

Drivers' Understanding of Simultaneous Traffic Signal Indications in Protected Left-Turns

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ABSTRACT

A comprehensive assessment of protected/permitted left-turn (PPLT) signal displays was performed considering safety, operational performance, and driver understanding measures. The research presented in this paper focuses on a study of driver understanding of protected left-turn indications. All currently used PPLT display arrangements and protected indication combinations were evaluated including those with simultaneous green arrow and red or green ball indications and those with the green arrow indication only. Driver understanding was evaluated through a computer-based driver survey completed by 2,465 drivers. In total, 73,950 survey responses were received pertaining to the 200 different survey scenarios evaluated, 24,863 pertaining to protected left-turn indications.

Findings indicate that the simultaneous illumination of the green arrow and red ball indications in a five-section PPLT signal display during a protected left-turn phase significantly reduces driver understanding and increases driver error. This finding is especially true for drivers over the age of 65. Simultaneous illumination of the green arrow and green ball indications also resulted levels of driver understanding lower than the green arrow only indication; however, these differences were not statistically significant.

Keywords: Protected/Permitted Left-Turn, Safety, Signal Display, Signal indication, Driver Behavior

INTRODUCTION

Part 4 of the Millennium Edition of the Manual on Uniform Traffic Control Devices (MUTCD) pertains to highway traffic signals (1). In section 4D.06 of Part 4, information on signal indications for left turns is provided along with a detailed description of specific requirements when protected/permitted left turn (PPLT) signal phasing is used. Recall that protected/permissive left-turn signal phasing provides a protected phase where left-turns are made and a permissive phase where left turns can be made after yielding to oncoming traffic and pedestrians, all within the same signal cycle. The MUTCD states that although a separate signal face for left-turn control is not required, shared signal faces in place shall operate during the protected left-turn phase as follows (1):

“During the protected left-turn movement, the signal face shall simultaneously display a left-turn GREEN ARROW signal indication and a circular signal indication that is the same color as the signal indication for the adjacent through lane on the same approach as the protected left turn.”

If a separate signal face is provided, it shall be considered a left-turn signal face and shall meet the following requirements:

“During the protected left-turn movement, the left-turn signal face shall simultaneously display a left-turn GREEN ARROW signal indication and a CIRCULAR RED signal indication.”

Other combinations of simultaneously displayed signal indications are allowed with visible-limited PPLT displays. Examples of the required indications are shown in Figure 1.

The mandate to simultaneously display the green arrow indication with a green ball or red ball requires two indications to be illuminated in the signal face controlling left-turn operations. A signal face with two indications illuminated, providing two potentially conflicting messages to the driver, can be confusing and lead to safety problems. This paper presents the results of a research study that explores drivers' understanding of simultaneous signal indications in a single left-turn display.

PREVIOUS RESEARCH

Several research studies have evaluated drivers' understanding of simultaneously illuminated indications as required with PPLT signal phasing. Asante, Ardekani and Williams evaluated five-section PPLT displays in Texas (2). Field studies were conducted at more than 100 sites and surveys were mailed to 6,000 Texas residents, of which 902 were returned. The driver survey form contained a perspective view of an intersection approach drawn from the viewpoint of the first-to-arrive left-turn driver. The mast arm mounted signal displays were shown in the perspective view along with an enlarged view of each signal display. Two check-box questions were presented first asking “are you allowed to turn left?” followed by question asking if the driver believes they must wait for a gap in opposing traffic or were free to turn left because oncoming traffic must stop. Selected survey results are presented in Table 1.

In scenarios without supplemental signs, 83 percent of drivers correctly understood the green arrow indication when presented alone in a five-section display. When the green arrow indication was simultaneously illuminated with the green ball in a five-section horizontal

display, 81 percent of drivers correctly understood the message. The correct response rate increased to 92 percent when a supplemental sign was added which read “protected left on green arrow.” When the green arrow indication was simultaneously illuminated with a red ball indication in a five-section horizontal display, only 77 percent of drivers correctly understood the message.

Asante’s data indicated a higher level of understanding when only the green arrow indication was displayed. Asante concluded that simultaneously displaying the green arrow and red ball indication in the same signal display confused many drivers. He also indicated that omitting the red ball indication (illuminating the green arrow only) had a significant positive impact in conveying the meaning of the signal indication to the driver, recommending that a green arrow and red ball indication should not be shown simultaneously in an exclusive five-section PPLT signal display.

Bonneson completed a similar study in Nebraska designed to evaluate drivers’ understanding of different PPLT signal display arrangements (3). Bonneson’s study evaluated the MUTCD protected phase (simultaneous indications) and compared the results to a modified version of the signal display showing only the green arrow during the protected phase. Both signal displays were evaluated in the five-section horizontal, vertical, and cluster arrangements.

