# Comparison of the Green Ball and Flashing Yellow Arrow Permitted Indications

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## INTRODUCTION

Safely and efficiently accommodating left-turning vehicles at the approximately 300,000 signalized intersections in the U.S. is a source of concern for traffic engineers, and this concern has resulted in the use of several unique traffic engineering practices (*1)*. Although dedicated turn lanes and protected left-turn phases have improved intersection operation and safety, they have done so at the expense of intersection efficiency, as the time provided for an exclusive left-turn phase must be taken away from other critical movements at the intersection. In an effort to minimize this problem, protected/permitted left-turn (PPLT) signal phasing was developed.

PPLT signal phasing provides an exclusive, or protected, phase for left-turns as well as a permitted phase during which left-turns can be made if gaps in opposing through traffic allow, all within the same signal cycle (*1*). The theory of PPLT signal phasing is to minimize the exclusive left-turn phase time requirements while increasing the opportunity for left-turn maneuvers. Use of PPLT phasing can lead to increased left-turn capacity and reduced delay, improving the operational efficiency of the intersection.

Although the potential benefits associated with PPLT have been identified, they can only be achieved when PPLT information is correctly presented to the driver. PPLT information is presented to the driver through the illumination of circular- and arrow-shaped indications within a traffic signal display. The meaning of all signal indications is transmitted through a combination of color, shape, orientation, and position of the signal display. Additional information may be provided to the driver in the form of supplemental signage.

## PROBLEM STATEMENT

Although the Federal Highway Administration (FHWA) recommends a five-section signal display for left-turn control, the Manual on Uniform Traffic Control Devices (MUTCD) does not require the use of a separate signal display for PPLT control (*2)*. Many states have adopted either the five-section cluster (doghouse), horizontal, or vertical display, located overhead between the through and turning lanes, which provides a green arrow for the protected phase and a circular green (green ball) for the permitted phase.

Despite the potential increase in left-turn capacity achieved with PPLT control, problems with PPLT signal phasing, primarily related to the green ball permitted indication, have been identified but not resolved (*1*). Many traffic engineers believe that the MUTCD green ball permitted indication is adequate and properly presents the intended message to the driver. Other traffic engineers believe that the green ball permitted indication is not well understood and therefore inadequate. The latter belief is based on the argument that left-turn drivers may

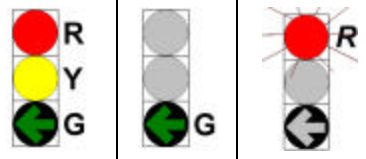
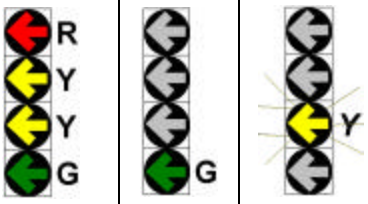
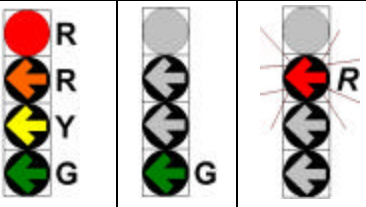
interpret the green ball permitted indication as a protected indication, creating a potential safety problem.

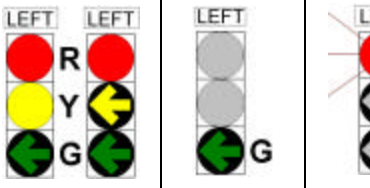
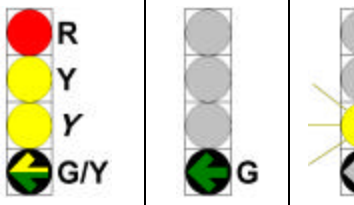
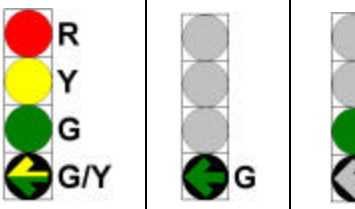
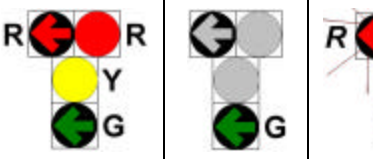
To overcome this potential problem, traffic engineers have developed at least four variations of PPLT permitted indications. These variations replace the green ball permitted indication with a flashing red ball, flashing yellow ball, flashing red arrow, or flashing yellow arrow indication. Additionally, variations in signal display arrangement and placement are applied. This variability has led to a myriad of PPLT signal displays and permitted indications throughout the United States that may confuse drivers and lead to inefficient and unsafe operations.

