

Simultaneous Signal Indications - Are We Confusing Drivers?

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INTRODUCTION

The Manual on Uniform Traffic Control Devices (MUTCD) provides several specific requirements when protected/permitted left-turn (PPLT) signal phasing is used (*1*). 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:

“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 in the PPLT display are allowed with visibility-limited displays. Examples of the required indications are shown in Figure 1.

The mandate to simultaneously display the green arrow indication with a red or green ball indication requires two indications to be simultaneously illuminated in the signal face controlling left-turn operations. A signal face with two lenses illuminated, providing two potentially conflicting messages to the driver, can be confusing and lead to safety problems.

This paper looks at the results of several research studies completed to explore driver's understanding and the effectiveness of simultaneous signal indications in a single left-turn display. Studies completed in Nebraska and Texas are presented along with the results of a national study completed by the author.

Area Used	Lens Color and Arrangement	Left Turn Indication ¹	
		Protected Mode	Permitted Mode
MUTCD 5-Section Horizontal			
MUTCD 5-Section Vertical			
MUTCD 5-Section Cluster			
	R = RED	Y = YELLOW	G = GREEN

1. The indication illuminated for the given mode is identified by the letter R (red) and G (green).

Figure 1 MUTCD Arrangements and Indications for PPLT Signal Displays

PREVIOUS RESEARCH

Several research studies have explored simultaneous indication illumination required with PPLT signal phasing.

Bonneson conducted a driver survey in Nebraska to evaluate driver's understanding of different PPLT signal display arrangements (2). Bonneson's study evaluated both the protected (green arrow with red ball indication) and permitted signal indication in the five-section horizontal, vertical, and cluster display arrangement. Approximately 115 responses were received for each display/indication combination. The results of the study are summarized in Table 1.

Table 1 Driver Understanding of Five-Section Signal Displays in the Bonneson Study

PPLT Display Arrangement	Through Movement Arrangement	PPLT Signal Display Placement	Percent Correct Response	
			Permitted	Protected
Cluster	Vertical	Center LT	66	80
Vertical	Vertical	Center LT	80	82
Cluster	Vertical	Lane Line	66	85
Horizontal	Horizontal	Lane Line	76	53
Cluster	Horizontal	Lane Line	63	84
Horizontal ¹	Horizontal	Center LT	80	88

1. Green arrow shown without corresponding through indication.

Bonneson found the green arrow indication in the five-section cluster display had the highest level of driver understanding; however, when the green arrow was shown without the corresponding through movement (ball) indication in the five-section horizontal display, a slightly higher level of driver understanding was found. Bonneson concluded that approximately 10 percent less drivers are able to understand the protected indication with simultaneous indications shown.

Asante and Williams evaluated the simultaneous use of the green arrow indication with the green or red ball indication in five-section PPLT displays in Texas (3). Field studies were conducted at more than 100 sites and surveys were mailed to 6,000 Texas residents, of which 902 were returned. The results are presented in Table 2. On average, 80 percent of Texas drivers correctly understood the green arrow protected indication when presented in a five-section horizontal display. Results were improved when the green arrow was presented independently for the protected indication.

Data indicated a higher level of understanding when only the green arrow indication was displayed as compared to when both the green ball and green arrow indications were displayed. When the green arrow indication alone was compared to the simultaneous red ball and green arrow indications, a larger significant difference in driver understanding was found. Asante concluded that a red ball and green arrow should not be shown simultaneously on a five-section PPLT display.

ANALYSIS OF PPLT DISPLAYS

The author recently conducted a research study that looked at all elements of PPLT signal displays, including the protected indications (4). To provide a data collection instrument that best simulated the drivers' view of a signalized intersection, a computer software program was developed. Photographs of actual signalized intersections were incorporated into the software as background scenes. Computer-based data collection methodologies provided a better presentation than traditional pencil and paper methods used in previous research studies.

Table 2 Driver Understanding Results from the Asante/Williams Study

PPLT Signal Indication¹	Through Indication¹	Supp. Sign²	Display	Number of Responses	Percent Incorrect
GA/RB	GB	No	5-Section Horz.	79	23
GA	GB	No	5-Section Horz.	93	13
GA/GB	GB	No	5-Section Horz.	80	19
GA	RB	No	5-Section Horz.	80	20
GA/GB	GB	a	5-Section Horz.	91	8
GA/RB	RB	b	5-Section Horz.	93	34
GA	GB	c	5-Section Horz.	93	18
GA	RB	d	5-Section Horz.	86	5
GA	RB	No	3-Section Vert.	96	9
GA	GB	No	3-Section Vert.	95	27
GA	RB	b	3-Section Vert.	103	17
GA	GB	e	3-Section Vert.	103	31
GA	RB	b	3-Section Vert.	92	14
GA	GB	b	3-Section Vert.	69	23
GB	GB	No	5-Section Horz.	79	25
GB	RB	No	5-Section Horz.	93	34
GB	RB	f	5-Section Horz.	92	14
GB	GB	g	5-Section Horz.	86	24
GB	GB	No	3-Section Vert.	84	50
GB	RB	No	3-Section Vert.	107	47

1. G=Green; Y=Yellow; R=Red; A=Arrow; B=Ball; F=Flashing.

- 2.
- a - PROTECTED LEFT ON GREEN ARROW.
 - b - LEFT TURN SIGNAL.
 - c - PROTECTED LEFT TURN ON ARROW ONLY.
 - d - PROTECTED LEFT TURN ON GREEN ARROW ONLY.
 - e - NO TURN ON RED.
 - f - LEFT TURN YIELD ON GREEN BALL.
 - g - LEFT TURN PROTECTED ON ARROW ONLY.

