Driver's Understanding of Protected/Permitted Left-Turn Signal Displays

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Paper Number: 01-2243 Sponsoring Committee: Traffic Control Devices
Prepared for the 80th Annual Meeting of the
Transportation Research Board, Washington, D.C.
January, 2001

Length of Paper:
4,493 words, 7 figures + 5 tables @ 250 words each
7,493 equivalent words

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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 permitted left-turn indications. All currently used PPLT display arrangements and permitted indication combinations were evaluated including those with flashing red and yellow permitted indications. 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.

The study results indicate that yellow or red flashing permitted indications may lead to higher levels of driver comprehension. Both the flashing red and yellow permitted indications had a significantly higher correct response rate than the green ball permitted indication. Drivers over the age of 65 found the flashing ball permitted indications easier to comprehend, and responded more quickly with less *fail critical* errors. Higher correct response rates with flashing permitted indications were also found in other important demographic areas including inexperienced drivers and drivers with limited education.

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

INTRODUCTION

Traffic engineers continue to look for ways to improve signal operations in an effort to move more vehicles through an intersection in a fixed amount of time. One of the signal phasing concepts that has proven effective is protected/permitted left-turn (PPLT) phasing. PPLT signal phasing provides an exclusive phase for left-turns and a permissive phase during which left-turns can be made if gaps in opposing through traffic allow, all within the same signal cycle (*1*). Consequently, PPLT signal phasing can improve operational efficiency by increasing left-turn capacity and reducing delay.

Guidance in the selection of traffic signal displays for use with PPLT signal phasing is provided in the *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*). Although the intent of the MUTCD is to provide a national *standard* for traffic control devices, a lack of specific mandates in the selection and use of traffic signal displays has led to a variety of applications. Most states have adopted a five-section PPLT signal display in either the horizontal, vertical, or cluster arrangement; however, few states require that only one of these display arrangements be uniformly applied. Regardless of which signal display arrangement is selected, the MUTCD is clear in stating that a green arrow indication shall be used for the protected left-turn phase and a circular green (green ball) indication for the permitted left-turn phase.

Problems with PPLT signal phasing, primarily related to the green ball permitted indication, have been identified but not resolved (*1*, *3*). Many traffic engineers argue that the MUTCD green ball permitted indication is adequate and properly presents the intended message to the driver. Other traffic engineers argue that the green ball permitted indication is not well understood and therefore inadequate. The latter argument is based on the belief that left-turn drivers may interpret the green ball permitted indication as a protected indication, creating a potential safety problem.

It has been suggested that drivers would better understand a permitted left-turn indication if it included a change in color, position, and mode of operation (i.e., flashing) (*3*). Consequently, traffic engineers have developed at least four variations of PPLT permitted indications. These variations replace the green ball permitted indication with either 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.

The primary objective of this research is to evaluate driver comprehension and safety associated with each of the different PPLT signal displays currently in use, leading to the recommendation of a uniform PPLT signal display(s). This paper presents a study of driver understanding, evaluating all existing PPLT signal display arrangements and permitted indications.

BACKGROUND

The green ball indication, as defined in the MUTCD, indicates that traffic may "proceed straight through or turn right or left except as such movement is modified by signs, markings or design" (*2*). This definition, consistent with the Uniform Vehicle Code (UVC), indicates that drivers facing a green ball indication have the right-of-way to proceed, intrinsic with the meaning of the green indication. The MUTCD definition continues with the following statement (*2*): "but, vehicular traffic, including vehicles turning right or left, shall yield the right-of-way to other vehicles, and to pedestrians lawfully within the intersection or an adjacent crosswalk, at the time such signal indication is exhibited." It is this caveat that allows the green ball indication to be used for permitted left-turn control.

The apparent inconsistency in the definition of the green ball indication may create problems for drivers. Staplin and Fisk found that the green ball permitted indication was one of the most problematic since it was to be interpreted by drivers as a cue for when not to precede when previously learned *automatic* response to green is an assumption of right-of-way (*4*). Similarly, a study by Knoblauch et al. found that nearly 20 percent of drivers over the age of 65 and 14 percent of drivers less than 65 said they could turn left without yielding when facing the green ball indication (*5*). Freedman et al. and Drakopoulos et al. reported similar problems with driver understanding of the green ball permitted indication in studies conducted in Philadelphia, Seattle, Dallas, and Lansing (*6, 7*).

Several research studies have tried to identify the combination of signal display indication and arrangement that results in a maximum level of driver understanding, with inconsistent results (*8, 9, 10, 11, 12*). The literature supports the concern of many traffic engineers—drivers may wrongly interpret the permitted green ball indication to mean that the left-turn movement has the right-of-way. It is this concern that has led to the development of several unique permitted left-turn indications.

Variations in Permitted Indication

Traffic engineers in California, Delaware, Maryland, Michigan, Nevada, and Washington have implemented either a flashing red or yellow permitted indication in an attempt to improve drivers' understanding of permitted left-turns. Michigan has approximately 40 installations of the flashing red ball permitted indication, mostly in urban areas with high-volume roadways. Requiring drivers to stop before completing a permitted left-turn is believed to increase left-turn safety. Studies have found that the Michigan three-section display with the flashing red ball permitted indication to be better understood by older drivers and performed equally to or better than four- and five-section PPLT displays using the permitted green ball indication (*6, 7*).

The flashing red arrow permitted indication is used at three locations in Cupertino, California, 13 locations in Maryland, and 40 locations in Delaware (*13*). Vehicles are permitted to turn left on a flashing red arrow indication after stopping and yielding to opposing traffic. Studies have shown that older drivers have trouble understanding what maneuvers are permitted or protected with the flashing red arrow indication (*5*). Freedman et al. evaluated the Delaware flashing red arrow permitted indication and found that *none* of the 180 respondents correctly understood the meaning of this indication (*6*).

The flashing yellow ball permitted indication has been used in the Seattle area and the flashing yellow arrow near Reno, Nevada. The objective of the flashing yellow ball indication in Washington state was to create an indication that was intuitively obvious in conveying the left-turn drivers' obligation to yield; i.e., the movement is not protected (*14*). A study of the flashing yellow ball permitted indication found that the difference in color from green to yellow provided additional

information and reduced the chance that a driver will not distinguish the change in right-of-way (*14*, *15*). Couples evaluated the flashing yellow ball permitted indication at 88 intersection approaches in Seattle and found an average left-turn crash rate lower than at intersection approaches using the green ball permitted indication (*14*). Couples results were significant during night conditions. Several studies have found a higher level of understanding in drivers of all age groups with the flashing yellow ball permitted indication and have recommended that the flashing yellow ball permitted indication be used to improve both driver understanding and safety (*5*, *8*, *15*).

