid Green Ball				
#	Questions to Be Answered	Traditional Five Section	Green Ball plus Flashing Arrow	Dallas Display	Flashing Yellow Arrow	Comments
VERSATILITY						
V-1	Does it allow permissive-only operation?	5	5	5	5	
V-2	Does it allow protected-only operation?	1	1	5	5	
V-3	Does it allow change between modes of operation by time of day?	1	1	5	5	
V-4	Can it be used on curved approaches?	5	5	1	5	
V-5	Does it allow two far-side LT heads in customary locations?	5	5	1	5	
V-6	Does it allow use of any phase sequence?	1	1	5	5	
V-7	Is it applicable to right turns as well as left?	3	4	3	5	
V-8	Can it be used with span wire-mounted signals?	5	5	3	5	
V-9	Can heads be in same location as permanent protected-only heads for easy conversion?	3	3	2	5	
V-10	Can heads be in same location as permanent permissive-only heads for easy conversion?	5	5	1	4	
V-11	Does it allow use of all of the opposing through green time for permissive turns?	2	2	5	5	
V-12	Can it be used when the left-turn lane is shared with through traffic?	5	5	1	5	
V-13	Can permissive, turning traffic proceed legally without stopping?	5	5	5	5	
V-14	Could it replace all current standard and non-standard PPLT indications?	2	2	1	5	
V-15	Can it be used where there is no adjacent through movement?	3	3	3	5	
V-16	Can it be used where the adjacent through movement is unsignalized?	1	1	5	5	
V-17	Can it be used when the left-turn slot is physically separated or on different alignment than through lane (wide median, etc.)?	1	1	3	5	
V-18	Can the signal indication be placed horizontally or vertically in the same arrangement?	3	3	3	5	
V-19	Does it work under all preemption scenarios?	1	2	5	5	
V-20	Does it avoid the yellow trap situation under all circumstances?	1	1	3	5	
V-21	Can the permissive indication be easily applied to other than PPLT situations?	1	1	1	5	
V-22	Will practitioners likely use the indication if made the standard, *or allowed alternate*?	5	3	3	5	

indicates that the flashing yellow ball used in Seattle, Washington has the lowest crash rate while the flashing red ball used in Oakland County, Michigan had the highest rate (Schattler et al., 2013). A rank order is shown in Table 2.8. The crash data were also analyzed by calculating the average number of left-turn crashes per 100 left-turning vehicles (Schattler et al., 2013). The rank order results of this analysis are presented in Table 2.9.

TABLE 2.5
Allowable Combinations of Placement, Indication Arrangement, and Phasing for Potential Indication Type (Noyce et al., 2007)

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	Y1
		Lag-Lag Lefts	Y2	N	Y1
		Lead-Lag Lefts	N	N	Y1
	5-Section Vertical	Lead-Lead Lefts	Y	N	Y1
		Lag-Lag Lefts	Y2	N	Y1
		Lead-Lag Lefts	N	N	Y1
	5-Section Horizontal	Lead-Lead Lefts	Y	N	Y1
		Lag-Lag Lefts	Y2	N	Y1
		Lead-Lag Lefts	N	N	Y1
Separate Indication	5-Section Cluster	Lead-Lead Lefts	Y	Y	Y
		Lag-Lag Lefts	Y2	Y	Y
		Lead-Lag Lefts	N	Y	Y
	5-Section Vertical	Lead-Lead Lefts	Y	Y	Y
		Lag-Lag Lefts	Y2	Y	Y
		Lead-Lag Lefts	N	Y	Y
	5-Section Horizontal	Lead-Lead Lefts	Y	Y	Y
		Lag-Lag Lefts	Y2	Y	Y
		Lead-Lag Lefts	N	Y	Y

Note:
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 2.6
Summary of Average Crash Rate (Schattler et al., 2013)

City		Portland, OR	Seattle, WA	Dallas, TX	College Station, TX	Orland, FL	Dover, DE	Oakland County, MI	Cupertino, CA
Display Type		5C GB	4V FYB	5H & 5V	5H &5C	5C GB	4C FRA	3V FRB	4V FRA
Crash Rate Range	**Lowest**	0.27	0.24	0.24	0.29	0.19	0.21	0.11	0.25
	Median	0.47	—	0.28	0.49	0.25	0.27	0.58	—
	Highest	0.80	0.43	0.44	1.31	1.03	0.40	0.64	0.31
Average		0.52	0.34	0.34	0.70	0.49	0.29	0.44	0.28
Standard Dev.		0.27	0.13	0.13	0.54	0.47	0.10	0.29	0.08

GB—Green Ball; FYB—Flashing Yellow Ball; FRB—Flashing Red Ball; FRA—Flashing Red Arrow; H—Horizontal; V—Vertical; C—Cluster.

TABLE 2.7
Rank Order by Display Type–Average Crashes per 100,000 Left-Turns × Opposing Vehicles (Schattler et al., 2013)

Rank Order	Display—Location
1	Flashing Yellow Ball—Seattle
2	Flashing Red Arrow—Cupertino
3	Green Ball—Orlando
4	Flashing Red Ball—Oakland County
5	Flashing Red Arrow—Delaware
6	Green Ball—Portland
7	Green Ball—Dallas
8	Green Ball—College Station

TABLE 2.8
Rank Order by Display Type—Average Left-Turn Crashes per Year (Schattler et al., 2013)

Rank Order	Display—Location
1	Flashing Yellow Ball—Seattle
2	Flashing Red Arrow—Cupertino
3	Flashing Red Arrow—Delaware
4	Green Ball—Portland
5	Green Ball—Orlando
6	Green Ball—Dallas
7	Green Ball—College Station
8	Flashing Red Ball—Oakland County

TABLE 2.9
Rank Order by Display Type—Average Left-Turn Crashes per 100 Left-Turn Vehicles (Schattler et al., 2013)

Rank Order	Display—Location
1	Flashing Yellow Ball—Seattle
2	Green Ball—Portland
3	Green Ball—Orlando
4	Flashing Red Arrow—Cupertino
5	Flashing Red Arrow—Delaware
6	Green Ball—Dallas
7	Flashing Red Ball—Oakland County
8	Green Ball—College Station

3. PUBLIC OUTREACH

Recognizing that this project lies at the crossroads of engineering, law enforcement, driver licensing, and drivers' education, partnerships with respective state agencies are necessary. In preliminarily reviewing the concept of the FYA with the Town of Munster's police chief, Stephen Scheckel, he noted that he saw neither any additional burden that this would place on law enforcement, any regulations that would need to be changed, nor any difficulty in communicating any implementation to his staff. Such feedback is critical as law enforcement completes a feedback loop to engineers through