Ongoing research has identified at least seven unique combinations of PPLT signal displays and permitted indications in the United States (*1*). Figure 1 presents several of the unique displays. Displays vary in arrangement, number of signal sections, and in permitted indications from the three-section vertical display with flashing red ball permitted indication in the Detroit, MI area, to the four-section vertical display with a flashing yellow ball permitted indication used in Seattle, WA, to the four-section cluster which uses a flashing red arrow permitted indication in Dover, DE (*1*). These unique combinations are in addition to the various arrangements of five-section displays that use the circular green ball for the permitted indication. Additional variations of PPLT control exist in signal phasing, signal placement, and the use of supplemental signs.

The National Committee on Uniform Traffic Control Devices is concerned that the variety of PPLT controls may be confusing to motorists, and has recommended a comprehensive, national research study to validate the operational advantages and safety aspects of the various left-turn controls. Specifically, there is need for research to address driver confusion issues related to the permitted indication. In addressing these problems, it will be necessary to consider the safety implications of increased signal efficiency and the difficulty in uniformity among states.

This paper discusses the results of a driver comprehension evaluation of the permitted indication of PPLT displays completed using full-scale dynamic driving simulators at University of Massachusetts – Amherst (UMass) and the Texas Transportation Institute (TTI). The objective of this research task was to evaluate the safety and effectiveness of selected PPLT signal displays and phasing for PPLT control.

| Area Used | Lens Color And Arrangement | Left-Turn Indication[a] | |
|---|---|---|---|
| | | Protected Mode | Permitted Mode |
| Maryland |  | | |
| Washington State |  | | |
| Reno, NV |  | | |
| Cupertino, CA |  | | |

| Area Used | Lens Color And Arrangement | Left-Turn Indication[a] | |
|---|---|---|---|
| | | Protected Mode | Permitted Mode |
| Michigan |  | | |
| Seattle, WA |  | | |
| Typical Bi-modal Signal Head |  | | |
| Delaware |  | | |

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

[a] The indication illuminated for the given mode is identified by the color letter

**Figure 1 Variations of PPLT Displays.**

## BACKGROUND

With the usage of PPLT displays to convey intended messages to the drivers at signalized intersections, driver comprehension must be maximized to obtain the potential benefits of PPLT display, including both safety and efficiency. The limited guidance of the MUTCD has led to a variety of PPLT displays, and the display that has become the most used, the green ball permitted indication, is perhaps confusing to drivers. Many transportation professionals have argued that the variety of PPLT displays as well as the green ball permitted indication has the potential to increase the likelihood of a crash. Dependent variables that should be measured to determine the operational efficiency of a PPLT display include driver comprehension of the display, particularly the permitted indication, as well as the signal arrangement.

The work completed in Phase I of National Cooperative Highway Research Program (NCHRP) Project 3-54 encompassed both a comprehensive agency survey and static driver survey of several PPLT displays including the permitted green ball and several flashing indications. Phase I results indicated that the flashing indications had high levels of comprehension and should be further evaluated (*1*).

In Phase I, a comprehensive study of PPLT signal displays was completed. The research surveyed a total of 2,465 drivers, from eight locations within the United States. Of the 30 PPLT displays evaluated during Phase I, the 3-section vertical display with a flashing red ball permitted indication had the highest level of driver comprehension. More significantly, Phase I showed that the green ball permitted indication had a lower driver comprehension level in most signal display arrangements, attributed to the dual meaning of the green ball indication which grants right-of-way movements to through drivers and requires left-turn drivers to yield *(1)*.