To obtain the desired realism, it was essential that all survey graphics depicted a signalized intersection from the perspective of a driver, looking through the windshield of his or her vehicle, while positioned in an exclusive left-turn lane. To fulfill this objective, photographs were taken at signalized intersections throughout the state of Texas and in California, Colorado, Florida, Maryland, Oregon, and Wisconsin. 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.

Photographs were digitally scanned to create an electronic format and copied into the software. 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 to replace the existing signal displays in each photo. Each animated signal display was enlarged to 110 percent of the original signal display size to add clarity to the presentation without disturbing proportionality. Backplates were included with each signal display.

PPLT signal displays used in the research represented every combination of protected left-turn indications, permitted left-turn indications, through movement indications, and PPLT signal display arrangements currently used throughout the U.S. Additionally, an all-red scenario was also 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 recommended 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 of them were evaluated in the photographic driver survey. Figure 2 presents a sample of a survey scenario.

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 photographic 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 effects 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...”



Figure 2 Photographic Driver Survey - Scenario Example

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

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

Note that the *yield - wait for gap* response applied to the green ball and flashing yellow permitted indications while the *stop - then wait for gap* applied to the flashing red permitted indications. The *go* response applied to all protected left-turn indication combinations presented. A 1, 2, 3, or 4 was recorded to identify the response selected. If no response was selected, a 0 was recorded.

One of the objectives 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 survey administrator as each driver completed the survey. To meet this objective, all survey instructions were voice recorded using Macromedia SoundEdit™ software and included as a sound track within the survey software. Along with the general survey instructions, the computer operations necessary to complete the survey were demonstrated through an example survey question. The voice instructions and survey example were choreographed, and appropriate sections of the computer screen highlighted when described. The computer clock time was used to record the time duration of each response. All data was automatically downloaded to an attached spreadsheet.

Data Collection Sites

The first step in the data collection procedure was to contact local officials in each of the eight geographic locations selected to assist in identifying sites to conduct the photographic driver surveys. Shopping Malls and state Department of Motor Vehicles (DMV) drivers license facilities were the targeted locations because of the large and diverse subset of drivers that were generally available. Additionally, mall shoppers and drivers waiting in line at the DMVs were often without time constraints. Table 3 presents the survey sites selected in each of the eight locations.

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. 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 each of these keys were highlighted with a colored sticker.

In the event that a respondent was concerned with the confidentiality of the demographic data requested in the survey, a disclaimer statement was prepared and available to all drivers. Essentially, the disclaimer stated that all responses were anonymous and they were not required to provide their name.

Table 3 Photographic Driver Survey Data Collection Sites

City	Days of Data Collection	Data Collection Site
Dallas	3	Dallas East - DPS Drivers License Facility
Dover	3	DMV Drivers License Facility
Pontiac (Detroit)	4	Summit Place Mall
		Oakland Mall
College Station	4	Post Oak Mall
		Memorial Student Center
		Texas A&M University Campus
Seattle	3	DMV Drivers License Facility
Portland	3	DMV Drivers License Facility (3 locations)
Cupertino	3	DMV Drivers License Facility
Orlando	3	DMV Drivers License Facility

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. Fifty-eight percent of the participating drivers were male, 41 percent were female. Twenty-seven 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. Fifty-eight percent of participating drivers lived in a city, 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. A relatively uniform distribution of driver education was found among the participants 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.

Sixty-eight of the 200 scenarios contained protected left-turn indications. 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 illuminated both the green arrow and through movement (green or red ball) indications as required by the MUTCD. The four and three-section displays presented only the green arrow. The correct response to each survey question was *go*.

A summary of the percentage of correct responses for each location is presented in Table 4. 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. Approximately 1,500 total responses to the five-section horizontal display and 2,200 responses for all other signal displays were received. In total, 87.2 percent of drivers participating in the survey correctly responded to the protected scenarios. When the scenarios containing a five-section signal display with a red ball through movement indication were removed from the data set, the overall correct response rate increased to 92.0 percent.

A comparison of correct response rates by PPLT signal display arrangement is presented in Figure 3. 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 red ball through movement indication were *stop, then wait for gap*, demonstrating the confusion associated with conflicting signal messages. Similar confusion was not found when the green arrow and green ball indications were shown simultaneously or when the green arrow indication was shown individually. Several related findings are identified in the following paragraphs.

