USING OF DRIVING SIMULATORS TO EVALUATE NOVEL TRAFFIC CONTROL DEVICES: PROTECTED/PERMISSIVE LEFT-TURN SIGNAL DISPLAY ANALYSIS

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ABSTRACT

This paper presents the results of a study that evaluated driver's comprehension of several experimental five-section protected/permissive left-turn (PPLT) signal displays using a full-scale driving simulator and static driver study. Study methods were compared while evaluating driver's comprehension and response to various combinations of five-section PPLT signal display arrangements (horizontal, vertical, and cluster) and permissive left-turn indications (green ball, flashing red ball, flashing yellow ball, flashing red arrow, and flashing yellow arrow).

The results showed that the type of five-section PPLT signal display arrangement has very little effect on driver comprehension of the permissive left-turn maneuver. The type of permissive indication used in five-section PPLT signal displays had a significant effect on driver comprehension as the green ball, flashing yellow ball, and flashing yellow arrow were the best understood. When combining five-section PPLT signal display arrangements and permissive indications, the five-section horizontal arrangement with a flashing yellow ball permissive indication had the highest level of driver comprehension.

The lack of surrounding driving cues in the static driver study led to significantly higher fail-critical (serious) response rates. The green ball permissive indication had a driver comprehension rate over 30 percent lower in the static study, clearly showing that drivers do not correctly comprehend the meaning of the green ball (assume it is protected) and use other information to make left-turn decisions while driving.

The findings of this research show that driving simulation provides an effective study method and effectively replicates the actual driving environment. Simulators should be considered when conducting driver comprehension analyses.

Keywords: Driving Simulation, Protected/Permissive Left-Turn, Safety, Signal Display, Driver Behavior

INTRODUCTION

Evaluating driver's comprehension of traffic control devices (TCDs) in a laboratory environment can be problematic. The problem lies in the ability to replicate the driving environment and place the TCDs in their proper context. Most studies of TCDs are completed in a static format. Although a measure of driver understanding can be determined, driver's reaction and corresponding comprehension to these devices cannot. A recent study by Noyce has validated the well known belief that what drivers says they will do in a static study, and what they actually do in the driving environment, are often not the same (*1*). Therefore, dynamic driving environments can greatly enhance the evaluation of driver's comprehension of TCDs.

Full-scale fixed-base driving simulators have recently been used to provide a dynamic driving environment for experimentation. Driving simulators require control, guidance, and navigation tasks, just like driving an actual vehicle. Although vehicle motion and associated forces are not replicated, driving simulators place the driver in an environment that replicates real roadway driving conditions. Further, driving simulators do not place study subjects in unsafe conditions, allow many different experimental conditions to be economically created without field installations, and allow researchers to control the dependent and independent experimental variables.

This paper presents the results of a study that evaluated driver's comprehension of five-section protected/permissive left-turn (PPLT) signal displays using a full-scale driving simulator and static driver study. The objective of this research was to evaluate driver's comprehension and response to various combinations of five-section PPLT signal display arrangements (horizontal, vertical, and cluster) and permissive left-turn indications (green ball, flashing red ball, flashing yellow ball, flashing red arrow, and flashing yellow arrow) in both static and dynamic study methods.

BACKGROUND

Significant variability exists in the application of PPLT signal displays throughout the United States (*2*). PPLT signal phasing provides a protected phase for left-turns as well as a permissive phase during which left-turns can be made if gaps in opposing traffic allow, all within the same signal cycle. Although the intent of the Manual on Uniform Traffic Control Devices (MUTCD) is to provide a national standard, only general guidance is provided in the selection and use of PPLT signal displays (*3*). Additionally, the MUTCD does not require a separate PPLT signal display for PPLT signal phasing. Consequently, PPLT signal displays have been implemented in a variety of configurations throughout the United States.

PPLT signal phasing and corresponding displays can be found at approximately 29 percent of intersections in the United States (*2*). The five-section cluster is the most common arrangement, used at approximately 63 percent of all PPLT intersections, but is not uniformly applied in placement, location, and use of supplemental signs (*2*). Within each PPLT signal display, the MUTCD requires a green arrow for the protected left-turn movement and a circular green (ball) indication for the permissive movement.

Problems with driver's comprehension of PPLT signal displays have been identified but not resolved. Specifically, the permissive (green ball) phase is a concern for many traffic engineers. The problem lies in the fact that drivers traveling through an intersection displaying a green ball indication may proceed straight through, with all other vehicles yielding the right-of-

way. Drivers turning left with a green ball indication are required to yield the right-of-way to opposing vehicles before proceeding. Therefore, the green ball indication has been challenged on the premise that it provides two different messages. The safety of left-turn drivers requires that the permissive phase be an unambiguous signal display arrangement and/or indication because of its unique turning requirements.

To improve driver comprehension, traffic engineers in California, Delaware, Michigan, and Washington, among others, have replaced the green ball permissive indication with one of several unique indications. These unique indications include a flashing yellow ball, a flashing red ball, a flashing yellow arrow, and a flashing red arrow. As shown in Figure 1, each of these permissive indications has been used in either a three-section or four-section signal display.

Research has indicated that flashing red or yellow permissive indications may lead to a higher level of driver comprehension at PPLT intersections (*2*). Further, a five-section PPLT signal display in a cluster arrangement, along with a flashing permissive indication, may increase driver comprehension. These research results were based on independent analyses, since flashing permissive indications in a five-section signal display did not exist in practice; and therefore, were not evaluated.