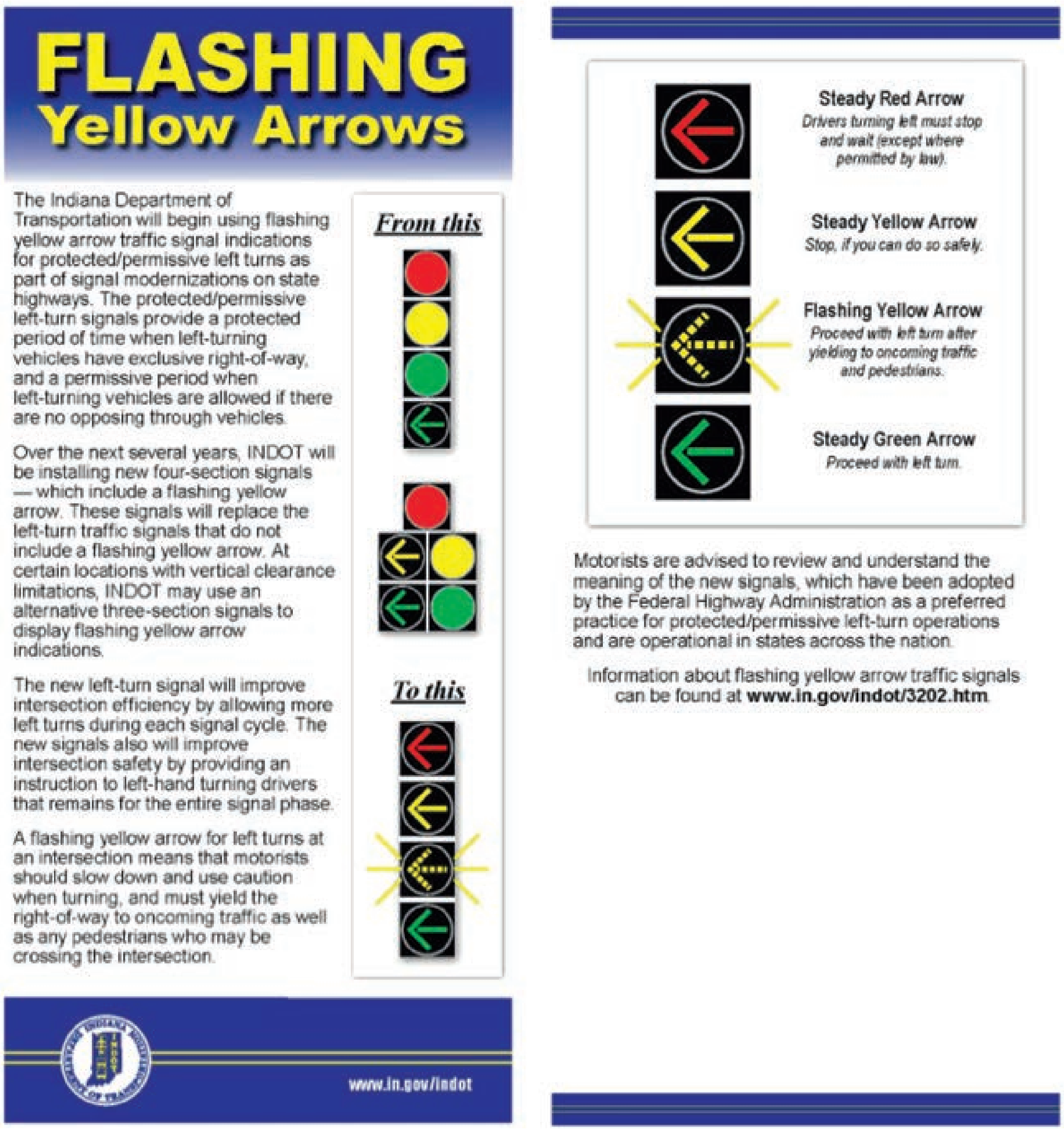


Figure 3.1 INDOT FYA community handout card.

enforcement actions and crashes reported in the ARIES system (Brehmer et al., 2003).

Beyond the actual physical implementation of a new signal, there are a number of other parts that can make implementation successful. This includes community outreach, publicity, and the development of promotional materials. Based on media feedback and a review of available materials several recent FYA implementations were of note. The Missouri Department of Transportation (MoDOT) has been very upfront with their 1-888-ASK-MODOT customer service helpline. This is the only DOT that appeared to be actively promoting such direct inquiries from the public. MoDOT also has also had a community relations staff member in recent years. Thus press inquiries were made "peer-to-peer" instead of "media-to-engineer." This is notable as a TV report from Round Rock, Texas falsely reported that "A federal mandate requires states install these lights at new intersections and when existing lights need repairs." and "We asked TxDOT [Texas Department of Transportation] if they keep track of the number of crashes at these intersections so they can see if they're actually improving driver safety. They said that's data they don't document." (Miller, 2013).

As part of any implementation the stakeholders should be prepared for negative public feedback, despite sound data in favor of using FYA signals. One newspaper editorial that typifies such a response was from Myrtle Beach, South Carolina. The local newspaper ran an editorial that opined "It would be folly to add a new, unfamiliar traffic signal to this already dangerous mix of impatient residents and dawdling sightseers navigating unknown roads. The flashing yellow arrow may be the best invention since chicken bog, but please, DOT, test it elsewhere first. On this, we're just fine being a late adopter." (Flashing Yellow? We'll Pass, 2013).

In reviewing media reports it was also notable to find anecdotal evidence in the media from Oregon that police officers were indeed citing drivers for violating FYA signals, but that some driver confusion remained after installation. In this case the question was "How does a driver know when a flashing yellow arrow is going to stop flashing and become a solid yellow arrow?" The answer that was given can be boiled down to the following: "So, too often, they creep into and block intersections, which is illegal regardless of whether the arrow is flashing or solid." (Rose, 2012).

For the State of Indiana, SAC members Joe Bruno and Brad Steckler prepared a bookmark style handout for public outreach. This handout was sized so that two could be printed on a standard sized paper (8.5″ × 11″). This Indiana handout can be seen in Figure 3.1. A narrated video was also produced and published on YouTube and on the INDOT website at http://www.in.gov/indot/3202.htm.

Related to public outreach, on a site specific basis, it may be necessary to take note of any other four section signal heads in use for non-FYA purposes. Several examples were located in Indiana where an extra lens was added to reinforce a left turn or right turn. The first example, as seen in Figure 3.2 shows a combination of a circular green indication and green arrow indication used for a split-phased traffic signal in Munster, Indiana. The second example, as seen in Figure 3.3, shows a signal head with dual green left-turn arrows.

Figure 3.2 Eastbound 45th Street at Calumet Avenue in Munster, Indiana.

Figure 3.3 Southbound Mississippi Street at 83rd Street in Merrillville, Indiana.

4. HARDWARE LIMITATIONS

As part of this study several manufacturers were contacted for information about their hardware offerings. The first manufacturer contacted was Reno A&E. Reno was one of the currently approved vendors by INDOT for their malfunction management units (MMU) in their signal control cabinets. In speaking with the company, the most important hardware issue to be dealt with would be if there were any older MMUs that were labeled as "MMU." Any such unit would have to be returned to the manufacturer for a software upgrade; however, not all older units would be upgradable. In the April 2012 revision to the NEMA TS-2 specifications, accommodations were explicitly specified for FYA as an allowable signal phase. MMUs meeting this standard are labeled as "MMU2." As this is an industry standard, any manufacturer selling a MMU with the label "MMU2" will support FYA operations. However, some may require a firmware update.

Recognizing special considerations for signals located near at-grade railroad crossings, a representative vendor that focuses on railroad interconnection was sought out. One manufacturer that currently meets these criteria and has an existing business relationship with INDOT is CTC Inc. Rick Campbell, president of the firm, agreed to speak on the record about such traffic signals. Rick's company has a demonstration panel that was on display at the 2013 American Railway and Maintenance of Way Association's annual meeting. The demonstration panel was able to be easily show FYA operations preempted by an approaching train, and could be configured for limited service mode during a crossing closure.

5. FIELD TEST SITES

Preliminary implementation of the FYA signals was conducted at two test sites. The first site was in Centerville, Indiana along US 40 at Salisbury Road on September 26, 2013. The second installation site was in Vincennes, Indiana at the intersection of US 41 and Old Wheatland Road (also known as Executive Boulevard). This second installation took place on November 18, 2013. These sites were the first sites chosen by INDOT for retrofit installation of FYA signals.

The next issue to address was selecting a supplemental sign (if any) to use adjacent to the signal. Based on an interpretation of current INDOT standards regarding signs, and upon the recommendation of Joe Bruno, the decision was made to use a regulatory black-and-white text only sign

Figure 5.2 Centerville, Indiana, FYA test site looking westbound toward Richmond.

that read "Left Turn Yield on Flashing Yellow Arrow." The standard drawing for this is shown in Figure 5.1 and is consistent with what is shown in Figure 2.3.

The Centerville site installation followed the customary practice of placing all the signal heads in a vertical orientation (Figure 5.2). Due to existing wires having enough conductors, no additional cables were installed. The span and catenary support system was also already high enough that no alterations were required. Prior to the installation of the FYA signal, the left-turn signal was a three section protected left-turn arrow. This FYA protected/permissive left-turn signal head was installed specifically for Sunday morning traffic headed from Richmond to two adjacent churches.

The Vincennes site installation required a special accommodation for the span and catenary system to maintain a minimum vertical clearance (Figure 5.3). To make this accommodation the FYA signal heads were placed in a horizontal position, while the through lane signal heads remained in a vertical orientation. No additional wires were needed to be pulled to the cabinet as this intersection too had sufficient wiring capacity.

Additional precautionary measures were established at both sites. The first measure instituted was a sign placed in the traffic control cabinet near the malfunction management unit (MMU). INDOT has a process where the MMUs are re-certified annually. This is customarily done by swapping the existing program card into a certified MMU, and then taking the removed MMU back to the shop for inspection and re-certification. However, due to the possibility that an incompatible MMU could be installed (not MMU2 compliant), which would prevent the signal from exiting an all-red flashing condition and entering normal service, an internal laminated card was placed in the cabinet as shown in

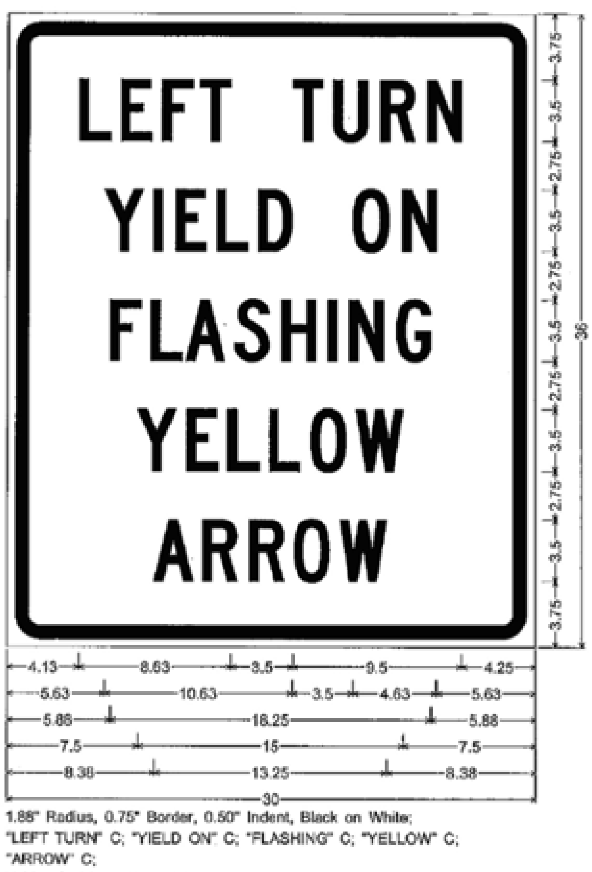


Figure 5.1 INDOT FYA supplemental sign.