One concern with the use of flashing permitted indications is the *arcade effect* when drivers can observe several intersections along an arterial simultaneously (*12*). Several agencies have implemented a lower wattage lamp (67 watts) to reduce the visual impact of the flashing indications (*14*). Nevertheless, Staplin suggested the use of flashing permitted indications as a method to ameliorate older driver problems in left turning situations (*16*). Similarly, Drakopoulos found that older drivers were less likely to misinterpret the meaning of the left-turn permitted indication when a flashing indication was used (*7*).

STUDY METHODOLOGY

Comprehension studies were performed to evaluate drivers' understanding of PPLT signal displays currently in use. College Station and Dallas, Texas; Portland, Oregon; Seattle, Washington; Oakland County, Michigan; Cupertino, California; Dover, Delaware; and Orlando, Florida were selected as data collection locations. Seattle, Oakland County, Cupertino, and Dover were selected because of the flashing permitted indications used in each location. Dallas was selected because Dallas Phasing was used with PPLT signal displays. Dallas Phasing is unique since permitted left-turns are allowed simultaneous with opposing protected left-turns and through movements. Therefore, permitted left-turn indications are simultaneously presented with red ball through movement indications on the same approach (left-turn indications are louvered). Orlando was selected because of the large population of older and out-of-state drivers. College Station and Portland provided a site near members of the research team. Figure 1 shows the PPLT signal displays currently implemented in each location and therefore illustrates the PPLT displays studied. Each of these signal displays were evaluated in the protected, permitted, and prohibited modes.

Department of Motor Vehicles (DMV) drivers license facilities were used for data collection at all locations except in Oakland County and College Station where Shopping Malls were included. To provide a data collection instrument that best simulated the driver's view of a signalized intersection, a computer software program was developed. Photographs of actual signalized intersections were incorporated into the software as background scenes. Six photographs were selected, two each with standard intersections and overhead PPLT signal displays, standard intersections and median post mounted PPLT signal displays, and narrow intersections (no median) with overhead PPLT signal displays. A standard intersection was considered one that had a single exclusive left-turn lane, two to three through lanes in each direction, a side street perpendicular to the main street, a roadway median, and no unique geometric features.

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, without a vehicle in the opposing through lane(s), was used as a control photo providing a means of analyzing the effect of a vehicle in the opposing through lane had on drivers' response. Supplemental signs were not included in the analysis since the objective was to evaluate each PPLT signal display without secondary influences.

Each of the PPLT signal display arrangements presented in Figure 1 were digitally recreated and placed within each photograph. Animation software was overlaid to create the flashing permitted indications. A total of 200 different photographic scenarios were developed to evaluate currently used combinations of the protected, permitted, and prohibited left-turn indications, through movement indications, and PPLT signal display arrangements. Of the 200 scenarios presented, 104 were evaluations of permitted indications. Presenting all 200 survey scenarios to each of the survey respondents was not timely or practical; therefore, a randomizer function was added to the survey software that presented a random subset of 30 scenarios to each driver.

Each scenario included the following question: *"If you want to turn left, and you see the traffic signals shown, you would..."*. Four responses to the question were included; GO (green arrow), YIELD - wait for gap (green ball/flashing yellow arrow or ball), STOP - then wait for gap (flashing red arrow or ball), and STOP (red ball). Driver understanding was determined by correct responses

to the PPLT signal display scenarios. Correct responses for each permitted indication (shown in parenthesis next to the response) were the MUTCD or implementing agency's intended permitted indication meaning. Figure 2 presents examples of survey scenarios.

Five demographic questions were asked at the beginning of the survey to determine the sex, age, living location (urban/rural), number of miles driven, and level of education for each driver. All driver instructions were voice recorded on a sound track within the survey software. Computer clock time was recorded for each response, measured from the time the scenario was presented on the computer screen to the time a response was selected. These data were used as a surrogate measure of driver understanding as response time and driver understanding were believed to be correlated (lower response times are associated with higher driver understanding). Response time was not intended to replicate perception/reaction time in the actual driving environment. A file writing procedure was included that automatically wrote each response along with the location, date, demographic, and response time data to a text file.

Recall that this paper presents only the results of the 104 scenarios evaluating permitted left-turn indications. The analysis of the permitted left-turn 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. Demographic factors affecting these variables were identified using analysis of variance (ANOVA) procedures (*17*). A correlation matrix was created to evaluate the relationship between variables.

The ANOVA was conducted using the Categorical Data Modeling (CATMOD) procedure in the SAS System (*17*). The null hypothesis was selected to be no difference in driver understanding of permitted indications based on the independent variable(s) evaluated. In addition, 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 ($\alpha = 0.05$).

DRIVER SURVEY RESULTS

All Indications and Arrangements

A total of 2,465 drivers completed the survey during a 3-month period in the summer of 1998. Total number of drivers at each site ranged from 289 in Orlando to 326 in Seattle. Since 30 scenarios were presented to each survey respondent, a total of 73,950 PPLT responses were obtained of which 73,188 were considered for analysis. A summary of demographic characteristics is provided in Table 1. Note that Table 1 includes the combined results of all left-turn indications (protected, permitted, prohibited) and arrangements evaluated.

The correct response rate for all 73,188 PPLT signal display scenarios evaluated was 72 percent. This correct response rate was higher than the 70 percent found in previous studies but consistent with the hypothesis that the number of correct responses may be lower due to the lack of dynamic visual information in the study environment (*10*, *11*).

Permitted Indications

Nearly 57 percent of drivers participating in the survey correctly responded to the permitted indication scenarios. A summary of the percentage of correct and total number of responses for each location is presented in Table 2.

Demographic Comparisons

Male drivers had a 57.7 percent correct response rate compared with 54.8 percent for female drivers. This difference was statistically significant ($p = 0.001$). Age was also found to be statistically significant ($p = 0.001$) as drivers over the age of 65 had a 51.4 correct response rate compared with a 57.5 percent correct response rate for the 24 to 44 age group. Table 3 presents the average correct response rate by age. Note that drivers over the age of 65 had extremely low correct response rates with the permitted green ball indications. With all flashing permitted indications, little difference in correct response rates among age groups was found.

Drivers' place of residence was found not to be significant (p = 0.064). City drivers had a 55.9 percent correct response rate compared with 57.7 percent for suburban drivers and 56.5 percent for rural drivers. The number of miles driven in the past year was statistically significant (p = 0.001) as drivers who did not drive at all in the past year had a 44.8 percent response rate while drivers who drove between 10,000 and 20,000 miles had a 59.7 percent correct response rate. The green ball permitted indication provided the most difficulty for drivers who did not drive in the past year (33 percent correct response rate).