It was hypothesized that flashing PPLT permissive indications in five-section signal arrangements will provide improvements in driver comprehension. Since none of the five-section PPLT displays with flashing permissive indications have been field implemented, and installing an experimental traffic control device in the field is costly and a potential safety problem, a study was designed to complete this analysis.

PREVIOUS RESEARCH

Many studies of PPLT signal display indications been conducted in recent years (*4-7*). In 1998, Noyce completed a comprehensive study of PPLT signal displays to determine driver comprehension of various PPLT signal displays (*2*). A total of 2,465 drivers, from eight United States cities, evaluated 30 PPLT signal display scenarios resulting in nearly 74,000 responses. Cities included Seattle, Washington; Detroit, Michigan; Cupertino, California; Dover, Delaware; College Station and Dallas, Texas; Portland, Oregon; and Orlando, Florida.

Noyce found that the three-section vertical display with a flashing red ball permissive indication had the highest level of driver comprehension. Note that only signal display arrangements and flashing permissive indication combinations shown in Figure 1 were evaluated (i.e., flashing permissive indications in five-section arrangements were not considered). Additionally, Noyce recommended that the five-section cluster display be further evaluated and considered as a standard display because it contained several important features:

- The display was unique in arrangement;
- 63 percent of all PPLT signal displays in the United States (1998) were five-section clusters; and
- There was no PPLT display arrangement that had a higher level of driver comprehension.

Evaluating the array of permissive indications in use, Noyce found the flashing permissive indications generally performed better than the green ball indication. Only 57 percent of drivers correctly understood the green ball permissive indication, compared to 56 percent for the flashing red arrow, 57 percent for the flashing yellow arrow, 62 percent for the flashing

yellow ball, and 64 percent for the flashing red ball. Analysis of serious error rates (fail-critical) produced similar results with the highest serious error rate being 25 percent for the green ball permissive indication. The results from this study are concerning because they suggest that the permissive green ball indication in PPLT applications, which is the most widely used in the United States, has a low level of comprehension and may be the most misunderstood by drivers, and therefore, unsafe.

Simulation of Traffic Signal Displays

Driving simulation has been used as a research tool to observe and record individual driving behavior. Studies have shown that driving simulators can accurately recreate driving conditions and, in turn, realistic driver behavior (*8-10*). Szymkowiak tested the reaction of 32 drivers to a set of 40 different left-turn signal display/sign combinations using a full-scale fixed-base driving simulator (*9*). Five-section cluster and dual three-section (six-section) vertical traffic signal arrangements were used along with combinations of supplemental signs. After completing the analysis of multiple signal displays, the researchers concluded that experiments using driving simulators "benefit from an even more realistic, that is, dynamic environment."

The Australian Federal Office of Road Safety conducted a study to compare the driving responses obtained on the road with those obtained in a driving simulator (*10*). The study was a "precursor to a full experimental program aimed at evaluating a range of low cost road treatments as a counter-measure to excessive speeding." Twenty-four drivers were recruited to drive a vehicle through a test route containing roadway sections with and without speed reducing treatments. The drivers then drove through the same test route recreated in a driving simulator. Speed, deceleration, braking, and lateral position data were collected and analyzed for stop signs, roundabouts, left-curves, and right-curves. Similar results were found between the driving simulator and roadway for many of the test conditions. The results led researchers to conclude that the driving simulator was an effective method to test drivers' perception of their surroundings and effectively represented the actual roadway environment.

EXPERMENTAL DESIGN

A research study was designed to evaluate five-section PPLT signal displays with each permissive indication described in Figure 1 using driving simulator and static testing methods (*11*). The simulator used was a full-scale fixed-base 1995 Saturn sedan, shown in Figure 2. Fifteen unique PPLT signal displays were created. These displays were the result of some combination of the two independent variables, five-section signal display arrangement and permissive indication. Arrangements evaluated included a five-section horizontal, five-section vertical, and five-section cluster. Within each, five different left-turn permissive indications were evaluated; a flashing yellow arrow, a flashing red arrow, a flashing yellow ball, a flashing red ball, and a steady green ball. Figure 3 presents each of the 15 different five-section PPLT signal display arrangement and indication combinations tested.

Each of the 15 five-section PPLT signal display arrangement/permissive indication combinations were tested with consistent and uniformly applied opposing traffic. When the driver arrived at the intersection, the opposing traffic was at a distance such that the driver did not know, simply by looking at the opposing traffic, whether opposing traffic was going to stop or continue through the intersection. The driver was required to base his/her left-turn decision

only on the five-section PPLT signal display arrangement and indication present at the intersection. The driver's left-turn decision; therefore, represented whether he/she understood the intended message conveyed by PPLT signal display arrangement and indication.

A computer-based (static) driver study was used to supplement the driving simulator results. Animated PPLT signal displays were superimposed on photos of intersections containing left-turn lanes, from the perspective of the driver. All 15 PPLT signal display arrangement and permissive signal indication combinations shown in Figure 3 were created with opposing traffic.

Procedure

A total of 24 intersections were presented in each of four simulator modules, including 10 permissive left-turn intersections. The routes for each module contained 12 left-turns (two protected), and 12 right-turn or through movements. The right-turns, through movements, and protected left-turns were added to introduce a higher level of realism, add variability, and to minimize driver learning during the testing period.

Each of the four modules had a different background scene, a different order of right, left, and through movements, and a different order of PPLT scenarios. The roadway configuration was consistent for all modules with only the roadside and background features differing. Three large signs containing arrows pointing left, right, or up were presented directing the driver on which maneuver to make at each intersection. Figure 4 shows a typical view of the simulation visual world.