Drivers were presented a survey form similar to the Asante study with a perspective view of an intersection approach drawn from the viewpoint of the first-to-arrive left-turn driver. The mast arm mounted signal displays were also shown in the perspective view along with an enlarged view of each signal display. A multiple-choice question with four possible responses, representing the appropriate driver action (stop, yield, go, not sure), was presented. Approximately 115 responses were received for each display/indication combination. Selected results of the study are summarized in Table 2.

Bonneson found the modified form of the protected indication (green arrow indication only) associated with greater driver understanding than the required MUTCD indication. Considering all five-section display arrangements, approximately 10 percent more drivers understood the green arrow only indication. This difference was statistically significant. The greatest benefit was gained with the horizontal PPLT signal display as approximately 25 percent more drivers were able to understand the protected indication when the red ball was *not* illuminated with the green arrow. In contrast, only slight increases in driver understanding were found with the green arrow only indication in five-section cluster displays. Bonneson concluded that the statistically significant difference was of sufficient magnitude to be of practical significance.

Noyce conducted several studies of the operational and safety effects of PPLT signal phasing (4). Twenty-four different PPLT intersections were evaluated at eight locations throughout the U.S. Each intersection was considered *typical*, meaning a right angle intersection with four approaches of two or three through lanes each, relatively flat grade, 12-foot lane width, no on-street parking, and no additional variables that directly affect the left-turn movement being evaluated. Intersections were different in PPLT display arrangement and permitted indication.

The first study looked at traffic conflicts and events. The purpose of the conflict and event study was to isolate the left-turn movement and evaluate the safety effects of the PPLT signal display. Because the study was focused only on the left-turn maneuver, and more specifically, on drivers’ understanding or lack of understanding of the left-turn signal display, only conflicts and events directly related to left-turns were recorded and evaluated.

Noyce found little difference in traffic conflicts due to the variance in PPLT signal displays. In contrast, traffic events involving left-turn vehicles hesitating or not turning left during the protected left-turn green arrow accounted for 60 percent of all events observed. Most

of these traffic events were found at intersections containing a five-section horizontal signal display, located over the lane line, using a leading (dual) left-turn signal phasing sequence. With a dual leading left-turn sequence, the green arrow indication was illuminated after the conclusion of the side street phase, while the adjacent through movements continued to receive a red ball indication. Subsequently, the green arrow and red ball indications were simultaneously illuminated in the five-section horizontal PPLT signal display. With the green arrow indication located to the right of the red ball indication in the five-section horizontal display, drivers appeared to either miss the initial illumination of the green arrow indication, be confused by its meaning, or hesitate for several seconds to be assured that making the left-turn maneuver was safe. Noyce hypothesized that this result suggested an increase in signal display complexity and driver workload with the simultaneous illumination of the green arrow and red ball indications in the horizontal display, ultimately leading to increased driver error.

In a related study, Noyce quantified saturation flow rate, start-up lost time, response time, and follow-up headway associated with selected PPLT signal displays (5). Start-up lost time (seconds) was computed by summing the difference between the average headway of each of the first five vehicles in the left-turn queue and the saturation headway. Average response time (seconds) was computed by averaging the time between the onset of the protected green arrow and the passage of a reference point by the first left-turn vehicle in queue.

Using the same set of 24 intersections in eight U.S. locations as the conflict study, Noyce found that start-up lost time and response time were larger when the green arrow and red ball were shown simultaneously than when the green arrow was shown with a green ball or separately. Start-up lost times averaged approximately 2.1 seconds and response times approximately 3.0 seconds. These results suggest that left-turn vehicle delay is increased when the green arrow and a red ball are simultaneously displayed, likely due to driver confusion associated with the conflicting meaning of these indications.

ANALYSIS OF PPLT DISPLAYS

The authors recently conducted a research study that looked at all elements of PPLT signal displays, including the protected indication (4, 6). All PPLT signal display arrangements and indications were evaluated with the objective of determining and comparing drivers' understanding of U.S. PPLT signal displays.

To provide a data collection instrument that best simulated the drivers' view of a signalized intersection, a computer software program was developed. The intent was to present a more realistic view of PPLT signal displays and the driving environment as compared to the pencil and paper studies completed in previous research efforts. To fulfill this objective, photographs were taken at PPLT signalized intersections throughout the U.S. Each photograph was taken from approximately the drivers' eye location as if the driver was positioned as the first left-turn vehicle in queue, in an exclusive left-turn lane. Six of the photographs were selected for survey backgrounds and digitally scanned to create an electronic format for software implementation. Five of the six photos contained a vehicle in the opposing through lane(s). Because of the static nature of the photo, it was impossible to determine if the opposing vehicle was stationary or proceeding through the intersection. The remaining photo did not contain opposing vehicles. Scenarios using this photo were used for control providing a means of analyzing the effect that the presence of a vehicle in the opposing through lane had on survey responses.