The level of drivers' education was found to be significant (p = 0.001) as drivers with high school educations had a correct response rate of 51.0 percent while drivers with a college degree had a 59.8 percent correct response rate. Drivers with only a high school education had the highest correct response rate with the flashing yellow ball permitted indication (60 percent) and the lowest with the green ball permitted indication (42 percent). Demographic findings were consistent with previous results (*8*, *11*).

Location Comparisons

Average correct response rates by location ranged from 46.7 percent in Dallas to 66.3 percent in Seattle. This difference in average correct response rate was statistically significant (p = 0.001). The most significant difference between locations involved the flashing red permitted indications. This result is more clearly presented in Figure 3. Average correct response rates to the flashing red ball and arrow indications ranged from 39.9 percent in Dallas to 77.2 percent in Dover. In contrast, average correct response rate for the green ball and flashing yellow permitted indications ranged more narrowly from 50.0 percent in Orlando to 66.4 percent in Seattle. In all locations, the flashing ball indications had a higher correct response rate than the flashing arrow indications. Dallas was the only location where the green ball permitted indication had a higher correct response rate than all flashing indications, consistent with previous studies (*8*).

Table 4 presents a comparison of the first and second highest correct response rate to the permitted indication commonly used in each location. Only Dallas and Oakland County were found to have the highest correct response rate associated with their commonly used permitted indication.

Portland, College Station, and Orlando, all locations that use the green ball permitted indication, had higher correct response rates with both the flashing red ball and flashing yellow ball indications. The flashing yellow ball permitted indication had the highest or second highest level of driver understanding in seven of the eight locations; the flashing red ball indication in six of the eight locations. The green ball permitted indication had the lowest level of driver understanding in Dover, Oakland County, Seattle, Portland, and Cupertino.

Figure 4 shows the correct response rates by permitted indication averaged over all locations. The differences in driver understanding between permitted indications was significant ($p = 0.001$).

Arrangement Comparisons

A comparison of correct response rates for each PPLT signal display arrangement is presented in Figure 5. Percentage of correct responses ranged from 44.5 percent for the five-section horizontal display with a red ball through indication to 64.5 percent for the three-section vertical display with a green ball through indication. This difference in correct response rates was statistically significant ($p = 0.001$). It is probable that most of this variation is explained by the corresponding permitted indications used within each display. Recall that the five-section horizontal display uses only the green ball permitted indication while the three-section vertical display uses only the flashing red ball permitted indication.

With all PPLT signal displays, driver understanding of the permitted indication was higher when the through movement indication was green. This finding contradicts the hypothesis that concurrent left-turn and through movement indications of the same color adds display complexity and driver error (*8*). It appears that left-turn driving decisions are affected by through movement indications as drivers may use this information to predict the actions of opposing traffic.

Response Time

Table 5 presents the average response time to each of the permitted indications. Average response time for all drivers was six seconds for each of the permitted indications except the

flashing red ball with a through movement green ball (five seconds). A trend in average response time by age was very evident as drivers over the age of 65 took between two and four seconds of additional time to respond when compared with drivers under the age of 24. All response time standard deviations were six seconds except the flashing red ball indication which had a four second standard deviation.

Failure Evaluation

Since the overall percentage of correct responses to the permitted indications was below expectations, an evaluation of the incorrect responses was undertaken. Two error modes were evaluated. Errors resulting from some drivers failure to accept a right-of-way situation were considered *fail safe* since the results would most likely have little safety impact. In contrast, errors resulting from drivers who turned left without the right-of-way were considered *fail critical* since this maneuver had the potential to lead to a significant safety problem. Since fail critical errors had the most significant safety impact, the analysis was focused accordingly.

Figure 6 provides a summary, by PPLT signal display type, of the fail critical results. Average fail critical responses across all locations was 24.9 percent for the green ball indication, 16.6 percent for the flashing yellow arrow indication, 3.5 percent for the flashing yellow ball indication, 1.8 percent for the flashing red arrow indication, and 0.5 percent for the flashing red ball indication. Clearly, these results were significant ($p = 0.0001$). In Portland, none of the 525 survey scenarios containing a flashing red ball permitted indication were incorrectly responded to in a fail critical mode. Recall that Portland uses a green ball permitted indication. Further, only 25 of the 4,386 total responses to scenarios containing the flashing red ball permitted indication were fail critical errors.

When considering the corresponding through movement indication, there was no difference in fail critical results for the yellow or red permitted indications with either through movement indication. A significant difference was found with the green ball permitted indication as the percentage of fail critical events were approximately 10 percent greater when the through movement had a red ball indication (versus the green ball indication). This result may indicate that drivers

assume the opposing through movement has a red ball indication when the adjacent through movement has a red ball indication.

When the green ball permitted indication was displayed with green ball through movement indication, the five-section horizontal display had the highest fail critical rate with nearly 25 percent fail critical responses. Forty percent of drivers over the age of 65 failed critical compared to less than 20 percent for all other age groups. Further, when the green ball permitted indication was displayed with a red ball through movement indication, the five-section horizontal display had the highest fail critical rate at 34.3 percent. Fifty-one percent of drivers over the age of 65 failed critical compared with 29.9 percent for the 45 to 65 age group and 26.5 percent for the 24 to 44 age group. In contrast, when a flashing red ball permitted indication was displayed with a red ball through movement indication, less than one percent of males and 0.1 percent of females failed critical. None of the drivers over the age of 65 failed critical.

Background Picture

A comparison of the differences in correct responses considering the background photos used in the survey found that the difference was significant ($p = 0.001$) as the average correct response rate for the background pictures containing an opposing vehicle was 58.0 percent as compared with 53.4 percent for background picture 5 (no opposing vehicle). The most common error with the green ball permitted indication was the selection of the *go* response. In reality, turning left without yielding is the maneuver most drivers complete although incorrect by definition. Therefore, there was evidence to suggest that the lack of opposing vehicles in background picture 5 effected drivers' decisions.

An additional query was conducted under two assumptions. First, since most drivers would proceed without yielding when facing a green ball permitted indication with no opposing traffic, the *go* response with scenarios containing no opposing vehicles was considered correct. Second, some drivers may not distinguish the difference between the *yield - wait for gap* and *stop - then wait for gap* responses since both can be correlated to opposing traffic. Thus, each response was considered correct. The results of this query is presented in Figure 7.

As expected the correct response rate under these assumptions resulted in significant increases in correct response rates for the green ball and flashing yellow permitted indications, compared to the data presented in Figure 4. The assumptions did not affect the flashing red results. Given these conditions, the flashing yellow ball and yellow arrow had significantly higher correct response rates than the green ball permitted indication.