Figure 5.3 Vincennes, Indiana, FYA test site looking eastbound.

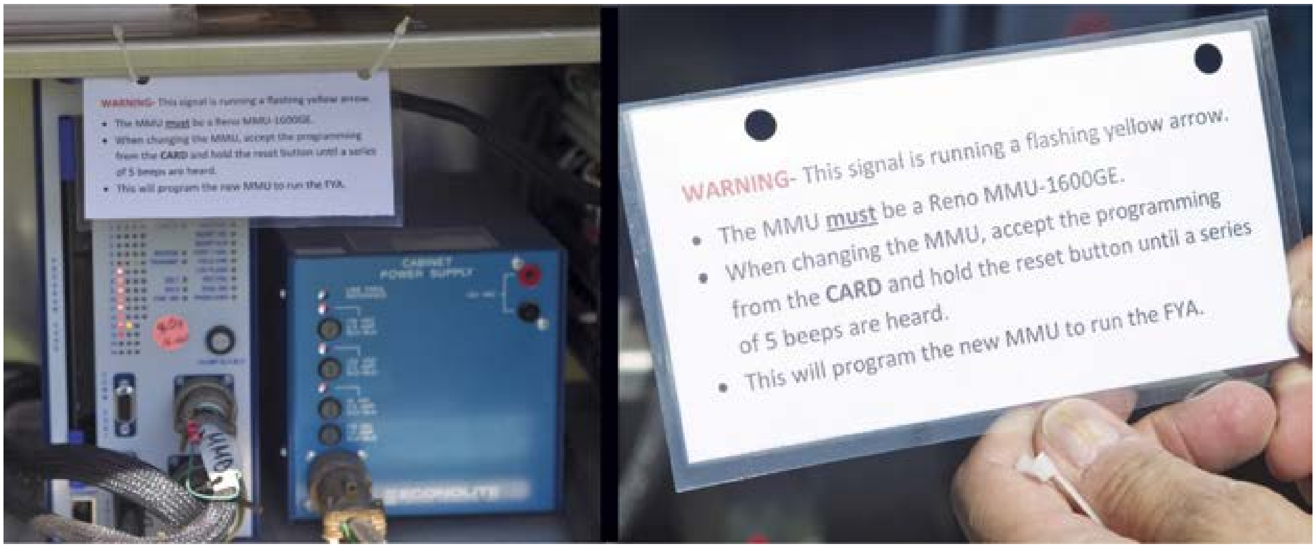


Figure 5.4 Warning card for correct MMU.

Figure 5.4. The second additional safety precaution instituted was to add a two second delay to the onset of the flashing yellow arrow to permit oncoming traffic to move first, thus hopefully reducing the likelihood of a left-turn vehicle attempting to beat oncoming traffic.

6. DATA COLLECTION

6.1 Crash Data

Crash records were obtained from the Indiana State Police for the test sites in Centerville, and Vincennes. Summary data was provided for all crashes since 2008. Based on this research project, specific crash reports were requested for all crashes occurring following the installation of the FYA signals, and injury crashes for the five years preceding the installations.

Figure 6.1 Field data collection setup.

6.2 Driver Performance Data

Data was collected at each intersection using an ATS Stalker II radar gun connected to a laptop. Each vehicle's data was collected only when there was a clear, unobstructed view from the observation point to the vehicle during the complete duration of that data. The observation point was set on the same side of the road as the approach after the intersection. A camera was placed at the observation point to record traffic for review if necessary. This setup is pictured in Figure 6.1 and Figure 6.2.

The result of this was time and speed data for each vehicle. Distance and time measurements began at the point where an observable vehicle entered the left-turn bay. This was normally at the rear of the bay, but it did include observations when the vehicle entered the bay by changing lanes across the left-turn bay longitudinal stripe. Data continued to be collected until the vehicle either came to a complete stop while yielding or began to execute the left turn when no visible stop occurred. Thus the distance traveled

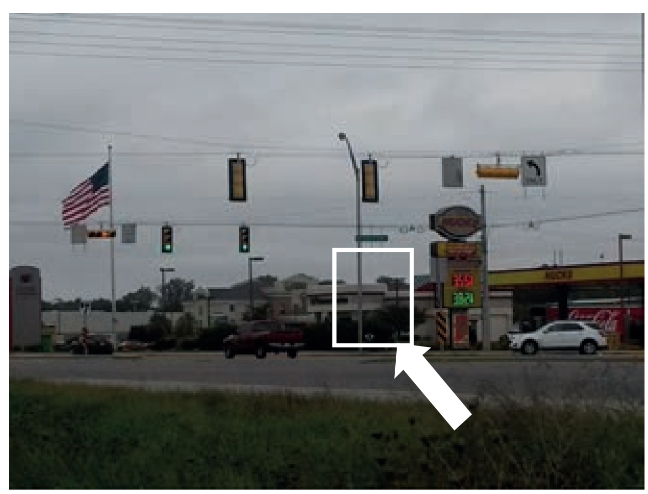


Figure 6.2 Field data collection as viewed from a distance.

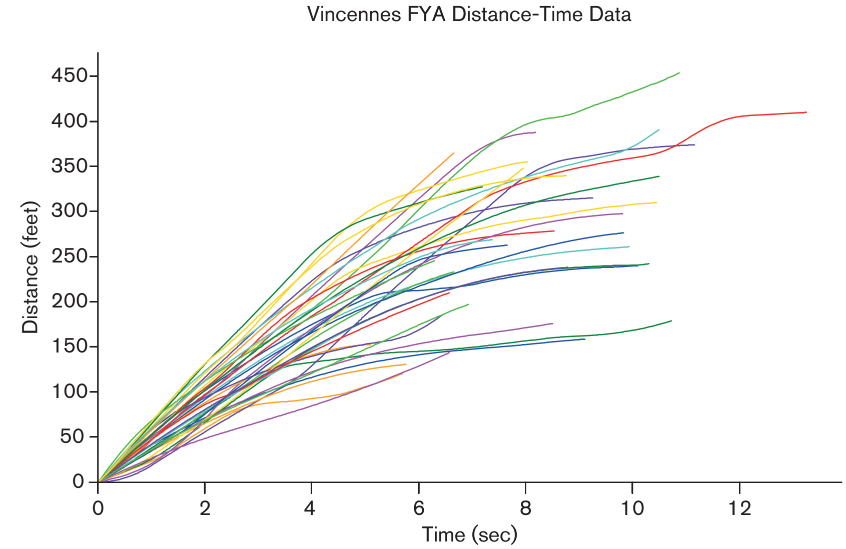


Figure 6.3 Vincennes distance-time data.

also included several vehicles entering the intersection beyond the stop bar. A sample of this data is plotted in Figure 6.3 and Figure 6.4.

Data was collected in Vincennes, Indiana for the eastbound approach on US 41 at Old Wheatland Road (also known as Executive Boulevard) on September 11, 2014 from 4:30 to 6:30 p.m. and on September 12 from 8:52 a.m. to 10:52 a.m. Due to the difficulty in obtaining a sufficient sample size for statistical confidence, data from both data collections was combined. During the observation hours a single tractor trailer was observed making a left turn. To ensure uniformity in the data this data point was discarded to focus on two axle passenger vehicles. The speed limit on the measured approach was 35 miles per hour.

A control location was chosen in Vincennes at the intersection of St. Clair and 2nd streets. The measured approach was the left turn from 2nd street onto eastbound St. Clair. The speed limit on the approach was 25 miles per hour. Data was collected from 4:45 p.m. to 6:45 p.m. September 12, 2014. Although there were pedestrian signals present, during the observation time they were not activated and no pedestrians attempted any crossings.

Data was collected in Centerville at the intersection of US 40 and Salisbury Road on September 14, 2014 from 8:50 a.m. to 10:50 a.m. The monitored approach west bound left turn. This was to correspond with traffic coming from Richmond and headed to two nearby churches: Fellowship Church and Victory Baptist Church.

A control location in adjacent Richmond was selected. The control location was at the intersection of US 40 and 18th Street. The measured direction was the eastbound approach for traffic desiring to turn left (north) on to 18th Street. Data was collected on September 13, 2014 from 7:15 p.m. to 7:45 p.m. and on September 14, 2014 from 11:55 a.m.