Supplemental signs were not included in the analysis since the objective of this study was to evaluate each PPLT signal display without secondary influences. Animated signal displays

were created and replaced the existing signal displays in each photo. Each animated signal display contained backplates and was enlarged to 110 percent of the original signal display size to add clarity to the presentation without disturbing proportionality.

PPLT signal displays used in the research represented every combination of indications arrangements currently used throughout the U.S. Additionally, an all-red scenario was created for each PPLT signal display arrangement. Therefore, 35 scenarios per photo were required to create each of the combinations described which resulted in a total of 210 unique scenarios. Because horizontal PPLT signal displays are not typical in median post mounted situations, the five-section horizontal display scenarios were removed from the two photos that contained median post mounted PPLT signal displays. A total of 200 scenarios remained and all 200 were evaluated in the photographic driver survey. Figures 2 through 4 present sample survey scenarios depicting the six backgrounds. Note that each PPLT signal display was evaluated twice, once showing the adjacent through movement with a green ball indication and once with a red ball indication. Five-section PPLT signal displays in the protected phase illuminated both the green arrow and through movement (green ball or red ball) indications as required by the MUTCD. The four and three-section displays presented only the green arrow.

Through movement signal displays were also animated and placed in either a horizontal or vertical position, in most cases consistent with the through movement displays in the original photo. Both horizontal and vertical through movement displays were used to provide diversity and to provide the opportunity to analyze the significance of this variable.

Due to time constraints, it was not possible to present all 200 survey scenarios to each of the driver survey respondents. Therefore, a randomizer function was added to the survey software allowing a subset of scenarios to be randomly selected for each respondent. The randomizer function added two important features to the survey software. First, it eliminated the need to develop multiple versions of the survey software to accommodate all 200 scenarios. Second, it strengthened the analysis by randomizing the data collection process and minimized potential bias due to learning effects from the presentation order of the scenarios.

A response question was developed that could be applied to each of the survey scenarios. Using only one question reduced the demand on the survey respondents and allowed each scenario to be consistently evaluated. The survey question was as follows:

“If you want to turn left, and you see the traffic signals shown, you would...”

Four responses to the question were developed, one that applied to each protected, permitted, and all-red left-turn indication. The four responses were:

- GO
- YIELD - wait for gap
- STOP - then wait for gap
- STOP

A 1, 2, 3 or 4 was recorded to identify the response selected, respectively. If no response was selected, a 0 was recorded. Note that the *GO* response applied to all protected left-turn indication combinations presented. The *STOP* response pertained to the scenarios containing all-red indications. The *YIELD – wait for gap* and *STOP – then wait for gap* represented correct responses to the permitted left-turn indications evaluated as part of this research. The results of the permitted indication analysis can be found in another paper (7).

Another objective in the development of the photographic driver survey was to make it as self-explanatory and self-administrating as possible, requiring little input from the administrator as each driver completed the survey. To meet this objective, all survey instructions were voice recorded and included as a soundtrack within the survey software. Computer operations necessary to complete the survey were demonstrated through a choreographed example survey question that highlighted the appropriate sections of the computer screen when described.

Each driver who volunteered to take the survey was asked to sit in front of a computer and press the *Enter* button on the computer keyboard. The *Enter* key initiated a run command that started the survey software. Drivers were told that all necessary instructions were explained in the survey, but to ask questions if any developed. Only the 1, 2, 3, 4, and *Enter* keys on the computer were needed to complete the survey and were highlighted with a colored sticker. Drivers were instructed to respond to each scenario as quickly as possible. Computer clock time was used to record the time duration of each response. Response time was used as a surrogate measure of driving understanding with the assumption that drivers who were unclear of the correct response would take longer to respond.

Demographic data, including gender, age, driving experience, driving location and education, were obtained in the survey. Drivers were presented with a disclaimer statement assuring that all data were anonymous. All demographic, response and response time data were automatically downloaded to spreadsheet software.

Data Collection Sites

Eight geographic locations were selected as photographic driver survey study sites. Shopping Malls and state Department of Motor Vehicles (DMV) drivers license facilities were targeted in each location because of the large and diverse subset of drivers that were generally available, often without time constraints. Study sites included:

- Dallas, TX - Dallas East Drivers License Facility;
- Dover, DE – Dover Drivers License Facility;
- Oakland County, MI – Summit Place and Oakland Malls;
- College Station, TX – Post Oak Mall, Texas A&M University;
- Seattle, WA – Drivers License Facility;
- Portland, OR – Drivers License Facility;
- Cupertino, CA – Drivers License Facility; and
- Orlando, FL – Drivers License Facility.