CONCLUSIONS

The research findings support the potential benefits of flashing permitted left-turn indications, especially for older drivers. All flashing red and yellow ball/arrow permitted indications had a significantly higher correct response rate than the green ball permitted indication, under each correct response assumption. Drivers over the age of 65 found the flashing permitted indications easier to comprehend and responded more quickly with less *fail critical* errors. Higher correct response rates were also found in other important demographic areas including inexperienced drivers and drivers with limited education. The flashing permitted indications led to higher levels of driver understanding in locations where the green ball permitted indication is always used.

Better comprehension of the flashing yellow and red indications may be related to the unique presentation and differentiation from the through signal indications. In addition, the well-learned meaning of yellow and red indications (yield or stop, respectively, before proceeding with the intended maneuver) is precisely the desired action for permitted left-turns.

RECOMMENDATIONS

The fact that drivers have a higher comprehension level and lower fail critical rate with the flashing permitted indications supports the belief of traffic engineers who have implemented these types of PPLT signal displays. In recognition of this finding, the use of flashing permitted left-turn indications warrants further consideration. Several operational questions remain pertaining to signal phase sequence flexibility and transition to change interval indications. Additional investigation of flashing permitted indications and operational issues should be conducted through simulation and field studies.

ACKNOWLEDGMENTS

Data described in this paper was obtained as part of the NCHRP 3-54 project entitled *An Evaluation of Traffic Signal Displays for the Protected/Permitted Left Turn Control*. This project is being conducted by Kittelson & Associates, Inc. in association with the University of Massachusetts and the Texas Transportation Institute.

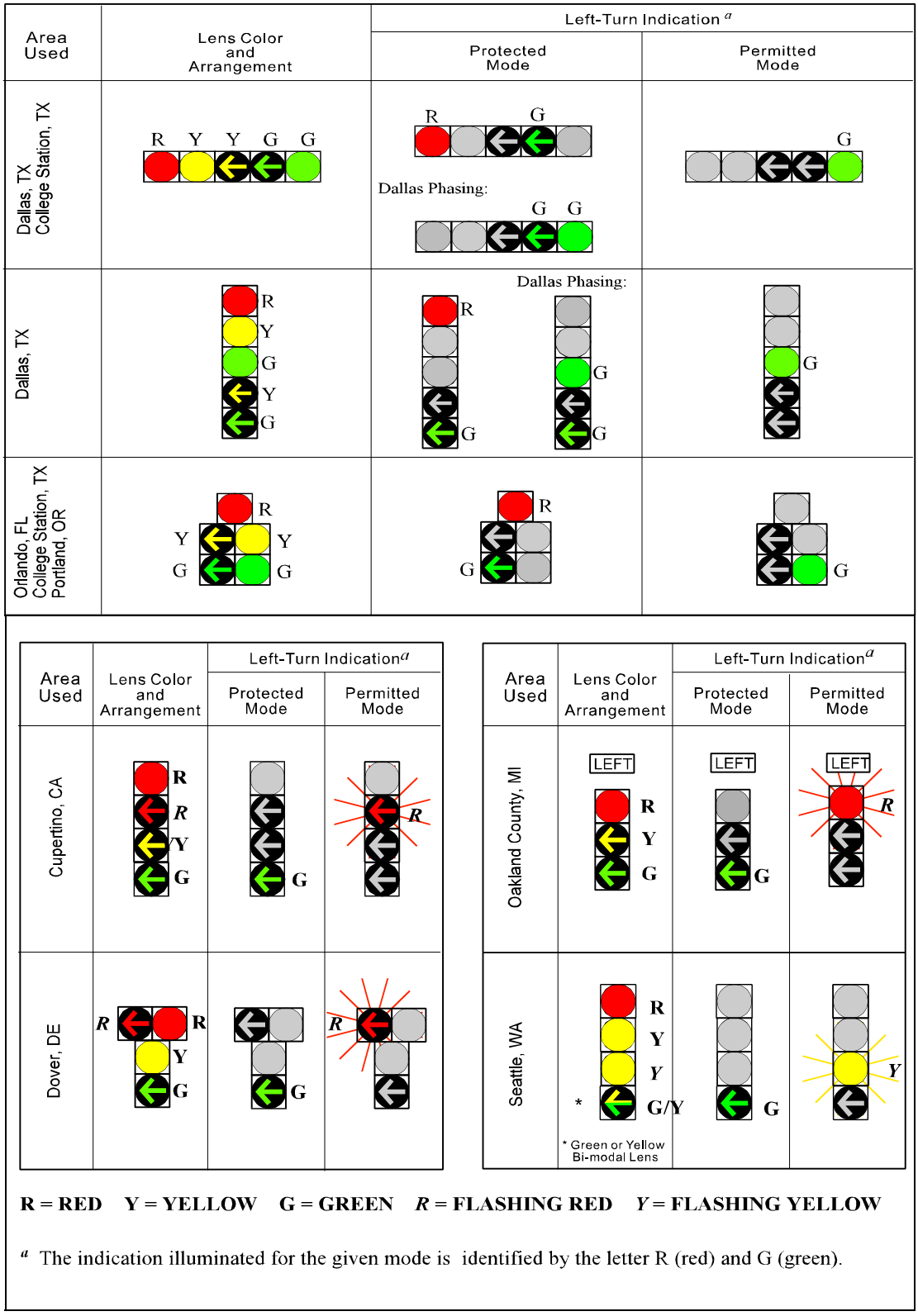
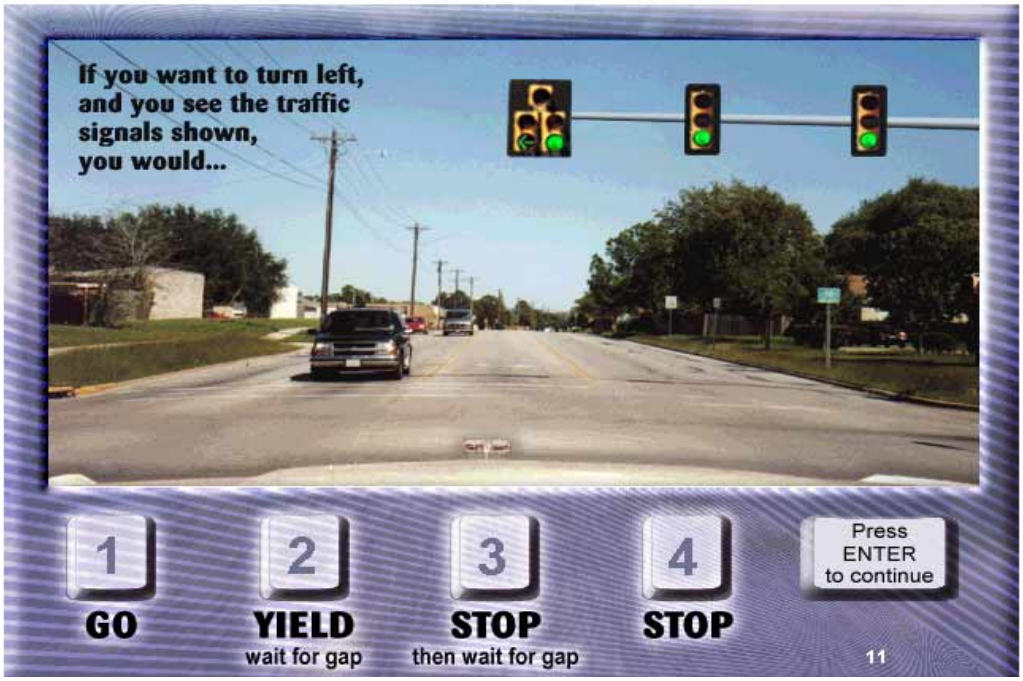


Figure 1 PPLT Signal Display Arrangements and Indications.