Each driver traversed through each of the four modules once. To prevent drivers from observing the PPLT scenarios in the same order, drivers began the modules at different locations. Driver's response to each PPLT scenario was manually recorded including the correct and incorrect response, indecision, unnecessary braking, and verbal comments. No spatial or operational data were collected. A video camera was used to record and review each driver's response.

Incorrect responses were broken into two different categories, fail-safe and fail-critical. A fail-safe response was one in which the driver did not correctly respond to the five-section PPLT signal display, but did not infringe on the right-of-way of the opposing traffic. Fail-critical responses were further divided into two separate categories, serious and non-serious. A fail-critical serious response was one in which the driver impeded on the right-of-way of opposing traffic, creating the potential for a crash. A fail-critical non-serious response resulted in an incorrect stop or yield but did not impede opposing traffic.

Figure 5 represents a typical image used in the static study. Drivers were presented with each of the 15 PPLT signal display images on a laptop computer. Software was used to implement flashing permissive indications at a rate of one flash per second. For each image displayed, the drivers had to choose from the following list of responses:

A. Go, you have the right-of-way.
B. Yield, go if an acceptable gap in opposing traffic allows.
C. Stop, then go if an acceptable gap in opposing traffic allows.
D. Stop, you do not have the right-of-way.

Drivers were asked to select one of the four responses after viewing each PPLT signal display image. Responses from the study were compared with the responses from the driving simulator to determine a relationship between the two testing methods.

Drivers also completed a demographic survey providing data on gender, age, education, and annual miles driven. Analysis of Variance (ANOVA) statistical procedures were used to isolate and assess sources of variation associated with the independent experimental variables (*12*).

RESEARCH RESULTS

Thirty-four drivers completed the driving simulation task and static driver study. Participants had driving experience from a number of different states. A total of 2,286 PPLT signal displays were evaluated. Seventeen males and 17 females completed the study. Seventeen drivers were less than 24 years of age and five were over 45. Nineteen drivers had only a high school education/some college while 15 drivers had a college degree. Ten drivers reported that they drove less than 10,000 miles in the previous year while four drivers indicated that they drove more than 20,000 miles.

Driving Simulation

A total of 991 responses were collected from permissive indication scenarios with opposing traffic. The overall correct response rate was 81.3 percent. Table 1 presents the overall number of observations and percentage of correct responses for all five-section PPLT signal display arrangement and permissive indication combinations. Variation in the total number of observations was the result of drivers not completing the simulator experiment and additional emphasis on the horizontal arrangement.

The correct response rate for male drivers was 85.3 percent as compared with 77.1 percent for female drivers. This difference was statistically significant ($p = 0.001$). As presented in Table 2, male drivers (93.1 percent) and female drivers (92.7 percent) had nearly identical levels of comprehension with the green ball permissive indication. Male drivers understood all five-section PPLT signal display arrangements equally well. Female drivers understood the horizontal arrangement slightly better than the cluster arrangement.

The correct response rate for each of the age ranges was 81.0, 86.1, and 68.6 percent, respectively. The difference in correct response rate was found to be statistically significant ($p = 0.0001$). Table 3 presents the percentage of correct responses for all five-section PPLT signal display arrangement and permissive indication combinations by age.

Drivers with a high school degree/some college had a significantly lower (79.1) correct response rate compared to drivers with a college degree (84.1) ($p = 0.045$). All drivers indicated they had driven some mileage in the past year; therefore, the categories analyzed were less than 10,000, 10,000 to 20,000, and over 20,000. The correct response rates for each category were 72.4, 83.2, and 93.3, respectively. The differences were statistically significant ($p = 0.0001$).

Figures 6 and 7 present the percentage of correct responses for the five-section arrangements and permissive indications, respectively. The average percentage of correct responses for the five-section PPLT signal display arrangements evaluated were similar and not statistically significant ($p = 0.116$). The difference in the percentage of correct responses for the permissive indications was statistically significant ($p = 0.0001$). The results suggest that the

green ball, flashing yellow arrow, and flashing yellow ball had a significantly higher level of driver comprehension than the flashing red arrow and flashing red ball.

The combination of the five-section horizontal arrangement and flashing yellow ball permissive indication had the highest level of driver comprehension with a 97.0 percent correct response rate. The five-section vertical arrangement with the flashing red arrow permissive indication was lowest with a 57.6 percent correct response rate.

Analysis of Incorrect Responses

Recall that incorrect responses could be fail-safe, fail-critical (non-serious), and fail-critical (serious). Table 4 shows the number of observations and percentage of incorrect responses for all PPLT signal display arrangement and permissive indication combinations.

Of the 18.7 percent of incorrect responses given, 15.6 percent were fail-safe. A fail-safe response generally does not have a serious safety impact but may increase intersection delay. Not unexpectedly, the data in Table 4 inversely follows trends discussed in the analysis of correct responses. The fail-safe responses to the flashing red ball and flashing red arrow permissive indications tend to be much higher than the green ball, flashing yellow ball, or flashing yellow arrow permissive indications. Additionally, the five-section cluster and five section vertical arrangements tended to produce slightly higher fail-safe responses than the five section horizontal PPLT signal display arrangement.

The most common fail-safe response to the permissive indications was drivers yielding instead of stopping for the flashing red ball and flashing red arrow indications. This result is not surprising considering many drivers on the actual roadway follow a similar practice. This conclusion is supported by verbal comments made by many drivers who indicated they needed only to yield before proceeding.