Data Analysis

The analysis of the driver survey data was composed of two tasks. First, the mean and standard deviation of the data were quantified for each demographic category and PPLT signal display type and indication. The data sort and computation techniques available in the spreadsheet software were used to complete this task. Demographic factors affecting these variables were identified using analysis of variance (ANOVA) procedures. A correlation matrix was created to evaluate the relationship between variables.

ANOVA was conducted using the Categorical Data Modeling (CATMOD) procedure. The CATMOD procedure was selected because of its ability to analyze categorical data with unequal sample sizes and consider several demographic factors and their interaction in a single

model. Moreover, the maximum-likelihood analysis option available in this procedure was able to overcome problems with small or unequal sample sizes for one or more factor levels. The cross-classification frequency procedure (FREQ) was used to establish contingency tables for each variable. Each procedure computed a Chi-Square statistic to evaluate the variable association. All statistical tests were completed using a 95 percent level of confidence ($\alpha = 0.05$).

STUDY RESULTS

A total of 2,465 drivers completed the photographic driver survey. Each of the eight survey locations had more than 300 drivers complete the survey except Orlando where 289 drivers participated. Since 30 scenarios were presented to each survey respondent, a total of 73,950 PPLT signal display scenarios were evaluated.

Sixty-eight of the 200 scenarios contained protected left-turn indications resulting in 24,863 survey responses. Between 134 and 201 responses to the five-section horizontal display and between 220 and 320 responses to all other signal displays were received at each location. In total, 1,500 responses to the five-section horizontal display and 2,200 responses for all other signal displays were received. A summary of the percentage of correct responses to the protected indications for each study location is presented in Table 3. The results show that 87.2 percent of drivers participating in the survey correctly responded to the protected scenarios.

Data pertaining to driver demographics is presented in Figure 4. Fifty-eight percent of the participating drivers were male, 41 percent were female. Male and female correct response rates were nearly identical at 86.2 percent. Considering age, 27 percent of participating drivers were less than 24 years of age, 44 percent were between 25 and 44, 21 percent were between 45 and 65, and seven percent were over 65. The difference in correct response rate by age was significant ($p = 0.0001$) as drivers over the age of 65 had an 81.6 percent correct response rate as compared to 87.2 for drivers between the ages of 24 and 44.

Fifty-eight percent of participating drivers lived in an urban location, 30 percent in a suburban location, and 11 percent in a rural location. Of these drivers, five percent did not drive at all last year, 31 percent drove less than 10,000 miles, 44 percent drove between 10,000 and 20,000 miles, and 19 percent drove more than 20,000 miles. No difference in correct response rate by drivers' place of residence was found. Drivers' who indicated that they had not driven in the past year had a correct response rate over 12 percent below drivers who had driven more than 20,000 in the past year. This result was statistically significant ($p = 0.0001$).

A relatively uniform distribution of driver education was found as 29 percent of drivers had a high school or equivalent education, 35 percent had some college education, and 35 percent had a college degree. Correct response rate increased with driver education as drivers with a high school education had an 82.3 percent correct response rate and drivers with a college degree had an 88.4 percent correct response rate. This result was also statistically significant ($p = 0.0001$).

A comparison of correct response rates by PPLT signal display arrangement is presented in Figure 5. Percentage of correct responses ranged from 61.6 percent for the five-section horizontal display with a red ball through movement indication to 93.3 percent for both the four-section cluster display with a red ball through movement indication and three-section vertical display with a green ball through movement indication. The difference in correct responses between display types was statistically significant ($p = 0.0001$). The majority of incorrect responses to the five-section displays with the green arrow and red ball indication were *stop, then wait for gap*, demonstrating some confusion with the simultaneously illuminated indications.

An additional analysis was conducted considering only drivers' age. The results are presented in Table 5. Correct response rates are relatively consistent amongst age groups with the simultaneous green arrow and green ball indications and the green arrow only indication. Approximately 89 percent of correct responses were obtained with the simultaneous green arrow and green ball indication, ranging from approximately 86 percent for drivers over the age of 65 to 90 percent for drivers between the ages of 24 and 44. Nearly 92 percent of drivers responded correctly to the green arrow only indication ranging from 89 percent for drivers over the age of 65 to over 96 percent for drivers between 24 and 44 years of age.