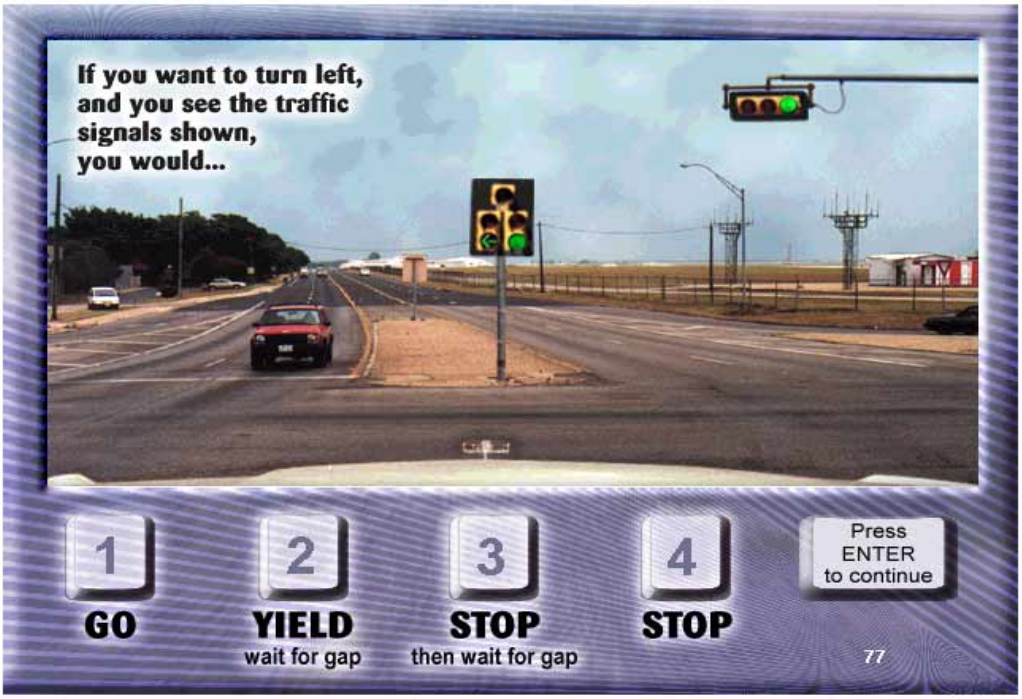


Figure 2 Driver Survey Computer Screens.

Table 1 Summary of Survey Scenario Demographics

Demographic	Level	Number of Responses	Percentage of Correct Responses
Location	Dallas	9,299	68.5
	Dover	9,039	75.6
	Oakland County	9,722	70.7
	College Station	9,034	74.6
	Seattle	9,658	78.5
	Portland	8,869	71.5
	Cupertino	8,923	69.7
	Orlando	8,226	66.7
Gender	Male	42,189	72.7
	Female	30,125	71.3
	Not Provided	456	68.9
Age	< 24	19,942	72.2
	24 - 44	32,191	73.1
	45 - 65	15,171	71.1
	> 65	4,958	67.3
	Not Provided	508	74.2
Residence	City	42,063	71.8
	Suburb	21,880	72.8
	Rural	8,528	71.8
	Not Provided	299	67.9
Miles Driven	None	3,344	62.7
	< 10,000	22,523	70.2
	10,000 to 20,000	32,746	74.1
	> 20,000	13,916	72.4
	Not Provided	241	77.2
Education	High School	20,738	67.4
	Some College	25,849	73.3
	College Degree	25,891	74.6
	Not Provided	292	66.8

Table 2 Percentage of Correct Responses to Permitted Indications

	Indication[1]		Location[2]								
Display	**Left**	**Thru**	**Dal**	**Dov**	**OC**	**CS**	**Sea**	**Por**	**Cup**	**Orl**	**Ave.**
5-Section Horz.	GB	GB	63.4[3] 183[4]	58.1 186	38.0 200	60.9 174	62.5 195	56.8 183	43.0 186	44.8 174	53.3 1481
5-Section Horz.	GB	RB	50.8 183	37.4 195	28.5 207	58.0 188	52.4 189	42.7 185	39.5 190	47.1 172	44.3 1509
5-Section Vert.	GB	GB	59.8 281	52.5 280	40.0 295	63.7 251	70.2 309	58.0 276	48.2 272	47.4 249	55.1 2213
5-Section Vert.	GB	RB	51.9 268	46.7 269	32.3 281	56.3 263	61.3 279	51.1 256	44.6 276	44.3 255	48.5 2147
5-Section Cluster	GB	GB	51.4 288	55.2 270	43.6 284	56.7 263	60.2 304	58.2 249	37.6 266	53.1 228	52.0 2152
5-Section Cluster	GB	RB	46.7 290	49.6 262	34.7 297	58.7 281	59.1 247	44.8 270	42.3 267	50.9 232	48.1 2146
4-Section Vert.	FYB	GB	50.0 278	63.8 268	69.2 267	64.1 281	80.2 308	60.9 256	61.5 257	54.5 266	63.3 2181
4-Section Vert.	FYB	RB	49.3 280	58.6 304	69.6 322	59.0 266	69.8 275	63.1 282	64.9 259	52.6 247	61.1 2235
4-Section Vert.	FYA	GB	43.5 269	61.7 256	67.1 301	58.8 260	69.4 281	50.6 247	58.8 267	49.0 253	57.7 2134
4-Section Vert.	FYA	RB	45.9 307	54.4 274	62.5 291	61.1 286	70.2 315	53.8 275	57.1 280	41.3 242	56.2 2270
4-Section Vert.	FRA	GB	41.1 297	78.7 272	66.0 268	55.3 264	62.7 279	60.2 241	61.3 282	45.1 244	58.8 2147
4-Section Vert.	FRA	RB	39.9 281	75.7 267	59.9 274	49.1 273	60.8 288	51.7 286	51.8 257	39.6 235	55.3 2161
4-Section Cluster	FRA	GB	33.8 275	77.8 279	65.7 286	48.6 286	61.5 296	60.6 269	55.2 261	37.2 247	55.4 2199
4-Section Cluster	FRA	RB	32.0 250	75.7 263	60.2 314	47.0 283	61.7 300	58.4 262	54.9 268	39.5 253	54.1 2193
3-Section Vert.	FYB	GB	53.3 270	66.1 257	72.1 280	69.9 289	69.9 269	64.1 276	61.9 270	55.1 267	64.1 2178
3-Section Vert.	FYB	RB	41.5 284	58.1 236	68.1 282	60.7 290	65.2 299	61.3 297	59.2 255	56.5 223	59.0 2166
3-Section Vert.	FRB	GB	46.8 282	77.5 284	74.5 321	56.5 269	76.8 306	63.4 268	67.3 251	53.0 234	65.1 2215
3-Section Vert.	FRB	RB	44.6 269	76.9 260	76.3 295	54.7 247	71.3 310	67.3 257	60.4 278	53.7 255	63.5 2171
Location Average			46.7	62.9	58.1	57.7	66.3	57.3	54.9	48.1	**56.7**