Expanding upon the research efforts of NCHRP 3-54, Smith combined five-section displays (horizontal, vertical, and cluster) with yellow and red flashing permitted indications and evaluated driver comprehension through the use of a driving simulator. This study was built on the premise that flashing permitted indications were promising, and five section signal displays were recommended, yet flashing permitted indications in five-section PPLT displays were not previously evaluated in combination.

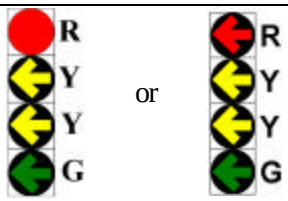
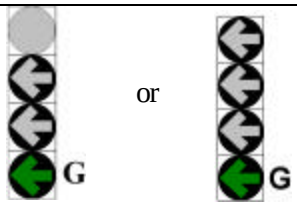
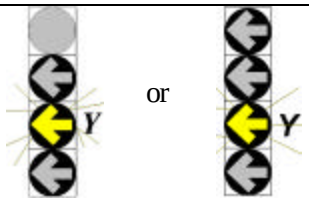
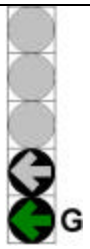
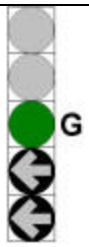
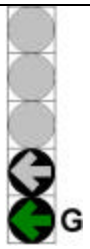
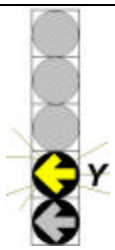
Using both a driving simulator and a static evaluation instrument (laptop computer), Smith tested driver comprehension of five section displays for five different permitted indications (*3)*. Testing the green ball permitted indication, flashing yellow ball and arrow permitted indications, and the flashing red ball and arrow permitted indications, Smith found the flashing yellow ball and arrow permitted indications yielded the highest percent of correct response rates. The green ball indication had levels of understanding similar to the flashing yellow ball and flashing yellow arrow, but significantly higher than the flashing red ball and flashing red arrow indications. With the static driver survey, Smith concluded that the flashing yellow indications again performed the best; however the green ball was the least comprehended. Left-turn drivers often assumed the green ball indication provided right-of-way. Furthermore, Smith's research indicated that the driving simulator could be utilized as an effective research tool in the evaluation of PPLT signal displays (*3)*.

## SIGNAL DISPLAYS

The PPLT signal displays selected for this research have evolved from previous research projects focused on the evaluation of PPLT signals, including Phase I of NCHRP 3-54. The NCHRP 3-54(2) project panel identified a set of 12 different PPLT signal displays for evaluation. The selected displays differ in permitted indication, arrangement, location, and through movement indication. Each of the 12 displays include only the green ball and/or flashing yellow arrow permitted indications. The green ball permitted indication represents the current state-of-the-practice and the flashing yellow arrow permitted indication is representative of the most promising alternative based on NCHRP 3-54(2) research to date. Figure 2 provides a visual representation of the PPLT displays evaluated in the driving simulator.

## SCOPE

The scope of this report was limited to driver understanding of selected PPLT signal displays evaluated at UMass and TTI. The scope of this research is limited to driver understanding of PPLT signal displays including the display arrangement, either vertical or cluster, location of the PPLT signal in relation to the left-turn lane, either shared or exclusive, and the permitted indication. Horizontal signal display arrangements were not included in this evaluation. The research focuses on the permitted indication, which has been associated with low levels of driver comprehension. The flashing red permitted indications, red ball and red arrow, as well as the flashing yellow ball permitted indication were not evaluated in this research. Other potential parameters that may effect drivers' understanding of PPLT signal displays such as geometric design issues, signal phasing, and supplemental signage were considered but not included as a detailed component of the simulator evaluation.

| Scenario[a] | Lens Color and Arrangement | Left-Turn Indication[b] | |
|---|---|---|---|
| | | Protected Mode | Permitted Mode |
| 1,2 |  |  |  |
| 3, 4 |  |  |  |
| 5,6 |  |  |  |
| 7, 8 |  |  |  |
| 9, 10 |  |  |  |
| 11, 12 |  |  |  |