The correct response rate with the simultaneous green arrow and red ball indications were much different. Average correct response rate was only 71 percent ranging from 62 percent for drivers over the age of 65 to nearly 75 percent for drivers less than 24 years of age.

Focusing on drivers over the age of 65, correct response rate for the simultaneous green arrow and red ball indications was 62 percent compared to the 86 percent for the green arrow and green ball combination and 89 percent for the green arrow indication only. This result was statistically significant ($p = 0.0001$). When considering only the five-section horizontal display with simultaneous green arrow and red ball indications, only 49 percent of the older drivers responded correctly.

Survey Scenario and Background Picture Comparisons

Two additional comparisons were made to evaluate the effect of the survey scenarios and background pictures. Correct response rates for each scenario ranged from 58.9 percent (five-section horizontal; red ball through movement; background picture 4) to 97.6 percent (three-section vertical; green ball through movement; background picture 5). This difference in correct response rates was statistically significant ($p = 0.0001$). When the five-section displays containing a red ball through movement indication were removed from the data set, the lowest correct response rate was 85 percent (five-section horizontal; green ball through movement indication; background picture 4). Although the differences among survey scenarios were still statistically significant ($p = 0.002$), the range of correct response rates was reduced by 70 percent.

When comparing background photos, the differences in correct responses were significant ($p = 0.001$) as the correct response rate for background picture 2 was 84.7 percent as compared with 89.7 percent for background picture 5. Recall that background picture 2 (Figure 1) was a narrow right-of-way with an opposing through and left-turn vehicle shown while background picture 5 was a wide cross-section with no opposing vehicles. This result suggests that the driving environment (i.e., opposing vehicles) was a significant variable in drivers' decision making. No significant differences in correct response rates were found when considering the median post mounted and mast arm mounted PPLT signal displays or position of the mast arm mounted signal displays.

Response Time

Average response time for all scenarios was four seconds with a five second standard deviation. There was noticeable variation in response times as average response time for scenarios containing a five-section signal display and the simultaneous green arrow and red ball indications was six seconds. Further, the five-section horizontal display with the simultaneous presentation of the green arrow and red ball had a seven second average response time compared

with five seconds for the five-section vertical and cluster displays. The added complexity associated with the five-section horizontal display was evident.

With all displays, the average response time increased with driver age. The three- and four-section displays, showing only the green arrow, had average driver response times range from three seconds for the under 24 age group to six seconds for the over 65 age group. A more dramatic difference was found with the five-section horizontal display showing a green arrow and red ball indication simultaneously as average response time was five seconds for the under 24 age group and 10 seconds for the over 65 age group. The over 65 age group average response time to the five-section horizontal display with simultaneous green arrow and red ball indications was nearly twice that of the green arrow only displays.

Average response time for drivers over the age of 65 was eight seconds for the five-section cluster and vertical displays showing a green arrow and red ball indication simultaneously. The average response time for the five-section signal displays showing a green arrow and green ball indication simultaneously were not different from the three- and four-section displays showing a green arrow indication only. There also was no difference in average response time between males and females.

CONCLUSIONS

The research results indicate that the simultaneous illumination of the green arrow and red ball indications in a five-section PPLT signal display during a protected left-turn phase significantly reduces driver understanding, adds response time to the driving decision, and increases driver error. This finding is especially true for drivers over the age of 65. The reason for this decrease in comprehension is likely due to the increased perceptual processing required and the associated increase in driver workload caused by the conflicting messages. This result was consistent with both Asante's and Bonneson's findings (2, 3). Simultaneous illumination of the green arrow and green ball indications also resulted in lower levels of driver understanding; however, these differences were not statistically significant.

When the green arrow and red ball indications are shown simultaneously in a five-section signal display, driver understanding is lowest with the horizontal arrangement. Locating the green arrow to the right of the red ball indication in a five-section horizontal display arrangement appears to provide additional confusion. When the green arrow and green ball indications are shown simultaneously, the five-section horizontal display also has the lowest level of driver understanding; however, nearly 89 percent of drivers correctly understood the meaning.

When only a green arrow indication is provided in a left-turn signal display, driver understanding of the protected indications was not affected by the through movement indication. Each of the four-section and three-section PPLT signal displays had levels of driver understanding that exceeded 91 percent with both the red and green ball through movement indications. This finding provides further evidence to suggest that the low level of driver understanding associated with five-section displays, when the green arrow and red ball are presented simultaneously, is due to conflicting messages. The added complexity of two more signal sections in a five-section display (as compared to a three-section display) did not appear to add confusion.

RECOMMENDATIONS

There is an increasing body of evidence to suggest that driver understanding decreases and driver error increases when conflicting simultaneous signal indications are presented in a single display.