[1] G = Green, Y = Yellow, R = Red, B = Ball, A = Arrow, F = Flashing
[2] Dal = Dallas, Dov = Dover, OC = Oakland County, CS = College Station, Sea = Seattle, Por = Portland, Cup = Cupertino, Orl = Orlando
[3] Percentage of correct responses
[4] Number of responses

Table 3 Correct Response Rate to Permitted Indications by Age

Signal Indication[1]		Drivers' Age			
Left	**Through**	**< 24**	**24 - 44**	**45 - 65**	**> 65**
GB	GB	53.7	56.1	52.1	34.8
GB	RB	49.4	50.8	43.6	28.5
FYB	GB	64.0	63.7	62.8	66.9
FYB	RB	63.0	59.4	57.1	58.0
FYA	GB	60.3	57.1	56.9	51.3
FYA	RB	62.7	56.3	51.2	48.8
FRA	GB	53.1	59.6	55.6	59.7
FRA	RB	51.0	53.3	58.6	55.8
FRB	GB	60.6	64.4	70.5	69.1
FRB	RB	60.3	63.0	65.3	70.3

[1] G = Green, Y = Yellow, R = Red, B = Ball, A = Arrow, F = Flashing

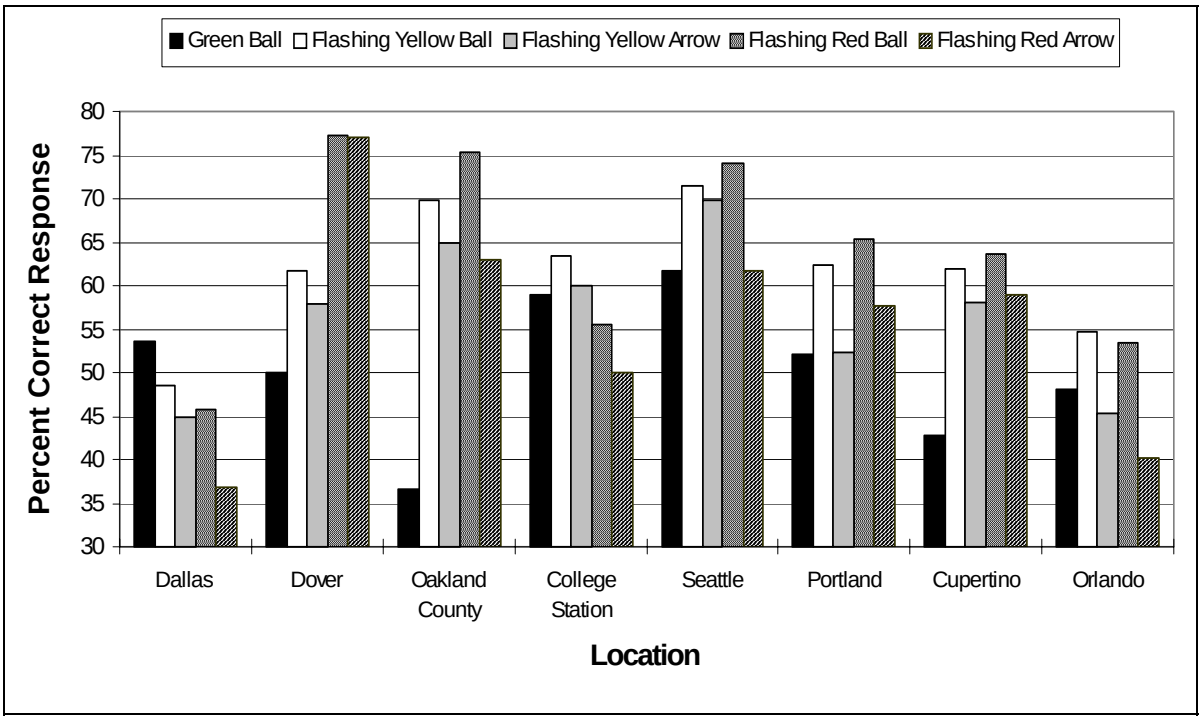


Figure 3 Permitted Indication Correct Responses by Location.

Table 4 Highest Correct Response Rates for Permitted Indications

Location	Permitted Indication Used	Correct Response Rate (Indication and Percent)			
		Highest		Second Highest	
Dallas	Green Ball	Green Ball	53.6	Flashing Yellow Ball	48.5
Dover	Flashing Red Arrow	Flashing Red Ball	77.2	Flashing Red Arrow	77.0
Oakland County	Flashing Red Ball	Flashing Red Ball	75.3	Flashing Yellow Ball	69.8
College Station	Green Ball	Flashing Yellow Ball	63.5	Flashing Yellow Arrow	60.1
Seattle	Flashing Yellow Ball	Flashing Red Ball	74.0	Flashing Yellow Ball	71.4
Portland	Green Ball	Flashing Red Ball	65.3	Flashing Yellow Ball	62.4
Cupertino	Flashing Red Arrow	Flashing Red Ball	63.7	Flashing Yellow Ball	61.9
Orlando	Green Ball	Flashing Yellow Ball	54.6	Flashing Red Ball	53.4