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

[a] 1, 3, 5, 7, 9, 11 – GB through indication; 2, 4, 6, 8, 10, 12 – RB through indication

[b] The indication illuminated for the given mode is identified by the color letter

**Figure 2 PPLT Displays Evaluated in Experiment.**

## RESEARCH PROCEDURES

### Driving Simulators

Fixed-base fully interactive dynamic driving simulators were used to complete the driving simulation experiment. The driving simulators at UMass and TTI are nearly identical. The vehicle base of the UMass driving simulator is a 1995 four-door Saturn Sedan. Drivers are capable of controlling the steering, braking, and accelerating similar to the actual driving process; the visual roadway adjusts accordingly to the driver's actions. Three separate images are projected to create the "visual world" on a large semi-circular projection screen creating a field-of-view which subtends approximately 150-degrees. The UMass simulator also features a Bose surround audio system, a 60 Hz refresh rate, and a resolution of 1024 x 768 dpi. The UMass driving simulator is housed in the Human Performance Lab, and is pictured in Figure 5.

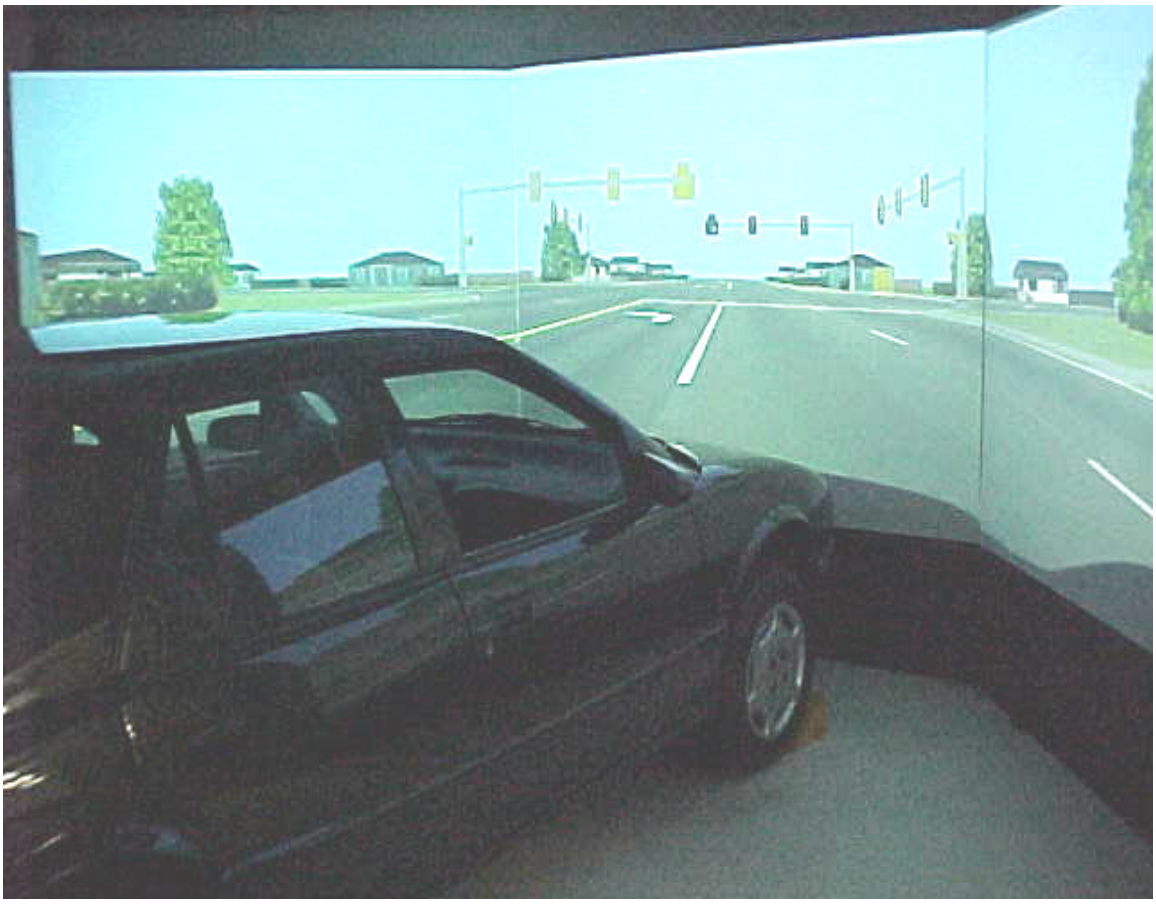


**Figure 3 UMass Driving Simulator**

## Development of Simulation

A "visual world" of intersections was developed for use within the driving simulators. One intersection approach was created for each of the 12 experimental PPLT signal displays, and the characteristics of each approach were identical, thus minimizing confounding variability. Drivers observed each of the 12 experimental displays once during the driving experiment. Additionally, several intersections that require the driver to turn right, proceed straight, or to turn left on a protected green arrow were included as part of the visual worlds. The additional movements were included to provide experimental variability and reduce the probability of drivers keying in on the nature of the evaluation.

The application of PPLT signal displays within the simulation was constant. All experimental signal displays within the simulation rested in a red ball or arrow indication as drivers approached the intersection. Signal displays changed to the *experimental* indications as the driver approached the intersection. Approximately 30 meters prior to the intersection stop bar, the PPLT signal display was "triggered" and changed from a red ball indication to the selected permitted or protected indication. Similarly, the through movement indication either stayed with the red ball indication or changed from a red ball to a green ball indication.

Each of the PPLT signal displays were evaluated with opposing traffic at the intersection. Opposing traffic required drivers to simultaneously evaluate the PPLT signal display, traffic movement, and opposing gaps to complete a safe permitted left-turn maneuver. This methodology was used to replicate the decision process required during actual operation of a motor vehicle within the roadway system.