The National Committee on Uniform Traffic Control Devices (NCUTCD) needs to consider the findings presented and reconsider the simultaneous indication requirements in future evaluation and revisions to the MUTCD. The requirement to simultaneously illuminate two indications in a signal display, especially a green arrow and red ball in a five-section horizontal display, should be eliminated.

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Figure 5 Drivers' Understanding of Protected Indications in PPLT Signal Displays.

Table 1 Drivers' Understanding of Protected Indications from the Asante Study

PPLT Signal Indication^a	Through Indication^a	Supp. Sign^b	PPLT Display	Number of Responses	Percent of Correct Responses
GA/RB	GB	No	5-Section Horz.	79	77
GA	GB	No	5-Section Horz.	93	87
GA/GB	GB	No	5-Section Horz.	80	81
GA	RB	No	5-Section Horz.	80	80
GA/GB	GB	1	5-Section Horz.	91	92
GA/RB	RB	2	5-Section Horz.	93	66
GA	GB	3	5-Section Horz.	93	82
GA	RB	4	5-Section Horz.	86	95
GA	RB	No	3-Section Vert.	96	91
GA	GB	No	3-Section Vert.	95	73
GA	RB	2	3-Section Vert.	103	83
GA	GB	5	3-Section Vert.	103	69
GA	RB	2	3-Section Vert.	92	86
GA	GB	2	3-Section Vert.	69	77
GB	GB	No	5-Section Horz.	79	75
GB	RB	No	5-Section Horz.	93	66
GB	RB	6	5-Section Horz.	92	86
GB	GB	7	5-Section Horz.	86	76
GB	GB	No	3-Section Vert.	84	50
GB	RB	No	3-Section Vert.	107	53

^a G=Green; Y=Yellow; R=Red; A=Arrow; B=Ball; F=Flashing

^b Supplemental Signs

- 1 - PROTECTED LEFT ON GREEN ARROW
- 2 - LEFT TURN SIGNAL
- 3 - PROTECTED LEFT TURN ON ARROW ONLY
- 4 - PROTECTED LEFT TURN ON GREEN ARROW ONLY
- 5 - NO TURN ON RED
- 6 - LEFT TURN YIELD ON GREEN BALL
- 7 - LEFT TURN PROTECTED ON ARROW ONLY

Table 2 Drivers' Understanding of the Protected Indication in Five-section Signal Displays – Bonneson Study

PPLT Display Arrangement	Three-Section Through Movement Arrangement	PPLT Signal Display Placement	Percent Correct Response	
			MUTCD ^a	Modified ^b
Cluster	Vertical	Center of Left-Turn Lane	80	92
Vertical	Vertical	Center of Left-Turn Lane	82	86
Cluster	Vertical	Lane Line	86	87
Horizontal	Horizontal	Lane Line	56	77
Cluster	Horizontal	Lane Line	83	83
Horizontal	Horizontal	Center of Left-Turn Lane	62	87

^a Simultaneous green arrow and red ball indication

^b Green arrow indication only

Table 3 Percentage of Correct Responses to the Protected Indications

Display	Indication ^a		Location ^b								Ave.
	Left	Thru	Dal	Dov	OC	CS	Sea	Por	Cup	Orl	
5-Section Horz.	GA GB	GB	89.9	89.5	83.6	91.1	94.8	90.4	87.7	84.3	89.0
5-Section Horz.	GA RB	RB	82.3	60.1	53.5	75.1	62.8	45.8	51.4	60.2	61.6
5-Section Vert.	GA GB	GB	89.8	90.3	88.0	96.2	93.1	89.2	87.2	86.4	90.2
5-Section Vert.	GA RB	RB	85.5	72.5	65.8	87.8	80.4	58.9	65.9	67.0	73.1
5-Section Cluster	GA GB	GB	93.8	92.6	86.9	94.9	91.8	92.7	87.2	92.6	91.5
5-Section Cluster	GA RB	RB	84.9	85.4	69.9	85.6	81.5	68.7	79.9	76.2	79.2
4-Section Vert.	GA	RB	94.7	90.2	88.2	96.8	96.5	94.6	91.7	90.3	92.9
4-Section Vert.	GA	GB	91.5	91.8	90.2	96.5	95.3	84.3	90.1	90.8	91.2
4-Section Cluster	GA	RB	93.8	92.3	88.6	96.2	96.7	94.6	93.7	91.0	93.3
4-Section Cluster	GA	GB	92.7	91.2	86.1	94.7	95.9	93.1	89.8	90.6	92.0
3-Section Vert.	GA	RB	92.6	92.2	86.5	97.5	96.4	95.2	91.1	88.1	92.4
3-Section Vert.	GA	GB	95.1	90.0	93.0	92.9	98.1	95.6	90.5	90.9	93.3
Location Average			90.9	87.0	82.2	92.5	91.0	84.6	84.7	84.7	87.2