The fail-critical (non-serious) responses were the second highest source of incorrect responses. Fail-critical (non-serious) accounted for 2.5 percent of all responses and 13.3 percent of the incorrect responses. Table 4 shows that the green ball permissive indication produced the most fail-critical (non-serious) responses. This was followed by the flashing yellow ball and flashing yellow arrow permissive indications with the flashing red ball and flashing red arrow indications producing the fewest fail-critical (non-serious) responses. As with the fail-safe responses, the five-section vertical and cluster arrangements produced higher fail-critical (non-serious) responses than did the five-section horizontal arrangement.

Familiarity with the green ball permissive indication may have led drivers to commit more fail-critical (non-serious) responses with this indication than with other indications. Drivers seemed to be more comfortable with the green ball permissive indication than with any other permissive indication and made their response decision quickly, allowing them to accelerate prior to the left-turn. The higher percentage of correct responses for the five-section horizontal arrangement may be due to drivers' caution and lack of experience with this display type. The researchers observed that drivers approached this arrangement slowly as they made a decision on their response and, in turn, yielded correctly to the PPLT display.

The final incorrect response, fail-critical (serious), is believed to have the largest potential safety impact. This response, therefore, is of most concern. Recall that during a fail-critical (serious) response, a driver travels through a permissive indication assuming it is protected. In total, there were five fail-critical (serious) responses. Table 5 shows the demographics, five-section arrangement, and permissive indication present when the fail-critical responses occurred.

All fail-critical (serious) responses were produced by drivers under the age of 24, with less than a college degree. Three females comprised four of the five fail-critical (serious) responses, all with the horizontal five-section PPLT signal display present. The green ball was the only permissive indication producing more than one fail-critical (serious) response, with the flashing red ball not producing any fail-critical (serious) responses.

Comparison of Simulator and Static Driver Study Results

The results of both the driving simulation and static driver studies found that the type of permissive indication used in a five-section PPLT signal display arrangement had a significant effect on driver comprehension. Figure 8 represents a comparison of the percentage of correct responses. Data suggest that the type of five-section PPLT signal display arrangement used was not significant in driver comprehension in either testing method. Further, the flashing yellow indications were best understood in both the driving simulation and static driver study. This result may be because a yellow indication has only one meaning to drivers, caution. The green ball, flashing red ball, and flashing red arrow permissive indications; however, show large discrepancies in driver comprehension between the two testing methods.

Consider again the different meaning of the green ball indication for through and left-turn drivers. Due to this confusion, drivers often used other surrounding cues to decide on their action. In the driving simulation task, drivers were able to react to the motion of the opposing traffic to assist in the left-turn decision of whether to stop, go, or yield. The static driver study did not have moving traffic or related cues, requiring drivers to make their left-turn decision solely on the meaning of the indication. Therefore, drivers in the static study had a much higher incorrect response rate.

The discrepancies in correct response rates between the two testing methods for the flashing red ball and flashing red arrow permissive indications follow the same logic as the discrepancies for the green ball. A red indication indicates that a driver is to stop and wait for a green indication before proceeding. A flashing yellow indication indicates that a driver must yield, then proceed when an acceptable gap in traffic becomes available. However, when a red indication is flashing, a driver must first stop, then proceed when an acceptable gap in traffic becomes available. Drivers who commented that they were unsure of the meaning of the flashing red ball or flashing red arrow indication tended to stop and wait for a signal change. Drivers who felt they were sure of the meaning of the flashing red ball and flashing red arrow permissive indication tended to treat the flashing red permissive indications as flashing yellow indications and yield, but not stop, before proceeding through an acceptable gap in traffic.

CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this research was to evaluate driver comprehension of 15 different PPLT signal display arrangement and permissive indication combinations using driving simulator and static methods. Additionally, a comparison of the correct and incorrect response rates collected during the driving simulation and static driver study was completed. The results showed that the type of five-section PPLT signal display arrangement has very little effect on the percent of correct responses for the permissive left-turn maneuver. The five-section cluster arrangement, which is most often used as the PPLT signal display, had the lowest percent of

correct responses (78.0), while the five-section horizontal arrangement, has the highest percent of correct responses (84.3). However, these differences were not statistically significant.

The type of permissive indication used in five-section PPLT signal displays had a significant effect on driver comprehension. Overall, the green ball, flashing yellow ball, and flashing yellow arrow were best understood (92.9, 92.9, and 91.9 percent correct responses, respectively), while the flashing red ball and flashing red arrow were least understood (69.3 and 59.6 percent correct responses, respectively). This result may be due to the obvious caution message the flashing yellow indication conveys and familiarity with the green ball indication. The flashing red ball and flashing red arrow produced extremely low levels of driver comprehension. This is most apparent when analyzing the incorrect responses, in particular, the fail-safe responses. Drivers tended not to come to a complete stop when approaching a flashing red indication, treating it as if the permissive indication was a flashing yellow or steady green ball. Older drivers found the flashing red indications confusing.

When combining five-section PPLT signal display arrangements and permissive indications, the five-section horizontal arrangement with a flashing yellow ball permissive indication had the highest level of driver comprehension. The five-section vertical arrangement with a flashing red arrow permissive indication produces the lowest percent of correct responses.

The five-section horizontal arrangement produced 80 percent of the fail-critical (serious) responses during the research while the remaining 20 percent came from the five-section cluster arrangement. The five-section vertical arrangement produced no fail-critical (serious) responses. Drivers had a higher comprehension of flashing ball permissive indications than flashing arrow indications.