The method of opposing traffic consistently applied gaps in the opposing traffic at intersections which drivers were required to make a permitted left-turn maneuver. The critical gap concept was used to select the gap sizes. The Highway Capacity Manual indicates that a critical gap value of five-and-a-half seconds for permitted left-turn maneuvers in the design of a four-lane roadway (*4*). Therefore, a gap size was selected below the critical gap that most drivers would not accept (three seconds) and a gap size was selected above the critical gap that most drivers would accept (seven seconds). Providing a consistent sequence of three and seven second gaps prevented gap size selection from being a significant variable in the PPLT analysis.

Six opposing vehicles were used to create the gap sequence. Two vehicles were always positioned at the stop bar in the two through lanes opposing the left-turn driver. The remaining four vehicles were positioned further upstream in a three and seven seconds series of seven-three-seven-seven; therefore, opposing vehicles crossed the intersection seven, 10, 17, and 24 seconds behind the two initially queued opposing vehicles.

## Experimental Process

Subjects were provided an overview of the experimental procedure and asked to sign an Informed Consent Form (per University policy) when they arrived to participate in the simulator experiment. Next, drivers were seated in the simulator and given procedural instructions.

Drivers were then asked to fasten their seatbelt, adjust mirrors and adjust the radio as they would in their own vehicle. The objective was to replicate their normal driving environment to the extent possible. Subjects were told that vehicle engine noise will be simulated (along with a small amount of vehicle vibration) and a circulating fan (not used at TTI) will simulate wind through the driver's side window. Subject drivers who preferred to have a driver side window closed were instructed to do so.

The driving portion of the study began with a practice module that provided the opportunity for drivers to traverse a virtual network and familiarize themselves with the operational characteristics of the simulator vehicle. Subjects were asked to *drive* the simulator vehicle as they would drive their own vehicle. Specifically, drivers were asked to not drive overly conservative nor drive extremely aggressive. At this stage of the study, the driver's well being was closely observed for any early signs of simulator sickness. Drivers who successfully completed the practice course, free of simulator sickness, were permitted to continue with the simulator study.