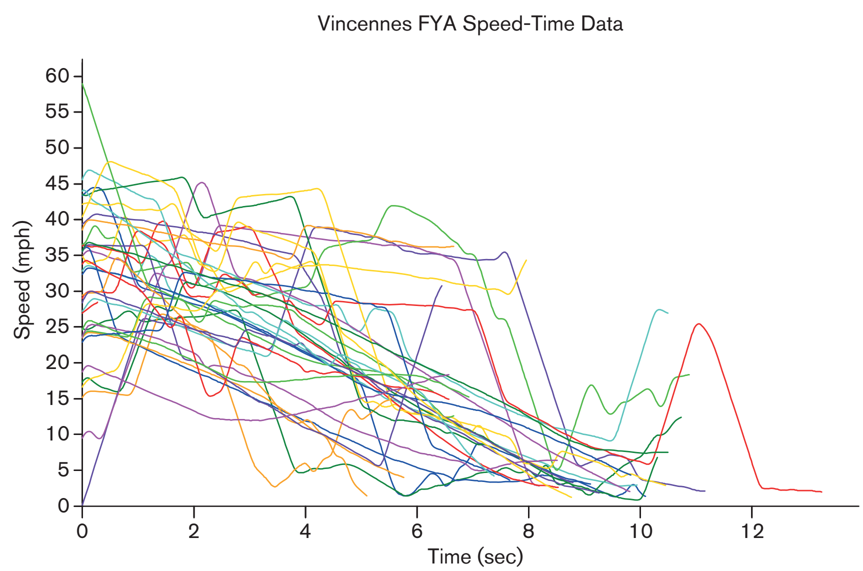


Figure 6.4 Vincennes FYA speed-time data.

to 12:50 p.m. using the same selection criteria. The speed limit on the approach was 35 miles per hour and no pedestrian signal heads were present.

6.3 Survey Data

Driver surveys were designed to check for driver understanding and to examine additional variables. The survey asked several demographic questions and had twelve scenarios. The twelve scenarios were as follows:

- *Scenario 1:* horizontal signal heads; solid green left-turn arrow, red ball for through traffic
- *Scenario 2:* horizontal signal heads; solid red left-turn arrow, red ball for through traffic
- *Scenario 3:* horizontal signal heads; solid yellow left-turn arrow, green ball for through traffic
- *Scenario 4:* horizontal signal heads; flashing yellow left-turn arrow, green ball for through traffic
- *Scenario 5:* vertical signal heads; solid green left-turn arrow, red ball for through traffic
- *Scenario 6:* vertical signal heads; solid red left-turn arrow, red ball for through traffic
- *Scenario 7:* vertical signal heads; solid yellow left-turn arrow, green ball for through traffic
- *Scenario 8:* vertical signal heads; flashing yellow left-turn arrow, green ball for through traffic
- *Scenario 9:* horizontal left-turn and vertical through signal heads; solid green left-turn arrow, red ball for through traffic
- *Scenario 10:* horizontal left-turn and vertical through signal heads; solid red left-turn arrow, red ball for through traffic
- *Scenario 11:* horizontal left-turn and vertical through signal heads; solid yellow left-turn arrow, green ball for through traffic
- *Scenario 12:* horizontal left-turn and vertical through signal heads; flashing yellow left-turn arrow, green ball for through traffic

Images of each of these scenarios can be seen in Appendix B. The survey were conducted at Vincennes University in Vincennes, Indiana, and along Main Street in downtown Richmond, Indiana. The survey was approved by the Purdue University Institutional Review Board (PUIRB) as protocol 1408015144 and the PUIRB determined that it met federal criteria for exemption under 45 CFR 46.101(b)(2).

7. DATA ANALYSIS

7.1 Crash Data

The crash data for the two installation sites was studied to look for trends and patterns. It is important to note that following the installation of the signal heads in the fourth quarter of 2013, several crashes were reported for this portion of the calendar year. This data is shown in Table 7.1 and Table 7.2.

In looking at annual crashes, the average annual crashes at the Centerville test site for the years 2008 to 2012 was 5 crashes per year. If the 2014 data is extrapolated to an annual number, the projected crashes for 2014 would be 5.14. At the Vincennes test site the average annual crashes from 2008 to 2012 was 2.60. Using 2014 crash data and extrapolating that out to a full year, the projected crashes for 2014 would be 5.14.

Looking further at the crash data predictions, several other observations were made. First, the projected annual crash count at the Centerville location increased by 2.8%, and the annual crash count for Vincennes is projected to be increased by 98% in the first year compared with the previous five year average.

Any reduction in crashes that might be observed at future installations would translate directly into a net cost savings for the State. According to the 2010 edition of the AASHTO *Highway Safety Manual,* the comprehensive costs associated with a property damage only crash is $7,400, for a possible injury crash the cost is $44,900, for an evident injury the cost is $79,000, for a disabling injury is $216,000, and for a fatality, the cost is $4,008,900. When looking at costs by

TABLE 7.1
Crash Data Summary

	Year	# of Crashes	# of Injuries	# of PDO	# of Fatalities	Left-turn Related	Right Angle or Head-On, Failure to Yield Right-of-Way
Centerville, Indiana Test Site							
Before Installation	2008	6	3	3	0	0	0
	2009	1	0	1	0	0	0
	2010	5	0	5	0	0	1
	2011	5	0	5	0	1	2
	2012	8	2	6	0	1	2
	2013	6	4	2	0	1	1
After Installation	2014 *(Through July)*	3	1	2	0	0	0
Vincennes, Indiana Test Site							
Before Installation	2008	3	1	2	0	0	1
	2009	1	0	1	0	0	0
	2010	2	0	2	0	1	1
	2011	5	2	3	0	0	1
	2012	2	1	1	0	1	1
	2013	8	3	5	0	0	5
After Installation	2014 *(Through July)*	3	1	2	0	1	1

TABLE 7.2
Crash Cause Summary at FYA Test Sites

Date	Time	Injury	PDO	Fatality	Left-turn Related	Reported Cause
Centerville, Indiana Test Site						
11/6/2013	2:25 PM	Yes	No	No	No	Following Too Closely
12/12/2013	7:41 AM	Yes	No	No	Yes	Failure to Yield Right-of-way
6/3/2014	6:00 AM	No	Yes	No	No	Animal / Object in Roadway
6/12/2014	7:12 PM	No	Yes	No	No	Following too Closely
7/9/2014	8:10 AM	Yes	No	No	No	Overturned Vehicle
Vincennes, Indiana Test Site						
11/20/2013	12:30 AM	No	Yes	No	Yes	Failure to Yield Right-of-way
11/25/2013	3:01 PM	No	Yes	No	No	Unsafe Lane Movement
11/21/2013	6:49 PM	Yes	No	No	No	Other
12/17/2013	5:15 PM	Yes	No	No	Yes	Failure to Yield Right-of-way
3/3/2014	8:02 AM	No	Yes	No	No	Speed too Fast for Weather Conditions
6/17/2014	12:40 PM	Yes	No	No	No	Left of Center
7/8/2014	05:57 PM	No	Yes	No	Yes	Failure to Yield Right-of-Way

crash types, the comprehensive crash costs can be tabulated slightly differently. Relevant costs for a conversion of a PPLT to FYA signal head are as follows. For a rear-end crash at a signalized intersection the cost would be $26,700, and an angle crash would be $47,300 (AASHTO, 2010; Council et al., 2005).

Additional examination of the crash reports for the after condition, the causes of these crashes were extracted from the reports and summarized in Table 7.2. Three of the eleven crashes were related to a left turn, but in this case the issue was a yielding conflict with a right-turning vehicle.

In looking further into the injury crashes, crash narratives were obtained.

The November 6, 2013 crash was the result of a driver rear-ending a vehicle yielding to make a left turn. The driver of the left-turning vehicle complained of pain after the crash.

The November 21, 2013 crash narrative reveals that the event sequence began with a driver in the left-turn bay facing a FYA signal. It is unclear exactly how the chain of events occurred based on the accounts of the two drivers and a witness from this point forward. It is most likely that the signal went straight to a flashing yellow arrow, skipping over the solid green arrow (protected left turn). The left-turning driver then proceeded as if they had the right-of-way, but was then struck by an oncoming vehicle. This crash caused air bags to deploy and one driver complained of pain.

The December 12, 2013 crash was the result of a collision near the intersection, but was not actually at the intersection. One vehicle attempted to make a left turn into a commercial center but did not have an adequate gap, resulting in a right-angle collision. The driver of the left-turning vehicle complained of neck pain afterwards.

The December 17, 2013 crash was the result of a driver making a left turn out of a parking lot adjacent to the intersection, and across traffic queued at a red signal at the intersection. This vehicle was then struck by an oncoming vehicle traveling away from the intersection. Thus the presence of the FYA was unrelated to this crash. Airbags were deployed in both vehicles, and one driver complained of pain in their chest.

The June 17, 2014 crash narrative noted that a driver in a through lane proceeded through the intersection to the left of the center and then collided with a vehicle waiting to make a left turn at the FYA. The driver of the on-coming left of center vehicle had a leg injury and was transported by an ambulance to a nearby hospital.