Table 4 Percentage of Correct Responses to the Protected Indications

Display	Indication ¹		Location ²								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

1. G=Green; Y=Yellow; R=Red; A=Arrow; B=Ball; F=Flashing.
2. 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.

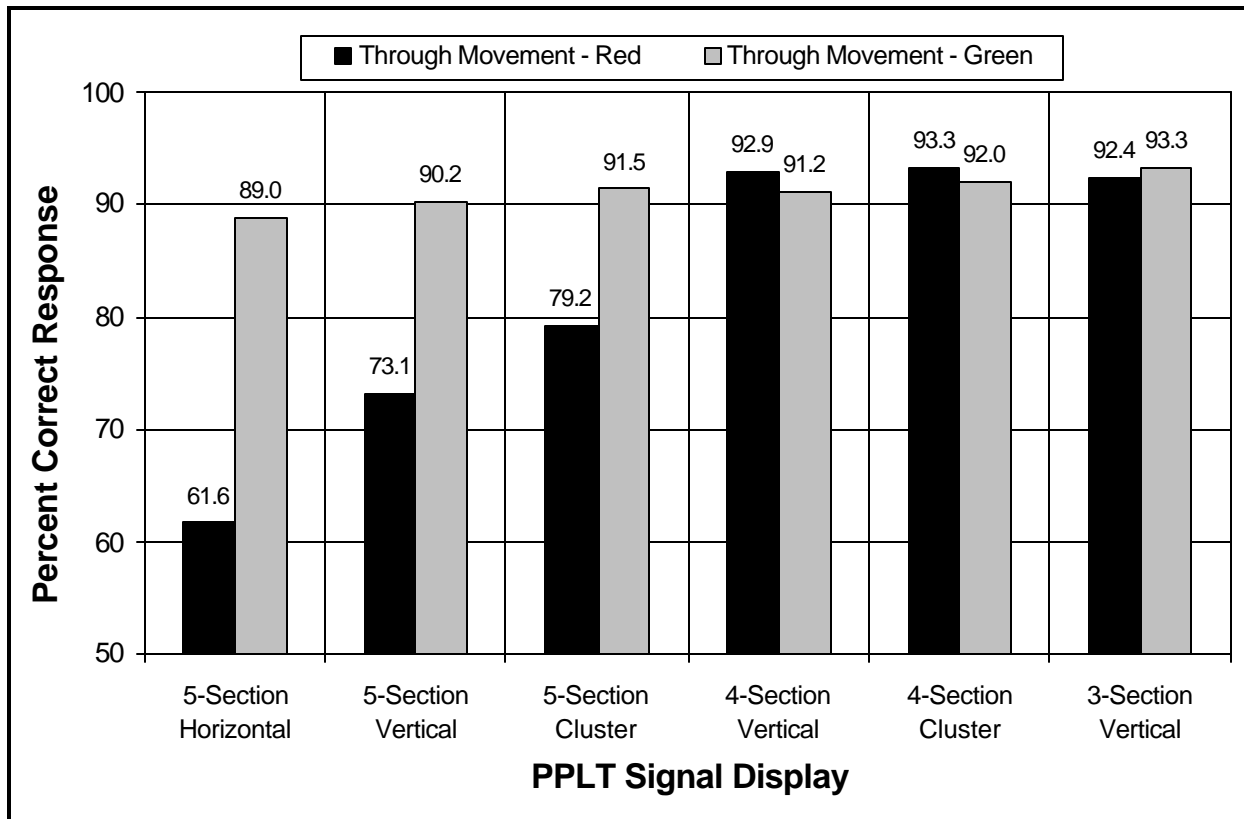


Figure 3 Driver Understanding of Protected Indications in PPLT Signal Displays

First, driver understanding is significantly reduced when a green arrow and red ball indication are presented simultaneously within a five-section PPLT signal display. Two simultaneous indications within a single signal display provides conflicting information that leads to increased driver error. None of the five-section signal displays showing the green arrow and red ball indications had a correct response rate that exceeded the desired 85 percent threshold. This result was consistent with both Asante's and Bonneson's findings (2, 3).

Second, 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, driver understanding exceeded the desired 85 percent threshold.

Third, 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 the five-section displays, when the green arrow and red ball are presented simultaneously, is due to conflicting right-of-way messages.

CONCLUSIONS

The results of the studies presented clearly show 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 reduced driver understanding and increased driver error. The reason for this decrease in comprehension is likely due to the increased perceptual processing required and the associated increase in driver workload. In addition, other research as shown that the simultaneous green arrow and red ball indications in a five-section horizontal display resulted in a significant number of traffic events (4). Driver understanding is increased when only the green arrow indication is illuminated during the protected left-turn phase. The National Committee on Uniform Traffic Control Devices (NCUTCD) should consider these results in future evaluation and revisions to the MUTCD.

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