^a G = Green; Y = Yellow; R = Red; A = Arrow; B = Ball; F = Flashing

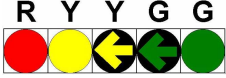
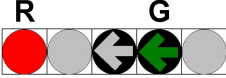


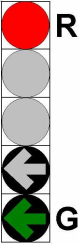
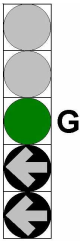
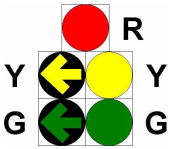
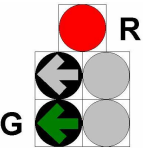
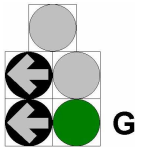
^b Dal = Dallas, TX; Dov = Dover, DE; OC = Oakland County, MI; CS = College Station, TX; Sea = Seattle, WA; Por = Portland, OR; Cup = Cupertino, CA; Orl = Orlando, FL

Table 4 Protected Indication Results by Demographics

Demographics		Total Responses	Percent Correct Responses
Sex	Male	14,405	86.1
	Female	10,285	86.2
Age	<24	6,829	86.2
	24-44	10,964	87.2
	45-65	5,211	85.3
	>65	1,654	81.6
Place of Residence	Urban	14,376	86.0
	Suburban	7,441	86.4
	Rural	2,914	86.3
Miles Driven in the Past Year	None	1,214	75.3
	<10,000	7,710	85.1
	10 – 20,000	11,066	87.4
	>20,000	4,757	87.7
Education	High School	7,048	82.3
	Some College	8,894	87.0
	College Degree	8,786	88.4

Table 5 Correct Responses by Protected Indications

Age	Protected Indication		
	Green Arrow/Green Ball	Green Arrow/Red Ball	Green Arrow
<24	87.8	74.6	90.7
24 – 44	89.9	72.4	96.1
45 – 65	89.4	68.3	91.1
>65	85.7	61.7	89.0

Arrangement	Lens Color and Arrangement	Left-Turn Indication ^a	
		Protected Mode	Permitted Mode
Horizontal			
Vertical			
Cluster			

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 assumes a red ball for the through movement.

Figure 1 PPLT Signal Display Arrangements and Indications



Figure 2 Driver Survey Scenarios – Background Picture 1 and 2.

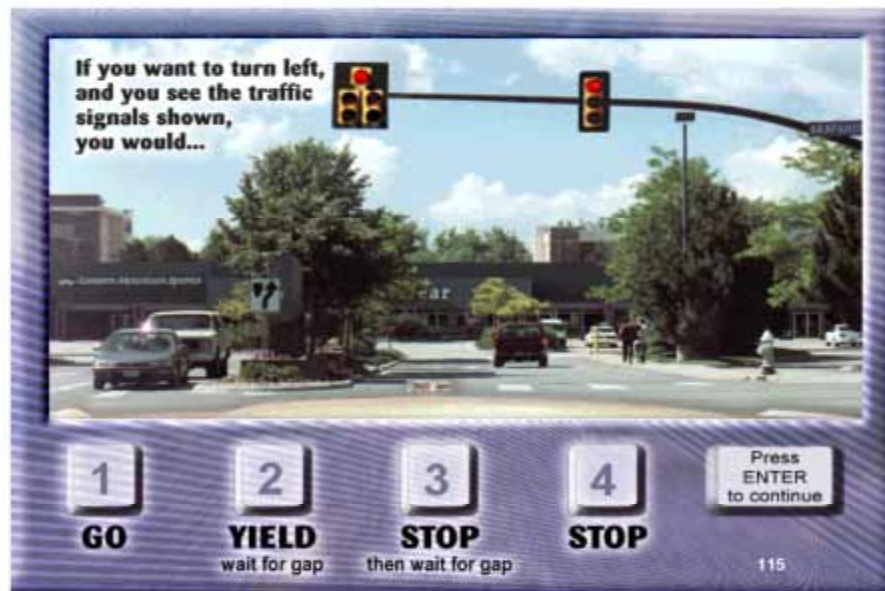


Figure 3 Driver Survey Scenarios – Background Picture 3 and 4.