The lack of surrounding driving cues in the static driver study led to significantly higher fail-critical (serious) response rates. The fail-critical (serious) response rate was 0.5 percent for simulation and 8.6 percent for static study. The flashing yellow ball and flashing yellow arrow permissive indications had similar levels of comprehension in both the driving simulation and static driver study. The flashing red ball and red arrow permissive indications had higher levels of comprehension in the static study as more drivers recognized the stop message. The green ball permissive indication had a comprehension rate over 30 percent lower in the static study, clearly showing that drivers do not correctly comprehend the meaning of the green ball (assume it is protected) and use other information to make left-turn decisions while driving.

The findings of this research show that driving simulation provides an effective study method and better replicates the actual driving environment. Simulators should be considered when conducting driver comprehension analyses. The PPLT analysis leads to the recommendation that the flashing yellow arrow, flashing yellow ball, and steady green ball be further tested in a driving simulation environment to determine which permissive indication has the highest level of driver comprehension. Additionally, the type of five-section PPLT signal display arrangement should also be evaluated to establish the effect, if any, it may have.

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FIGURES and TABLES

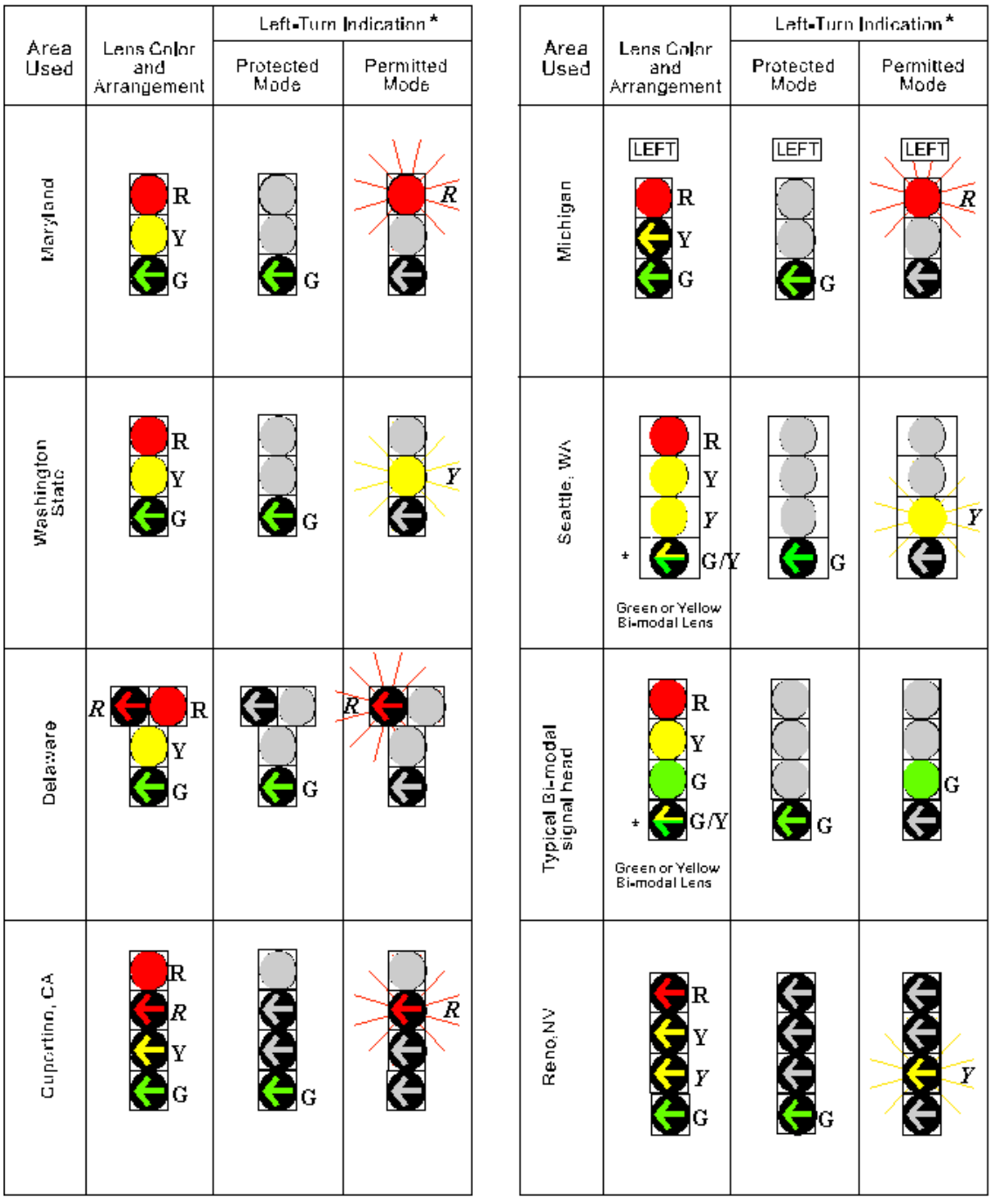
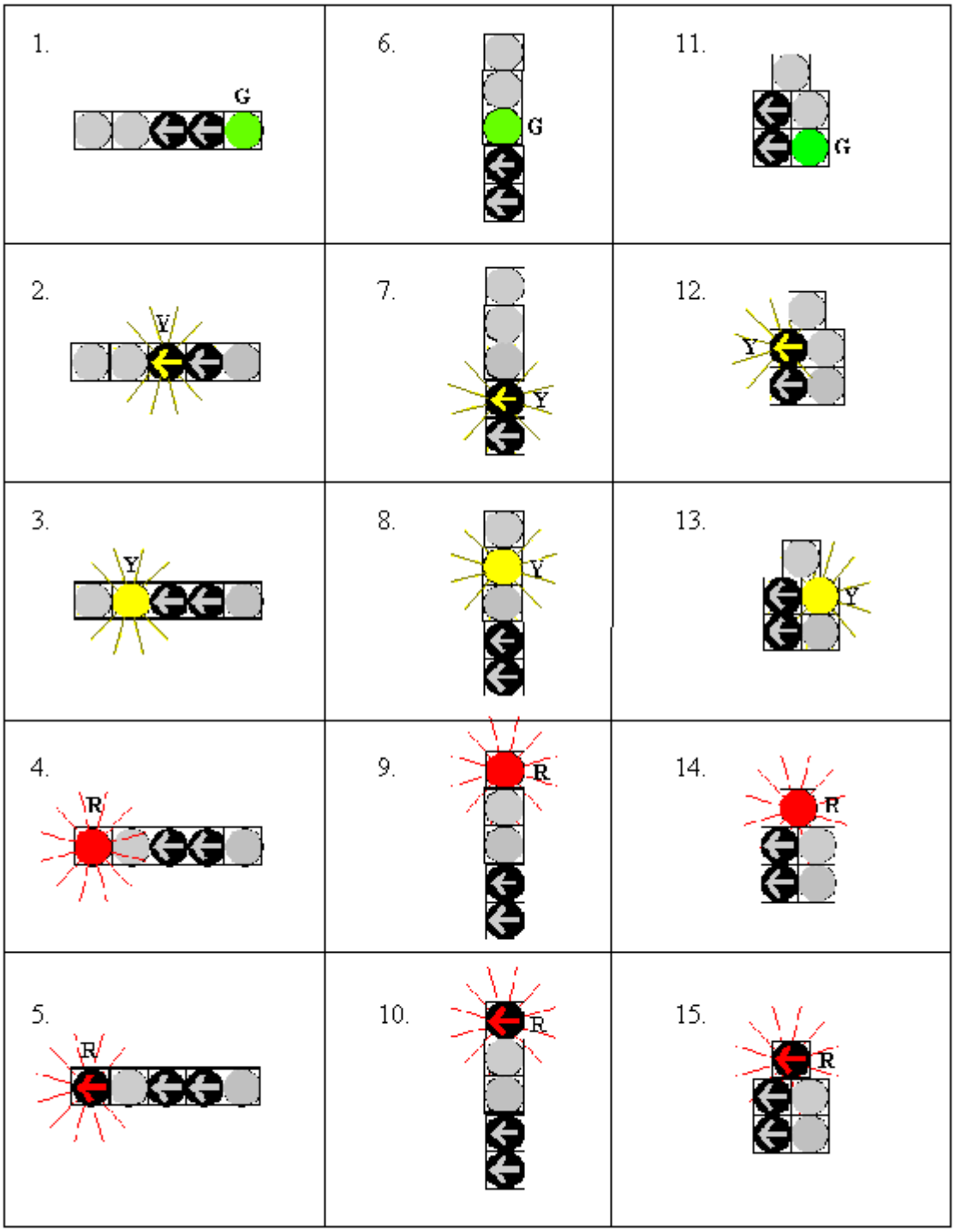