The July 8, 2014 crash was the result of a moped falling over and then sliding along the roadway. It is unclear from the narrative what caused the tip over, but it appears to be unrelated to the FYA installation.

Considering the six injury crashes reported, only one might possibly have had anything to do with the presence of the FYA, and it is unclear if it actually contributed to it or not. While it is possible that the left-turning driver of the November 21, 2013 crash may have misinterpreted the meaning of a flashing yellow arrow on the FYA signal head, it is notable that no statement about this was present in the police report.

7.2 Driver Performance Data

The fundamental reason for the driver performance data was to be able to establish variations in driver performance between the different intersections and provide a surrogate measure of safety. As the speed limits of the approaches at the various intersections differed, this had to be accounted for. To account for this, linear regressions for each speed profile were done using Microsoft Excel. The coefficients and r-squared values were recorded. By taking the value of the coefficient resulting from the derivative of each regression, the result is the average acceleration/deceleration for their driving pattern. The value then removes the approach speed from the result leaving only the rate of speed change as the parameter for comparison. A sample of a single vehicle trajectory plot is shown in Figure 7.1. The coefficients for all vehicles at each location were compared to

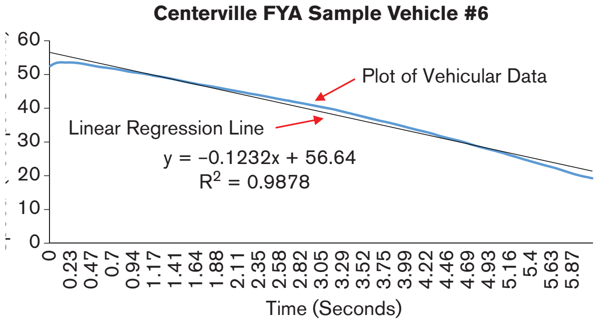


Figure 7.1 Centerville FYA sample vehicle #6 trajectory.

TABLE 7.3
Summary of Vehicle Performance Data

	Centerville FYA	Centerville Control	Vincennes FYA	Vincennes Control
Sample Size	31	30	36	24
Average Acceleration (Feet/Second^2)	−0.099	−0.102	−0.090	−0.102
Standard Deviation of Acceleration	0.073	0.064	0.070	0.080

other locations using two sample t-test with the null hypothesis that there was no statistical difference observed. A summary of this data is provided in Table 7.3.

Further analysis of the data was done to investigate if there were any statistical differences in the observations. A two sample t-test was conducted on each pair of sites in each city to compare the site with the FYA and the traditional PPLT signal, then a two sample t-test was done to compare the control sites, and then two sample t-tests were done to compare the two FYA sites. In all of the test had a null hypothesis that the means were the same (no statistical difference), and the alternate hypothesis was that there was a difference in the means. In all cases the null hypothesis failed to be rejected. A summary of these results, including rejection status of the null hypothesis along with p-values, is presented in Table 7.4.

A similar test was done comparing the average results of the R^2 values for each regression curve. This was done to check for any errors that may result from less than ideal regressions. The null hypothesis was that the differences in mean R^2 values was zero. A summary of these results, including rejection status of the null hypothesis along with p-values, is presented in Table 7.5.

7.3 Survey Data

Evaluating the survey responses, a tabulation was made and is shown in Table 7.6. This survey data was collected from 53 individuals and their demographic responses are shown in Table 7.7.

Several of these survey results are important to consider. When considering an all horizontal arrangement of signal heads (Scenario 4), there was an 11% fail-critical response rate. These are drivers desiring to go with the right-of-way when presented with a flashing yellow arrow. In this circumstance, either a yield (correct response) or

TABLE 7.4
Results of Two Sample T-Tests for Differences in Mean Acceleration

Site	Centerville FYA	Centerville Control	Vincennes FYA	Vincennes Control
Centerville FYA	—	Do Not Reject H_0 P = 0.123	Do Not Reject H_0 P = 0.593	Do Not Reject H_0 P = 0.887
Centerville Control	—	—	Do Not Reject H_0 P = 0.276	Do Not Reject H_0 P = 0.134
Vincennes FYA	—	—	—	Do Not Reject H_0 P = 0.537
Vincennes Control	—	—	—	—

TABLE 7.5
Results of Two Sample T-Tests for Differences in Means of R^2 Regression Values

Site	Centerville FYA	Centerville Control	Vincennes FYA	Vincennes Control
Centerville FYA	—	Do Not Reject H_0 P = 0.460	Do Not Reject H_0 P = 0.930	Do Not Reject H_0 P = 0.749
Centerville Control	—	—	Do Not Reject H_0 P = 0.325	Do Not Reject H_0 P = 0.260
Vincennes FYA	—	—	—	Do Not Reject H_0 P = 0.775
Vincennes Control	—	—	—	—

TABLE 7.6
Summary of Survey Responses to Research Questions

Question	Options		Responses	Percentages	Fail-critical (FC)	FC Responses
1	A	Go	42	79%		3
	B	Yield	8	15%		
	C	Stop	3	6%	X	
2	A	Go	0	0%	X	1
	B	Yield	1	2%	X	
	C	Stop	52	98%		
3	A	Go	10	19%	X	10
	B	Yield	36	68%		
	C	Stop	7	13%		
4	A	Go	6	11%	X	6
	B	Yield	43	81%		
	C	Stop	4	8%		
5	A	Go	50	94%		3
	B	Yield	0	0%		
	C	Stop	3	6%	X	
6	A	Go	1	2%	X	3
	B	Yield	2	4%	X	
	C	Stop	50	94%		
7	A	Go	1	2%	X	1
	B	Yield	42	79%		
	C	Stop	10	19%		
8	A	Go	2	4%	X	2
	B	Yield	46	85%		
	C	Stop	5	9%		
9	A	Go	51	96%		2
	B	Yield	0	0%		
	C	Stop	2	4%	X	
10	A	Go	1	2%	X	1
	B	Yield	0	0%	X	
	C	Stop	52	98%		
11	A	Go	5	9%	X	5
	B	Yield	37	70%		
	C	Stop	11	21%		
12	A	Go	2	4%	X	2
	B	Yield	46	87%		
	C	Stop	5	9%		

Note: See Appendix B for driver survey images.

stop (sometimes correct as part of a yielding behavior) would not result in a right angle crash, though a rear-end crash may still result if the following driver is too close and does not anticipate a stop coming from the vehicle in front of them. This 11% fail-critical rate was greater than the 4% same fail-critical response rate observed for all vertical signals and for mixed orientation signals. The highest observed fail-critical response was observed for Scenario 3, in which 19% of respondents incorrectly indicated a desire to proceed with the right-of-way on a solid yellow arrow in a horizontal signal head adjacent to horizontal signal heads displaying a solid circular green indication. Another key pair to consider was that Scenarios 8 and 12. This pair showed a permissive left turn with a flashing yellow arrow, but with the left-turn signal head orientated vertically in Scenario 8 and horizontally in Scenario 12; both scenarios used vertically oriented three section signal heads for through traffic. The

TABLE 7.7
Survey Response Summary

Question	Response	Number of Responses	Percentage
Age Range	18–21	25	47%
	22–25	0	0%
	26–35	6	11%
	36–45	6	11%
	46–55	9	17%
	56–64	8	15%
	65 or more	0	0%
Gender	Male	31	58%
	Female	22	42%
	Prefer Not to Say	0	0%
	Other	0	0%
State of Residence	Indiana	53	100%
	Illinois	0	0%
	Wisconsin	0	0%
	Michigan	0	0%
	Ohio	0	0%
	Kentucky	0	0%
	Other	0	0%
Education	Less Than High School	0	0%
	High School	5	9%
	Some College, No Degree	31	58%
	2-year College Degree	5	9%
	4-year College Degree	7	13%
	Master-Level Degree or Higher	5	9%
Annual Miles Driven	< 10,000	18	34%
	10,000–20,000	21	40%
	> 20,000	14	26%

fail-critical rate for both of these Scenarios were identical at 4%.

8. CONCLUSIONS

Based on the driver behavior observed and monitored, there was no statistical difference between braking (deceleration) values between the control sites, between the sites in the same geographic location, and between sites where the FYA signal head orientation was rotated 90 degrees. Therefore no adverse impacts (relative to a conventional five section PPLT signal head) are anticipated based on this data.

Considering that the use of FYA signal heads is still a relatively new development in the history of traffic signals, there is still a need for a proactive public outreach to accompany new installations. As previously discussed, if this is not strategically done, the media can mangle the message, or allow a needless sense of fear to fester in the community. Using the tools developed during this study, including the Community Handout Card (Figure 3.1), the INDOT webpage, and the YouTube video, carefully crafted press releases should be done proactively in conjunction with installations. Where new FYA installations occur along specific corridors, economies of scale can be realized on community outreach investments.

When looking at the driver survey data several conclusions can be reached. First, it would seem to follow that any placement of all horizontal signal heads should be avoided unless absolutely necessary due to these circumstances contributing to the top two fail-critical response rates. Secondly, there was no difference in fail-critical responses from those surveyed between reactions to all vertical signals and mixed orientation signals (Scenarios 8 and 12). It is interesting to note that the data indicated that a fail-critical response rate for a horizontally placed left-turn signal could be reduced from 19% to 4% by simply changing the orientation of the adjacent through lane signal heads from horizontal to vertical (Scenario 3 versus 12).