Following the practice course, drivers completed the experimental modules. As noted, drivers observed each of the 12 experimental PPLT signals displays once during the driving simulator experiment. To avoid the need for verbal communication during the experiment, drivers were navigated through the modules by guide signs provided on each intersection approach. In addition, drivers were asked to observe speed limit signs (30 mph), providing a higher level of realism and speed control during the experiment. The driving portion of the experiment, including the practice module, required between 15 and 20 minutes to complete.

**Data Collection**

Drivers' responses to each PPLT signal display scenario were manually recorded as correct or incorrect. Incorrect responses were further classified as being fail-safe or fail-critical. A fail-safe response was one in which the driver did not correctly respond to PPLT signal display, but did not infringe on the right-of-way of the opposing traffic. A fail-critical response was an incorrect response in which the driver incorrectly responded to PPLT signal display and impeded the right-of-way of opposing traffic, creating the potential for a crash. Table 1 summarizes the six possible responses in the simulator experiment.

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

**Table 1 Summary of Possible Driving Simulator Responses**

| Response Type | Category | Sub-category | Driver Action |
|---|---|---|---|
| 1 | Correct | — | Yield, go if an acceptable gap in opposing traffic allows |
| 2 | Fail-safe | By movement | Stop, instead of yield before proceeding through intersection |
| 3 | | | Stop and remain stopped (must be directed to proceed) |
| 4 | | By traffic | Stop, wait for all opposing traffic to pass before proceeding (driver did not accept several large gaps) |
| 5 | Fail-critical | Non-serious | No visible stop or yield before attempting to proceed through the intersection (avoided conflict by stopping short of opposing traffic) |
| 6 | | Serious | Go through intersection incorrectly taking the right-of-way from opposing traffic (created crash potential or crashed with opposing traffic) |

Driver comprehension of the 12 experimental signal displays was statistically analyzed using statistical procedures. Specifically, the distribution of correct and incorrect responses was used to complete an analysis of variance (ANOVA) to compare driver comprehension related to the 12 selected PPLT signal displays. For each analysis, the 95 percent confidence interval was calculated based on a binomial proportion as follows:

$$95 \text{ percent C.I.} = p \pm 1.96\sqrt{\frac{pq}{n}}$$

where: $p$ = sample proportion;
1.96 = value associated with 95 percent confidence level;
$q = 1 - p$; *and*,
$n$ = number of trials.

Confidence intervals will straddle the estimated parameter a specified percent of time in repeated sampling; therefore, in this analysis the 95 percent confidence interval is used, indicating that if the experiment were repeated 100 times than the mean would be within the calculated confidence interval 95 percent of the time. Minitab© release 13.31 was used to complete the analysis (*5*).

**RESULTS AND ANALYSES**

A total of 316 driver completed the driving simulator completed the experiment as described in this report (223 drivers at UMass and 93 drivers at TTI). The drivers evaluated a total 3,402 simulator approaches with one of the 12 experimental PPLT signal displays. Overall the percentage of correct responses was 70 percent. Correct responses ranged from 67 percent to 75 percent for the 12 PPLT signal displays. The percentage of correct responses is presented in Table 2 with a 95 percent confidence interval. Using the ANOVA model with a 95 percent confidence level and testing the null hypothesis that all 12 means were equal, a p-value of 0.542 is obtained indicating that the percent of correct responses for the 12 PPLT signal displays do not differ significantly; a p-value greater than 0.05 indicates that the null hypothesis can be accepted at the 95 percent level, and a p-value less than 0.05 indicates that the null hypothesis can be rejected at the 95 percent level.

An argument can be made that drivers making a Response Type 4, the *fail-safe by traffic* response, have not actually committed a driving error. With this response drivers chose to wait for all opposing vehicles to pass before completing the permitted left-turn maneuver despite the presence of several large gaps in the opposing traffic stream. In reality, all these drivers have done is operated the vehicle in the simulated environment in an overly cautious manner. Based on driver comments recorded throughout the experiment, two prevalent explanations as to why drivers elected to wait rather than proceed were noted:

- Drivers were in fact unfamiliar with the vehicle/surroundings and were therefore unsure if they could safely execute the left turn maneuver within the opposing gap provided;
- They were just cautious by nature.