Figure 1 Variations in PPLT Signal Displays *(2)*.

Figure 2 Driving Simulator



Permissive Indications: R = FLASHING RED Y = FLASHING YELLOW G = STEADY GREEN

Figure 3 PPLT Signal Displays Evaluated

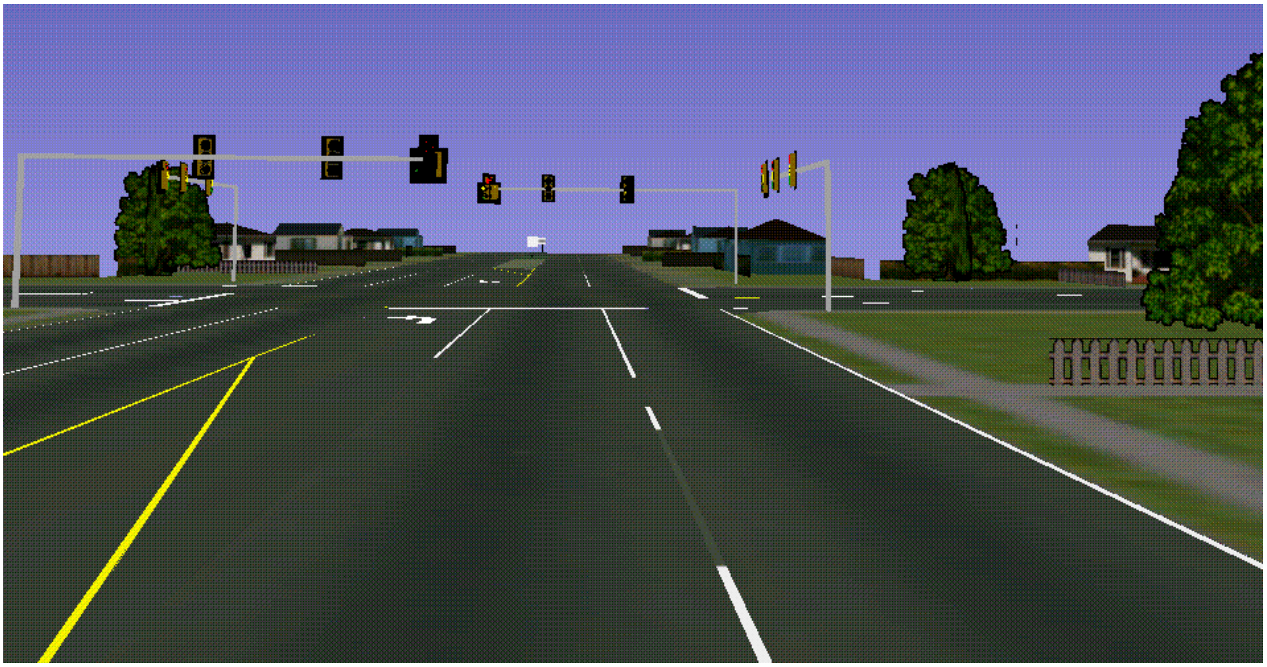


Figure 4 Typical Image from the Driving Simulation

Figure 5 Typical Computer-Based Study Image

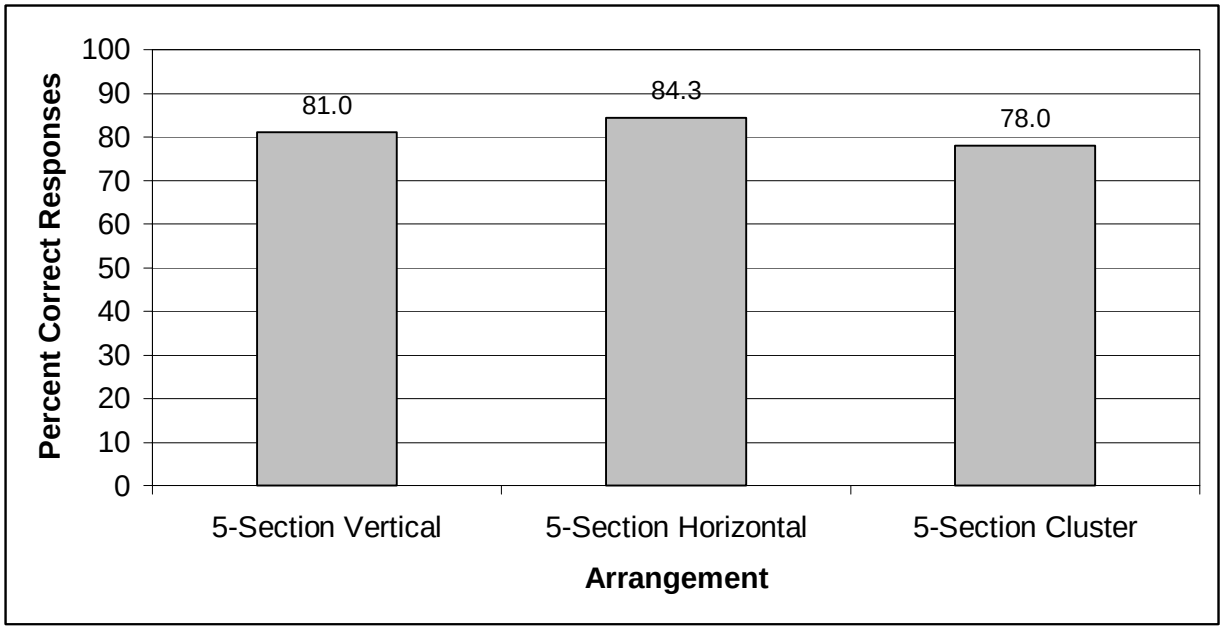


Figure 6 Percent Correct Responses to Five-Section Arrangements in Simulator Study