The *Crash Modification Factors Clearinghouse* (CMFC) provides a point of reference for this data. The CMFC provides an organized database of projected crash modification factors that can be used to consider the implications of various changes in traffic operations. The CMFC data for switching from a protected only left turn to a FYA, predicted an increase in crashes between 33.8% and 124.2% (the projected increase was 2.8% for Centerville and 98% for Vincennes) (AASHTO, 2010). Compared to the CMFC data observed, the Indiana data collected in this study showed that the results were safer than projected for Centerville, and within expectations for Vincennes.

On a practical implementation note, in locations where additional conductors would be necessary, a small concern was raised about the feasibility of pulling new wires through possibly collapsed conduit. In such a circumstance excavation, boring, and/or drilling may be necessary, additional expenses required for retrofit installation of FYA signal heads. Based on feedback received from the Study Advisory Committee, the situation of collapsed or damaged conduit was seen as a situation that would need to be ruled out for each intersection rather than assumed not to exist.

When considering a benefit-cost analysis for installing FYA signals this cost could create additional complexities. In regards to costs for installing the FYA signals, the largest costs, in the worst case, would be that of replacing the signal controller, the MMU, and the cost of temporary traffic control including the cost of labor. New FYA signal heads could be created out of existing signal component inventories that are reconfigured at an INDOT shop into an FYA arrangement. The final cost item would the fabrication of a supplemental sign (as seen in Figure 5.1). Similar signs are already fabricated for PPLT signals, thus no additional costs would be projected for this item.

When considering Federal Highway Administration guidance directed towards installing one signal head per lane of traffic (including dedicated turn lanes, both right and left), there will be a need statewide to add additional signal displays. The vehicular performance data, crash data, and survey data reveal no reason to believe any adverse impact will occur by installing the FYA for permissive left turns as a replacement for a five section PPLT head. Thus, in addition to mobility improvements, there are not expected to be any safety concerns. However, the choice remains between installing a dedicated three section left turn signal, a three section FYA without a protected left-turn phase, a five section PPLT signal or a FYA signal. If a dedicated turn signal is not warranted, the FYA offers the additional operational benefit of allowing lagging left turns without creating a yellow trap. Additionally, just like a five section PPLT signal, a FYA signal could be set to operate in protected mode only during selective conditions, and could be adopted for use with right turns.

While this research focused on the use of a flashing yellow arrow for left turns, it was identified by the Study Advisory Committee, that the same principles could be used for right turns. In particular, when pedestrians are present and a walk sign is activated at the same time as parallel through traffic has a circular green, there would be the same issue of the same color and shape of a circular green indication conveying to drivers that they both have the right-of-way to go straight but must yield to pedestrians when making a right turn. The ideal location to test this would be a dedicated right-turn lane at an intersection in an area of high pedestrian traffic volumes.

When considering the results of the two test sites, the motorist survey, FHWA guidelines, and experiences from other states, implementation of the flashing yellow arrow is an important effort for INDOT to pursue. In the operational environment of INDOT that includes extensive use of span and catenary signal head supports instead of mast arms, and in consideration with the reduced reaction time found in NCHRP report 20-07, this research finds that the implementation of FYA is worthwhile as it is expected to be a win-win for the State, reducing crashes and improving traffic mobility. Given proper engineering judgment is applied on a site-by-site basis, the option of placing a FYA signal head in a horizontal configuration while leaving through lane signal heads vertically orientated should not be eliminated. There were no indications from this research that such signal placements would adversely affect traffic safety, or impair driver understanding. The data suggests that the same standard of care is provide for in this configuration as in an all vertical configuration. While the actual crash reports do not offer any additional guidance one way or the other, this should be reviewed periodically.

9. ACKNOWLEDGMENTS

The authors would like to acknowledge the members of the Study Advisory Committee and the JTRP staff for their assistance with this project.

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APPENDICES

APPENDIX A: STATE-BY-STATE IMPLEMENTATIONS OF FYA

State	FYA Implementation	Cities with FYA Implementation	Yellow Ball/Arrow	Red Ball/Arrow	Vertical/Horizontal	Type
Alabama	Yes	1	Arrow	Arrow	Vertical	4-section
Alaska	Yes	3	Arrow	Arrow	Vertical	4-section
Arizona	Yes	3	Arrow	Arrow	Vertical	4-section
Arkansas	Yes	1	Arrow	Arrow	Vertical	4-section
California	Yes	3	Arrow	Arrow	Vertical	4-section
Colorado	Yes	2	Arrow	Arrow	Vertical	4-section
Connecticut	No	N/A	N/A	N/A	N/A	N/A
Delaware	No	N/A	N/A	N/A	N/A	N/A
District of Columbia	No	N/A	N/A	N/A	N/A	N/A
Florida	Yes	2	Arrow	Arrow	Vertical	4-section
Georgia	Yes	1	Arrow	Arrow	Vertical	4-section
Hawaii	Yes	1	Arrow	Arrow	Vertical	4-section
Idaho	Yes	3	Arrow	Arrow	Vertical	4-section & 5-section (dog house)
Illinois	Yes	2	Arrow	Arrow	Vertical	4-section
Indiana	—	—	—	—	—	—
Iowa	Yes	2	Arrow	Arrow	Vertical	4-section
Kansas	Yes	3	Arrow	Arrow	Vertical	4-section
Kentucky		1	Arrow	Arrow	Vertical	4-section
Louisiana	Yes	1	Arrow	Arrow	Vertical	4-section
Maine	No	N/A	N/A	N/A	N/A	N/A
Maryland	Yes	1	Arrow	Arrow	Vertical	4-section
Massachusetts	No	N/A	N/A	N/A	N/A	N/A
Michigan	Yes	1	Arrow	Arrow	Vertical	4-section
Minnesota	Yes	1	Arrow	Arrow	Vertical	4-section
Mississippi	No	N/A	N/A	N/A	N/A	N/A
Missouri	Yes	3	Arrow	Ball	Vertical	4-section
Montana	No	N/A	N/A	N/A	N/A	N/A
Nebraska	No	N/A	N/A	N/A	N/A	N/A
Nevada	Yes	4	Arrow	Arrow	Vertical	4-section
New Hampshire	Yes	1	Arrow	Arrow	Vertical	4-section
New Jersey	Yes	Not Found	Arrow	Arrow	Vertical	4-section
New Mexico	Yes	2	Arrow	Arrow	Vertical	4-section
New York	Yes	2	Arrow	Arrow	Vertical	4-section
North Carolina	Yes	1	Arrow	Arrow	Vertical	4-section
North Dakota	No	N/A	N/A	N/A	N/A	N/A
Ohio	Yes	1	Arrow	Arrow	Vertical	4-section
Oklahoma	Yes	2	Arrow	Ball	Vertical	4-section
Oregon	Yes	1	Arrow	Arrow	Vertical	4-section/ 3-section (Bi-modal)
Pennsylvania	No	N/A	N/A	N/A	N/A	N/A
Rhode Island	Yes	2	Arrow	Arrow	Vertical	4-section
South Carolina	Yes	1	Arrow	Arrow	Vertical	3-section (Bi-modal)
South Dakota	Yes	2	Arrow	Arrow	Vertical	4-section
Tennessee	Yes	1	Arrow	Arrow	Vertical	4-section
Texas	Yes	4	Arrow	Arrow	Vertical/Horizontal	4-section (V)/ 5-section(H)
Utah	Yes	1	Arrow	Arrow	Vertical	4-section
Vermont	No	N/A	N/A	N/A	N/A	N/A
Virginia	Yes	3	Arrow	Ball	Vertical	4-section
Washington	Yes	3	Arrow	Arrow	Vertical	4-section
West Virginia	No	N/A	N/A	N/A	N/A	N/A
Wisconsin	Yes	1	Arrow	Arrow	Vertical	4-section
Wyoming	Yes	1	Arrow	Arrow	Vertical	4-section

APPENDIX B: DRIVER SURVEY IMAGES

Scenario 1

Scenario 2

Scenario 3

Scenario 4

Scenario 5

Scenario 7

Scenario 6

Scenario 8

Scenario 9

Scenario 11

Scenario 10

Scenario 12

APPENDIX C: INDOT OPERATIONS MEMORANDUM 13-04

INDIANA DEPARTMENT OF TRANSPORTATION

Driving Indiana's Economic Growth

100 North Senate Avenue
Room N955
Indianapolis, Indiana 46204

PHONE: (317) 234-7949
FAX: (317) 232-5551

Michael R. Pence, Governor
Karl B. Browning, Commissioner

DATE: September 25, 2013

TO: District Deputy Commissioners
District Technical Services Directors
District Traffic Engineers

OPERATIONS MEMORANDUM 13-04
SIGNALS

FROM: Brad Steckler, Director 9-26-13
Traffic Engineering Division

SUBJECT: **Flashing Yellow Arrow Signal Indications for Protected/Permissive Left Turns**

I) Background

Traffic signal heads with flashing yellow arrow (FYA) indications, as shown on page 4, are used for protected/permissive left turns (PPLT) – the flashing yellow arrow is displayed for the permissive movement. The use of the four section FYA signal indication in left turn signals has been shown to reduce crashes and improve safety by, among other things, eliminating the "Yellow Trap" (conflict with permissive left turns being made on yellow while opposing through movements still have green) and to improve mobility by providing more flexibility in phasing. This and other benefits are documented in *NCHRP Report 493* and provisions for the optional use of the FYA signal indication were incorporated into the *2011 Indiana Manual on Uniform Traffic Control Devices* (IMUTCD).