Considering both *Response Type 1 (correct) and Response Type 4* (*fail-safe by traffic)* as a correct response the adjusted percent of correct response is presented in Table 3. After adjusting to account for both accepted correct responses the overall percentage of correct responses was 91 percent. There was no statistically significant difference in the percentage of correct responses to any of the PPLT signal displays ($p = 0.611$). For the remainder of the analysis both *Response Type 1* and *Response Type 4* were considered as correct responses.

Further evaluation of the data was completed considering permitted indication, arrangement, location, and through indication. These results are presented in Table 4. Left turn permitted indications were either green ball (GB), flashing yellow arrow (FYA), or a simultaneous combination (GB/FYA) of the two displays. Arrangements evaluated were five-section cluster, four-section vertical, and five-section vertical. Location was either shared or exclusive and described the location of the PPLT section head. The through indication was either GB or red ball (RB).

**Table 2 Percent of Correct Responses in Driving Simulator Experiments**

| Sc[a] | Arrangement[b] | Permitted Indication[c] | Thru Indication[d] | Obser.[e] | Percent Correct[f] | 95% C.I. |
|---|---|---|---|---|---|---|
| 1 | 5-Section Cluster | GB | GB | 279 | 71 | ±5 |
| 2 | 5-Section Cluster | GB | RB | 286 | 75 | ±5 |
| 3 | 5-Section Cluster | FYA | GB | 282 | 70 | ±5 |
| 4 | 5-Section Cluster | FYA | RB | 285 | 67 | ±5 |
| 5 | 5-Section Cluster | GB/FYA | GB | 286 | 69 | ±5 |
| 6 | 5-Section Cluster | GB/FYA | RB | 279 | 69 | ±5 |
| 7 | 4-Section Vertical | FYA | GB | 281 | 70 | ±5 |
| 8 | 4-Section Vertical | FYA | RB | 288 | 69 | ±5 |
| 9 | 5-Section Vertical | GB | GB | 290 | 74 | ±5 |
| 10 | 5-Section Vertical | GB | RB | 281 | 73 | ±5 |
| 11 | 5-Section Vertical | FYA | GB | 289 | 67 | ±5 |
| 12 | 5-Section Vertical | FYA | RB | 276 | 71 | ±5 |
| TOTALS | | | | 3402 | 70 | ±2 |

[a] Scenario identification number
[b] PPLT signal display arrangement
[c] Left-turn permitted indication GB = Green Ball; FYA = Flashing Yellow Arrow
[d] Indication for adjacent through lanes GB = Green Ball; RB = Red Ball
[e] Number of Observations
[f] Percent Correct which is Response Type 1

**Table 3 Adjusted Percent of Correct Responses in Driving Simulator Experiments.**

| Sc[a] | Arrangement[b] | Permitted Indication[c] | Thru Indication[d] | Obser.[e] | Percent Correct[f] | 95% C.I. |
|---|---|---|---|---|---|---|
| 1 | 5-Section Cluster | GB | GB | 279 | 90 | ±4 |
| 2 | 5-Section Cluster | GB | RB | 286 | 93 | ±3 |
| 3 | 5-Section Cluster | FYA | GB | 282 | 90 | ±3 |
| 4 | 5-Section Cluster | FYA | RB | 285 | 90 | ±4 |
| 5 | 5-Section Cluster | GB/FYA | GB | 286 | 94 | ±3 |
| 6 | 5-Section Cluster | GB/FYA | RB | 279 | 90 | ±4 |
| 7 | 4-Section Vertical | FYA | GB | 281 | 92 | ±3 |
| 8 | 4-Section Vertical | FYA | RB | 288 | 91 | ±3 |
| 9 | 5-Section Vertical | GB | GB | 290 | 92 | ±3 |
| 10 | 5-Section Vertical | GB | RB | 281 | 91 | ±3 |
| 11 | 5-Section Vertical | FYA | GB | 289 | 89 | ±4 |
| 12 | 5-Section Vertical | FYA | RB | 276 | 90 | ±4 |
| TOTALS | | | | 3402 | 91 | ±1 |