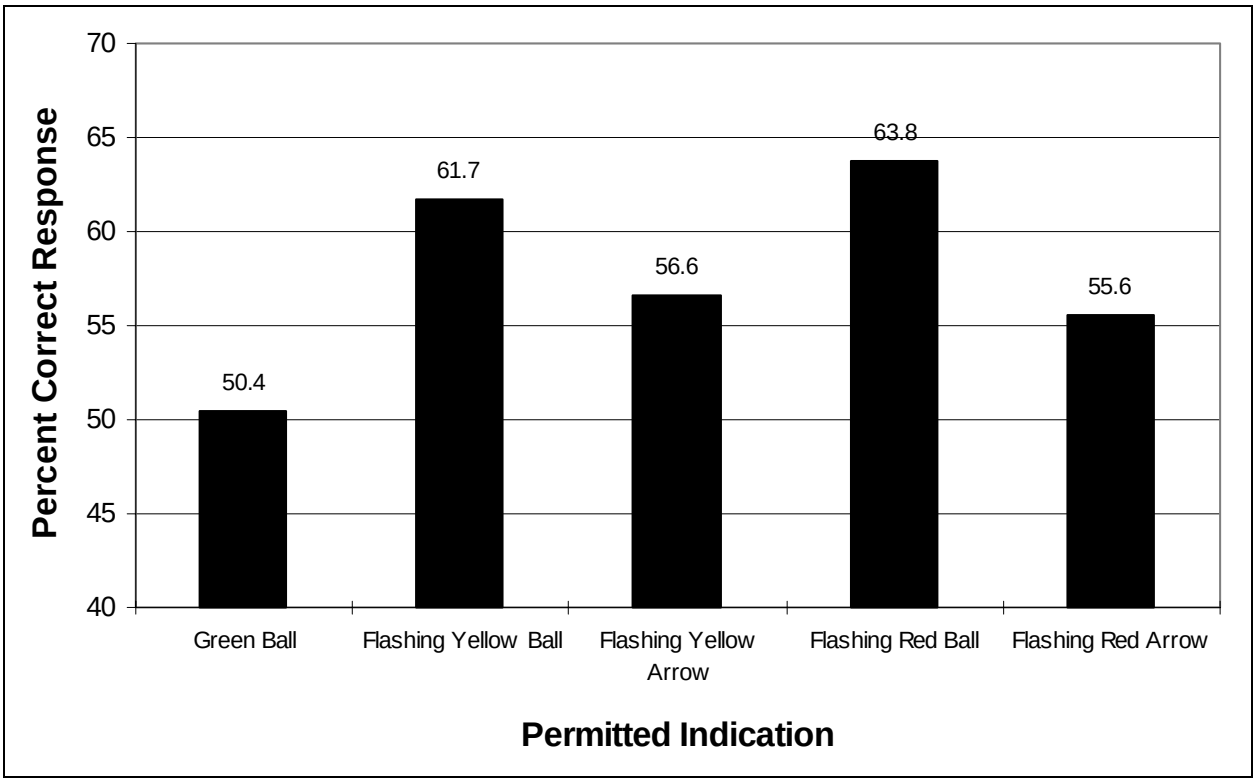


Figure 4 Percentage of Correct Responses for Permitted Indications.

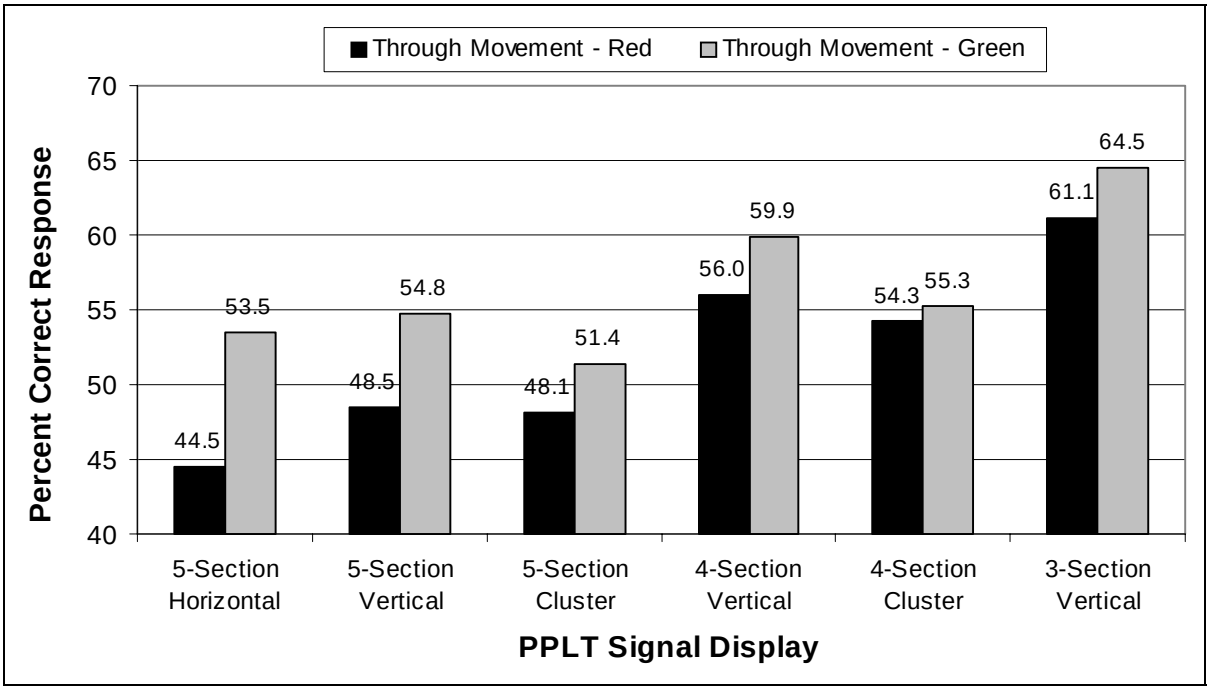


Figure 5 Driver Understanding of Permitted Indications in PPLT Signal Displays.

Table 5 Average Response Time (Seconds) to Permitted Indications

Signal Indication[1]		Gender		Age			
Left	**Through**	**Male**	**Female**	**< 24**	**24 - 44**	**45 - 65**	**> 65**
GB	GB	6	6	5	6	7	9
GB	RB	6	8	5	6	8	8
FYB	GB	6	6	5	6	6	7
FYB	RB	6	6	5	6	7	7
FYA	GB	6	6	5	6	7	9
FYA	RB	6	6	5	6	7	8
FRA	GB	6	6	5	6	7	8
FRA	RB	6	6	5	6	7	9
FRB	GB	5	5	4	5	6	8
FRB	RB	6	6	5	6	7	8