II) Purpose

To initiate and facilitate the use of FYA signal indications for protected/permissive left turns on the state highway system as a means to enhance safety and mobility.

III) Implementation

Signal heads that incorporate FYA signal indications should be used as follows:

1. To replace a five section PPLT head when a traffic signal is scheduled to be modernized or if substantial maintenance work is otherwise needed at the intersection. A five section signal head, as shown on page 4, may still be used where appropriate such as at an intersection approach with no dedicated left-turn lane and split phasing.

2. For approaches with a single left turn lane, an existing protected only left turn movement may be converted to protected/permissive if operational benefits can be realized without an impact on traffic safety.

   When a protected only left turn signal is replaced with FYA, the District Traffic Engineer should monitor the performance for a two year period after the conversion to determine if a

Page 1 of 6

safety problem develops. Should related safety problems occur, consideration must be given to converting back to the protected-only mode operation, either full time or during peak periods.

Heads incorporating FYA should not be used for approaches with more than one left turn lane.

Before installation, the District Traffic Engineer will review the intersection for compatibility with the four section FYA signal indication. This review involves checking for adequate vertical clearance – a minimum 17 ft. must be maintained – as well as the compatibility of the controller, cabinet, wiring, and MMU. Information regarding the controller and MMU models should be obtained from the Traffic Control Systems Office, which can also provide guidance on what adjustments are needed. Additional heads for the through movements may be needed when replacing an existing five section head for PPLT – a minimum of two through heads per approach is required. One of these through heads may be pedestal mounted when cantilever supports are used.

Implementation of this Policy for in-house work should begin immediately upon issuance (implementation for contracted work should begin with the February 2014 letting). The District Media Relations Office enacts the public information strategy for each location and that Office must be notified of an impending FYA installation.

IV)Installation Considerations

Refer to Appendix A for installation details – this drawing may also be used as a unique plan detail for contracted work.

A. FYA Signal Head

1. Lateral Position. Signal heads that include FYA for PPLT will be offset 4 ft. to the right of the left side of the left turn lane.

2. Number of Sections and Alignment. The signal head display should be a four section signal face that is aligned vertically. Vertically aligned heads should be "top justified" that is the red or top indication should be at the same elevation and towards the upper span cable.

   Where signal head height limitations exist so that it is not feasible to use a vertical four section signal head, consideration may be given to mounting the head horizontally.

   Three section signal heads with FYA should not be specified until such time that they are available on the approved materials list.

B. Phasing. The controller shall be programmed so that FYA indications will only be displayed simultaneously with green circular indications for the opposing through movements.

C. Wiring. To accommodate a FYA indication, one 7C/14 signal cable is needed from the head to the disconnect hanger and either one additional 7C/14 cable or one 9C/14 cable should be installed form the disconnect hanger to the controller.

D. Supplemental Sign. To supplement traffic signal control, a "LEFT TURN YIELD ON FLASHING YELLOW ARROW" sign will be installed adjacent to the left-turn signal face when a FYA is added. See Appendix B for the sign detail.

E. Additional Heads for Through Movements. For instances when a head with FYA is replacing a five section head, additional heads for the through movements may be needed to satisfy the following:

1. A separate three section signal head should be provided for each through lane.

2. For approaches with one through lane and one exclusive left turn lane, two three-section heads will be provided for the through lane.

V) Protected/Permissive Right Turn (PPRT) Signals

Five section heads should continue to be used for protected/permissive right turns; FYA indications should not be used at this time for right-turn applications.

VI) Public Outreach

Until such time as the public has become familiar with FYA indications and at least through the 2014 calendar year, the District Traffic Engineer must notify the District Media Relations Director of each location where a FYA signal indication will be installed. The District Traffic Engineer should assist, as needed, with any targeted public education plan for the location.

Figure 4D-11. Typical Position and Arrangements of Shared Signal Faces for Protected/Permissive Mode Left Turns

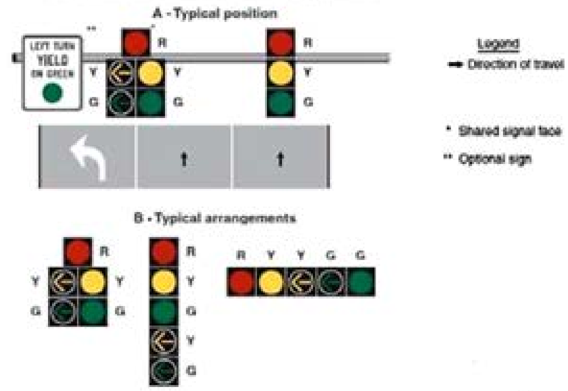
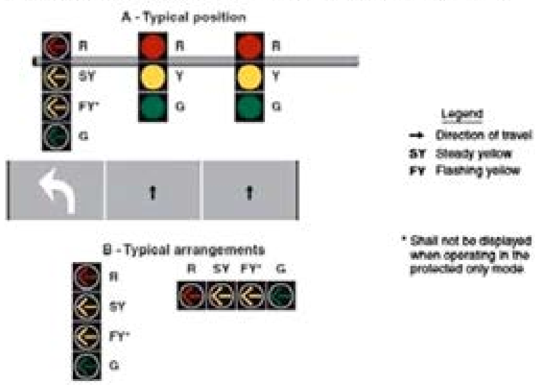


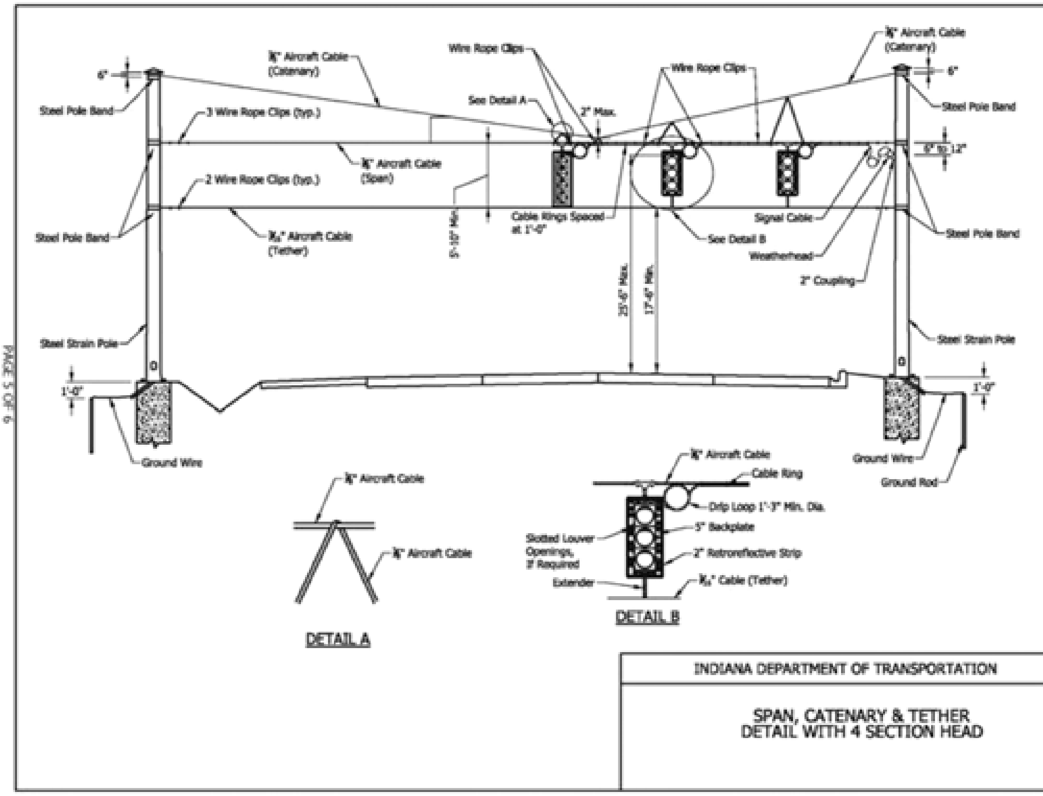
Figure 4D-12. Typical Position and Arrangements of Separate Signal Faces with Flashing Yellow Arrow for Protected/Permissive Mode and Protected Only Mode Left Turns