[a] Scenario identification number
[b] PPLT signal display arrangement
[c] Left-turn permitted indication GB = Green Ball; FYA = Flashing Yellow Arrow
[d] Indication for adjacent through lanes GB = Green Ball; RB = Red Ball
[e] Number of Observations
[f] Percent Correct which is Response Type 1 and 4

**Table 4 Percent Correct by PPLT Display Component**

| PPLT Display Component | Level | Obser. | Percent Correct[a] | 95% C.I. | Statistical p-value |
|---|---|---|---|---|---|
| Permitted Indication[b] | GB | 1136 | 91 | ±2 | 0.433 |
| | FYA | 1701 | 90 | ±1 | |
| | GB/FYA | 565 | 92 | ±2 | |
| Arrangement[c] | 5-Section Cluster | 1697 | 91 | ±1 | 0.747 |
| | 4-Section Vertical | 569 | 91 | ±2 | |
| | 5-Section Vertical | 1136 | 90 | ±2 | |
| Thru Indication[d] | GB | 1707 | 91 | ±1 | 0.716 |
| | RB | 1695 | 91 | ±1 | |
| Location[e] | Shared | 846 | 90 | ±2 | 0.206 |
| | Exclusive | 2556 | 91 | ±1 | |

[a] Response Types 1 and 4
[b] Left-turn permitted indication
[c] PPLT signal display arrangement
[d] Indication for adjacent through lanes
[e] Location of PPLT Signal Display

The percentage of correct responses by permitted indication ranged from 90 to 92 percent; however, permitted indication was not statistically significant (p = 0.433). Similarly, the arrangement of the PPLT signal display was not significant in determining driver comprehension (p= 0.747). The percentage of correct responses was 91 percent regardless of the through indication, indicating that this variable was not significant (p = 0.716). Isolating the location of the PPLT signal display was not statistically significant (p = 0.206).

An analysis of driver comprehension by the geographic region was also completed. Drivers participating in the simulator study at UMass responded correctly 90 percent of the time, and drivers at TTI responded correctly 93 percent of the time. This difference is statistically significant (p = 0.012). Because of this finding the data were cross-analyzed by the percent correct at each of the 12 PPLT signal displays and the location where drivers participated in the experiment (UMass or TTI). This analysis yielded no statistically significant differences in the percent correct for each of the 12 experimental PPLT signal displays at both experiment locations (p = 0.529)

## SUMMARY OF FINDINGS

The findings of the driving simulator experiment include:

- The gap sequence of the opposing traffic was selected such that drivers waiting to make a left-turn would have sufficient time and space to do such; however, in the simulator many drivers opted to wait for all of the opposing vehicles to pass before proceeding with the left-turn maneuver even when they understood the permitted indication. As a result this response (*fail-safe by traffic)* which was originally considered to be an incorrect response was considered as a correct response throughout the analysis.
- The percentage of correct responses to the 12 PPLT signal displays ranged from 89 to 94 percent, and there was no statistically significant difference.
- Within the data set there was no significant differences among the PPLT display components. Specifically, there was no significant difference in the percentage of correct responses by permitted indication (GB, FYA, or GB/FYA), PPLT display arrangement (five-section cluster, four-section vertical, or five-section vertical), PPLT display location (shared or exclusive), or adjacent through indication (GB or RB).
- Overall, the percentage of correct responses for drivers participating in the experiment at TTI were statistically higher than drivers at UMass; however when the data is cross-analyzed by the 12 experimental PPLT signal displays and geographic location there is no significant differences in the percent of correct responses.

A complete analysis of the permitted indications discussed in this paper is currently being conducted as a component of NCHRP 3-54(2), and in addition to the simulator data presented here, a statistical analysis of incorrect responses, demographic data, and results of a simultaneously conducted static evaluation are being conducted.

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