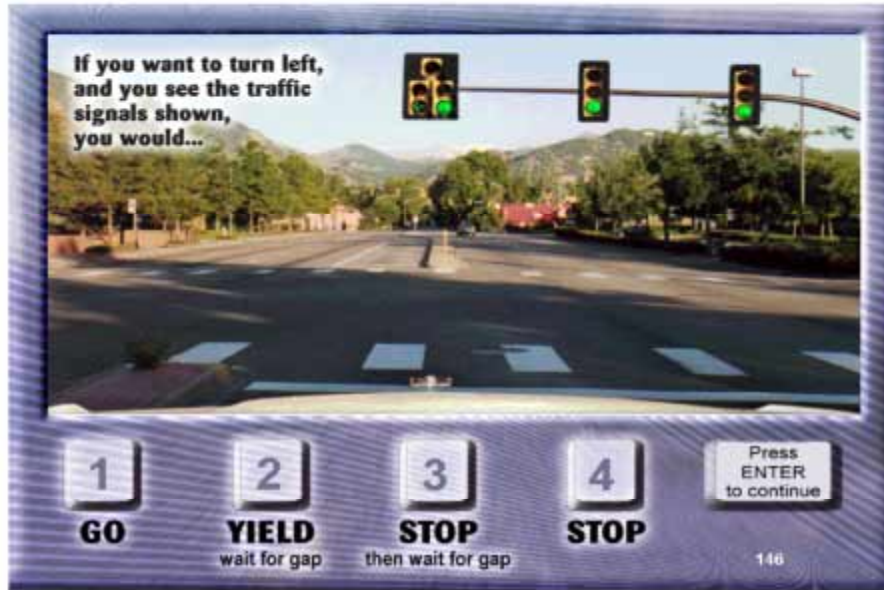


Figure 4 Driver Survey Scenarios – Background Picture 5 and 6.

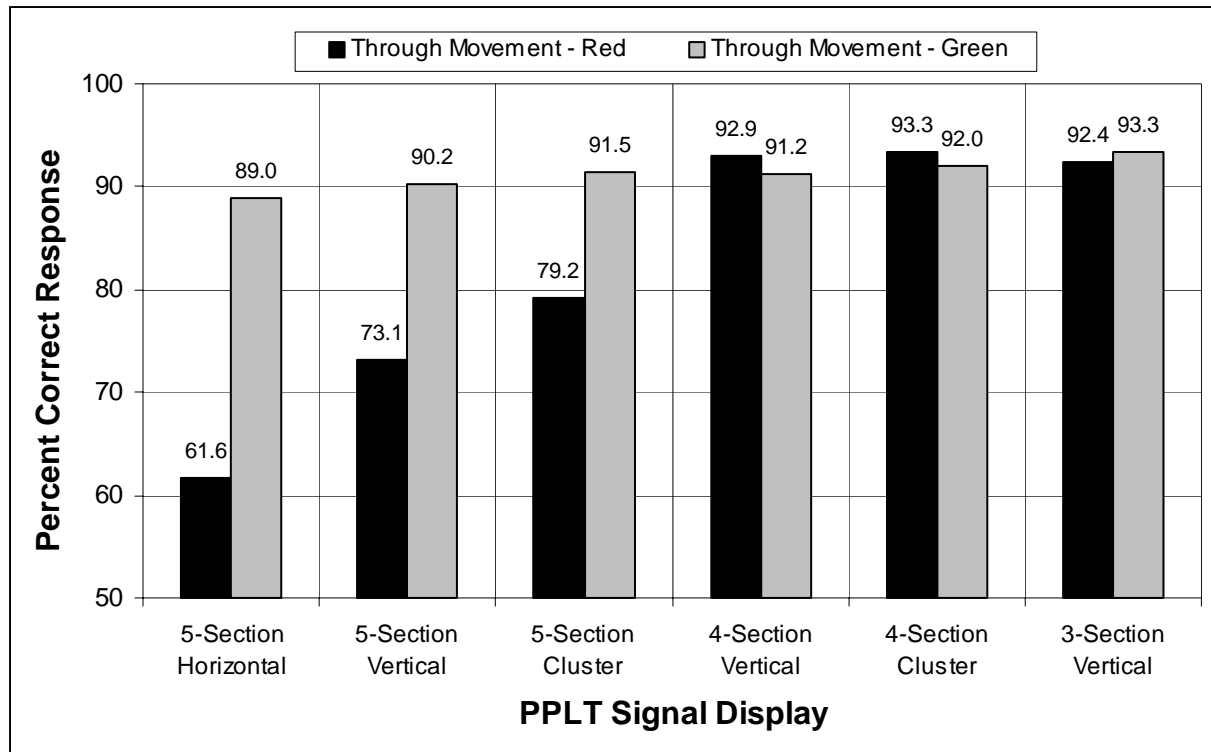


Figure 5 Drivers' Understanding of Protected Indications in PPLT Signal Displays.