[1] G = Green, Y = Yellow, R = Red, B = Ball, A = Arrow, F = Flashing

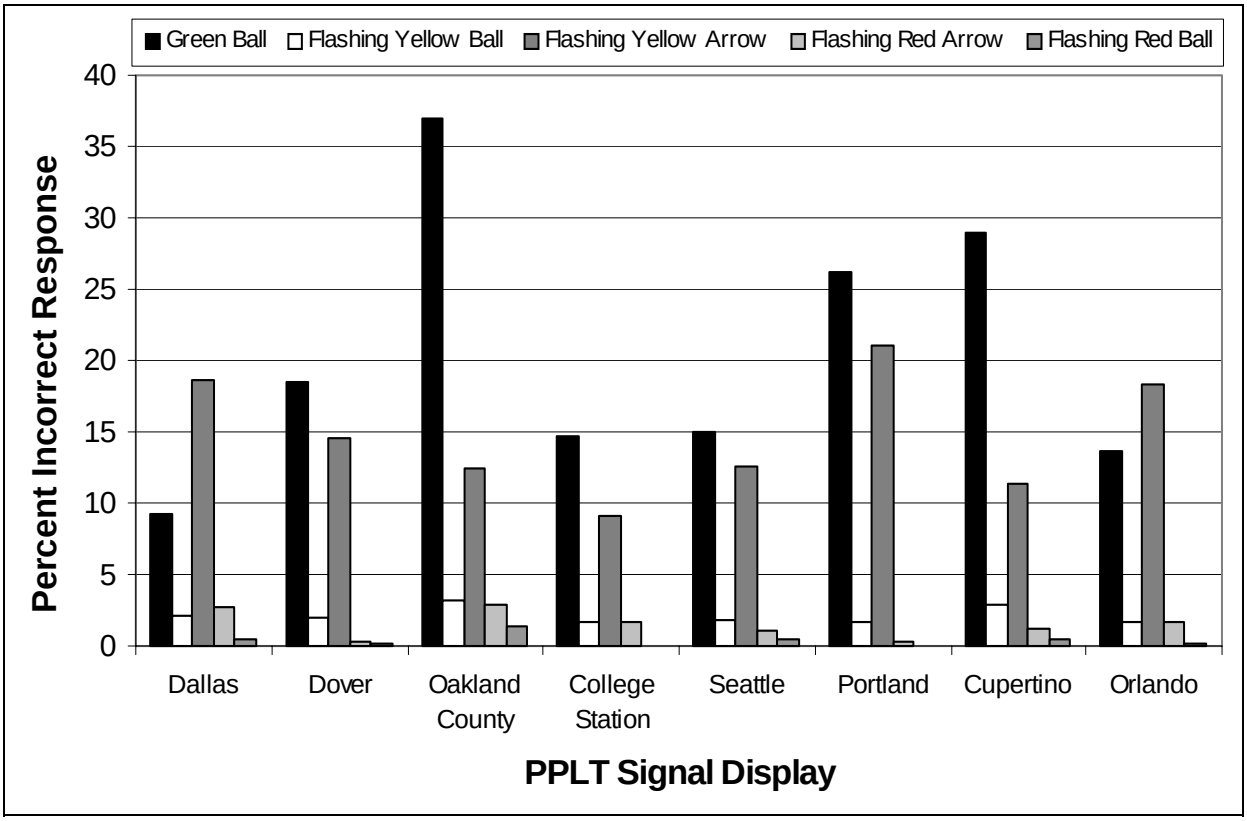


Figure 6 Fail Critical Responses to Permitted Indications by Location.

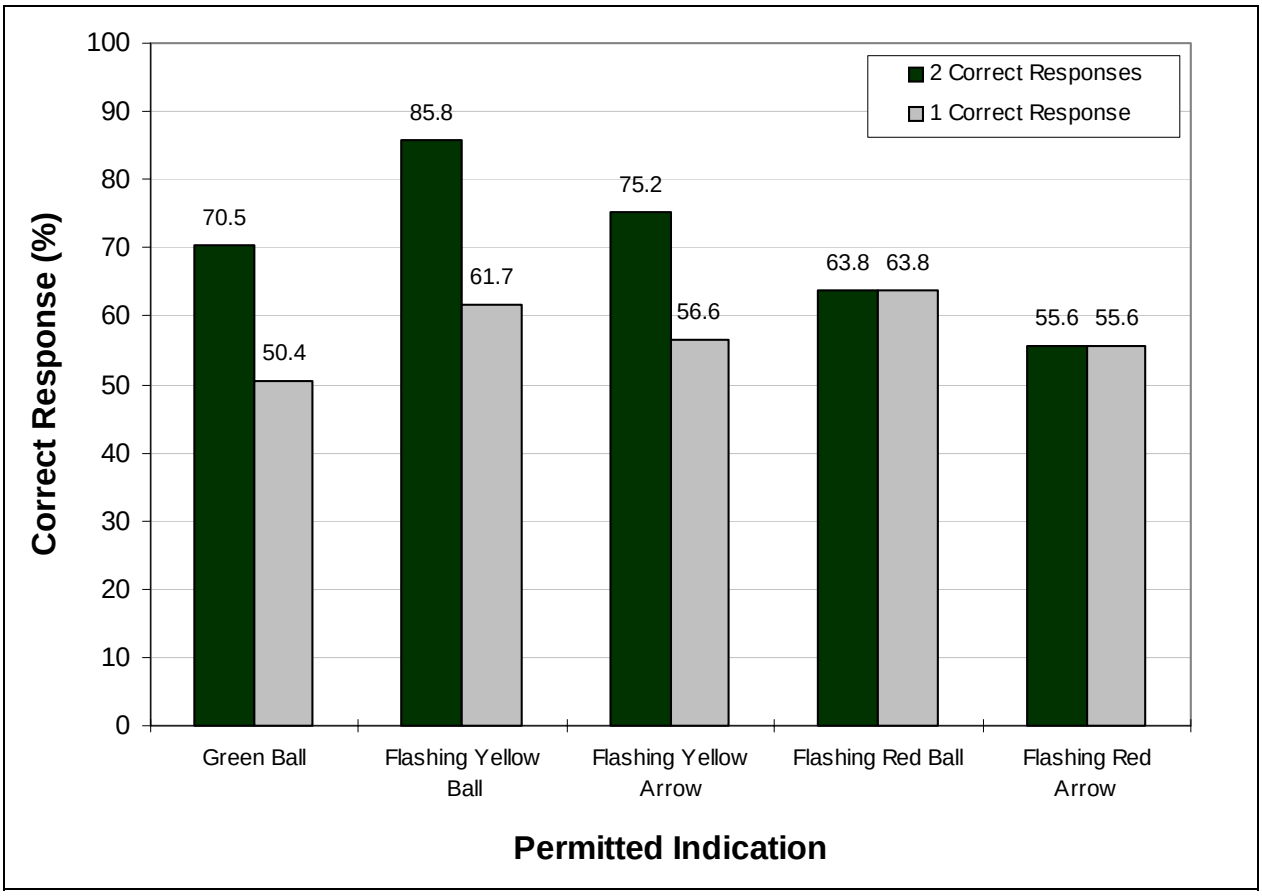


Figure 7 Percentage of Correct Responses for Permitted Indications - Revised.

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