Source: *2011 Indiana MUTCD with Revision 1*

BLS/dhb/jeb

cc: Jim Sturdevant
Ed Cox
Greg Richards
Signal Systems Engineers
District Capital Program Management Directors
Alfredo Hanza
Jason Jones
Melody Coleman
Linda McGrannahan-Roberson
Ed King



" Aircraft Cable (Catenary)
Wire Rope Clips
See Detail A
2" Max.
Wire Rope Clips
" Aircraft Cable (Catenary)
6"
Steel Pole Band
3 Wire Rope Clips (typ.)
" Aircraft Cable (Span)
2 Wire Rope Clips (typ.)
6" to 12"
Steel Pole Band
" Aircraft Cable (Tether)
5'-10" Min.
Cable Rings Spaced at 1'-0"
Signal Cable
See Detail B
Weatherhead
2" Coupling
25'-6" Max.
17'-6" Min.
Steel Strain Pole
1'-0"
Ground Wire
Ground Rod
PAGE 5 OF 6
APPENDIX A
" Aircraft Cable
" Aircraft Cable
DETAIL A
" Aircraft Cable
Cable Ring
Drip Loop 1'-3" Min. Dia.
5" Backplate
Slotted Louver Openings, If Required
2" Retroreflective Strip
Extender
" Cable (Tether)
DETAIL B
INDIANA DEPARTMENT OF TRANSPORTATION
SPAN, CATENARY & TETHER DETAIL WITH 4 SECTION HEAD

APPENDIX B

For Multi-Lane and Expressways

For 2-Lane Conventional Roads

PAGE 6 OF 6

APPENDIX D: INDOT DESIGN MEMORANDUM

INDIANA DEPARTMENT OF TRANSPORTATION

Driving Indiana's Economic Growth

Design Memorandum No. xx-__
Technical Advisory

November 13, 2013

TO: **All Design, Operations, and District Personnel, and Consultants**

FROM: ____________________
David Boruff
Manager, Office of Traffic Administration
Traffic Engineering Division

SUBJECT: **Four-Section Signal Heads with Flashing Yellow Arrows Indications for Left Turn Movements**

REVISE: ***Indiana Design Manual Sections* 77-4.05 & 77-5.01(01)**

EFFECTIVE: **Lettings on or after March 1, 2014**

The five-section signal heads INDOT has been using display a green ball indication for the permissive phase of the left-turn movement. A new four-section head that displays a flashing yellow arrow for this permissive movement should be specified in lieu of the five-section head for lettings on or after March 1, 2014.

Based on research findings from NCHRP Report 493, *Evaluation of Traffic Signal Displays for Protected/Permissive Left-Turn Control*, four-section heads with flashing yellow arrow indications should be specified for protected/permissive left turn movements instead of five-section heads.

The research concluded that flashing yellow arrows in this application accomplish the following:

- provide more consistent response from drivers as to the correct action,
- increase safety by eliminating the 'yellow trap'. Yellow trap can occur when the permissive left turn movement of one approach ends before the through movement of the opposite approach. Under this phasing the permissive left turn phase cycles out to a yellow circular 'clear the intersection' indication while the opposite through approach

still has a green circular indication. This can lead to drivers making left turns in conflict with opposing traffic that is not stopping or even slowing.

- Increase intersection efficiency while maintaining safety by allowing protected/permissive left turn movements during lower demand times but restricting to protected only during higher demand.

A four-section head with flashing yellow arrow (FYA) should be identified in the plans as such and should be paid for under pay item 805-78225 Traffic Signal Head, 4 Section, 12 in., red arrow, amber arrow, amber flashing arrow, green arrow.

The sign fabrication detail to be included with each contract that contains an FYA signal head is an attachment to this memo.

Until such time as a recurring plan detail is adopted, a unique plan detail should be included for projects specifying four-section FYA mounted on cable span supports. The attached detail shows the necessary spacing between span and tether cables and also the hardware to be used for mounting the heads for the through and right turn movements.

Revisions to the referenced *Indiana Design Manual* Sections provide guidance on incorporating FYA into a project and are an attachment to this memo.

Attachments
DHB//

77-4.05 Traffic Signal Displays

The traffic-signal head consists of the signal head, signal face, optical unit, visors, backplates, etc. The criteria set forth in *IMUTCD* Part 4, the INDOT *Standard Specifications*, and ITE's *Equipment and Material Standards of the Institute of Transportation Engineers* should be followed in determining appropriate signal display arrangements and equipment. The following provides additional guidance for the selection of the signal display equipment.

1. Signal-Head Housing. The signal head housing is made from polycarbonate plastic. For new traffic signal installations on the State Highway system, the signal-head housing should have a black color. For traffic signal modernization projects on the state highway system, the existing yellow signal heads may be reused if approved by the District Traffic Engineer

2. Signal Faces *and Flashing Yellow Arrow Indications*. Section 77-5.01 provides the face arrangement for use on a State highway. The signal lenses should be placed in a vertical line rather than horizontally except where an overhead obstruction can limit visibility. Where protected left turns are followed by permissive left turns, the ~~five-section~~ *four-section* signal head *with a flashing yellow arrow indication* should be used. *IMUTCD* Part 4 provides additional information on the arrangement of signal heads.

   Considerations when specifying a four-section flashing yellow arrow (FYA)] indication include:

   a. Lateral Position Signal heads that include FYA for PPLT will be offset 3 feet right from the extension of left side of the left turn lane.

   b. Number of Sections and Alignment. The signal head display should be a four-section face that is aligned vertically. Vertically aligned heads should be "top justified", that is the RED or top indication should be at the same elevation and towards the upper span cable.

   Where signal head height limitations exist so that it not feasible to use a vertical four section signal head, consideration may be given to mounting the head horizontally.

   c. Wiring. A 7C-14 signal cable is needed for each four-section head to the disconnect hanger and a 9C-14 cable should be specified from the disconnect hanger to the controller.

   d. Supplemental Sign. To supplement traffic signal control, a "LEFT TURN YIELD ON FLASHING YELLOW ARROW" sign should be provided adjacent to the left-turn signal face when a FYA is used.

e. Modernizations and Additional Heads for Through Movements. When converting a PPLT to a four-section FYA head, additional heads for the through movement may be needed to satisfy IMUTCD requirements for the number of through heads:

i. one for each through lane for approaches with multiple through lanes.

ii. two heads for approaches with a single through lane.

77-5.01(01) Signal Displays

The *MUTCD* requires at least two signal indications for each through approach to an intersection or other signalized location. A single indication is permitted for control of an exclusive turn lane, provided that this single indication is in addition to the minimum two for through movements. For multiple left turn lanes, one indication per lane shall be provided.

Supplemental signal indications may be used if the two signal indications are marginally visible or detectable. One signal head per approach lane has been shown to provide a benefit in reducing crashes. Situations where supplemental indications can improve visibility include the following:

1. approach in excess of two through lanes;
2. location where there may be driver uncertainty;
3. where there is a high percentage of trucks which can obscure the signal indications; or
4. where the approach alignment affects the continuous visibility of normally-positioned signal indications.

The following figures illustrate the placement for signal heads.

Figure 77-5A, offsetting intersection
Figure 77-5B, urban street with parking on the near side, no left-turn lane
Figure 77-5C, urban street with parking on the far side and a near-side left-turn lane
Figure 77-5D, left-turn lanes with permissible left turns, but no separate left-turn phase
Figure 77-5E, left-turn lanes with protected left-turn phase
Figure 77-5F, left-turn lane with both protected-phase and permissible left turns~~, and 5-section head. This figure also illustrates the preferred 5-section head display~~
Figure 77-5G, multiple-lanes approach with left-turn lanes and protected left-turn phase
Figure 77-5H, multiple-lanes approach with both left- and right-turn lanes and protected phases
Figure 77-5 I, multiple-lanes approach z-span with supplemental far-side heads
Figure 77-5J, rural one-lane approach with truck obstruction
Figure 77-5K, rural one-lane approach with obstructed sight distance, near-side signal indication, advance warning sign, and flasher.

About the Joint Transportation Research Program (JTRP)

On March 11, 1937, the Indiana Legislature passed an act which authorized the Indiana State Highway Commission to cooperate with and assist Purdue University in developing the best methods of improving and maintaining the highways of the state and the respective counties thereof. That collaborative effort was called the Joint Highway Research Project (JHRP). In 1997 the collaborative venture was renamed as the Joint Transportation Research Program (JTRP) to reflect the state and national efforts to integrate the management and operation of various transportation modes.

The first studies of JHRP were concerned with Test Road No. 1—evaluation of the weathering characteristics of stabilized materials. After World War II, the JHRP program grew substantially and was regularly producing technical reports. Over 1,500 technical reports are now available, published as part of the JHRP and subsequently JTRP collaborative venture between Purdue University and what is now the Indiana Department of Transportation.

Free online access to all reports is provided through a unique collaboration between JTRP and Purdue Libraries. These are available at: http://docs.lib.purdue.edu/jtrp

Further information about JTRP and its current research program is available at: http://www.purdue.edu/jtrp

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