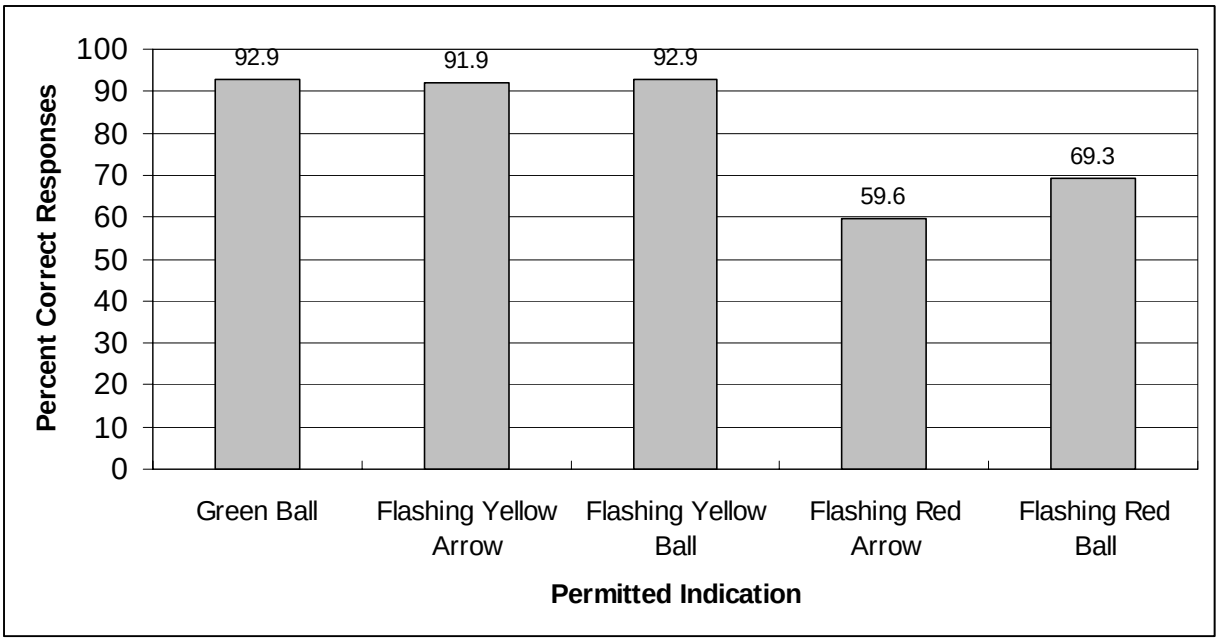


Figure 7 Percent Correct Responses to Permissive Indications in Simulator Study

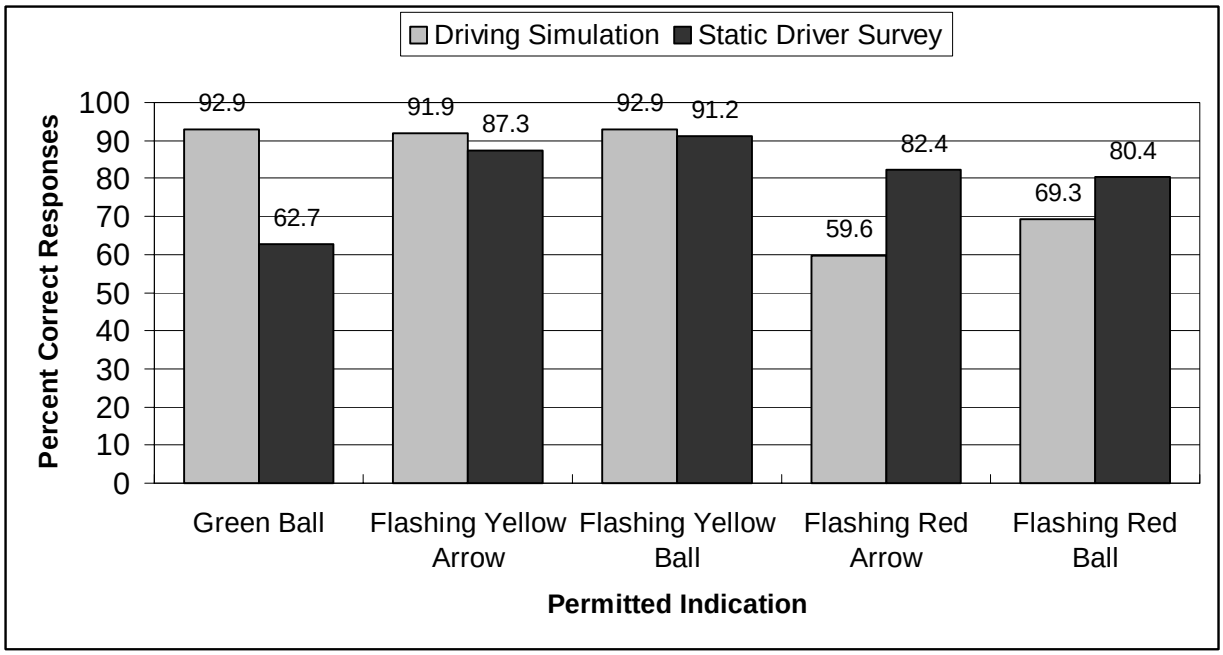


Figure 8 Comparison of Correct Responses for Permissive Indications

Table 1 Observations and Percent Correct Responses to PPLT Displays

Display	Permitted Signal Indication	Number of Observations	Percent Correct Responses
5-Section Vertical	Green Ball	66	92.4
	Flashing Yellow Arrow	66	92.4
	Flashing Red Arrow	66	57.6
	Flashing Yellow Ball	66	92.4
	Flashing Red Ball	67	70.1
5-Section Horizontal	Green Ball	100	93.0
	Flashing Yellow Arrow	66	93.9
	Flashing Red Arrow	66	60.6
	Flashing Yellow Ball	66	97.0
	Flashing Red Ball	66	72.7
5-Section Cluster	Green Ball	32	93.8
	Flashing Yellow Arrow	66	89.4
	Flashing Red Arrow	66	60.6
	Flashing Yellow Ball	66	89.4
	Flashing Red Ball	66	65.2
Total		**991**	**81.3**

Table 2 Observations and Percent Correct Responses by Gender

Display	Permitted Signal Indication	Male		Female	
		Observations	Percent Correct	Observations	Percent Correct
5-Section Vertical	Green Ball	34	94.1	32	90.6
	Flashing Yellow Arrow	34	97.0	32	87.5
	Flashing Red Arrow	34	59.0	32	56.3
	Flashing Yellow Ball	34	94.1	32	90.6
	Flashing Red Ball	34	76.0	32	63.6
5-Section Horizontal	Green Ball	51	92.2	49	93.9
	Flashing Yellow Arrow	34	100.0	32	87.5
	Flashing Red Arrow	34	61.8	32	59.4
	Flashing Yellow Ball	34	100.0	32	93.8
	Flashing Red Ball	34	76.0	32	68.8
5-Section Cluster	Green Ball	17	94.1	15	93.3
	Flashing Yellow Arrow	34	97.0	32	81.3
	Flashing Red Arrow	34	67.6	32	53.1
	Flashing Yellow Ball	34	94.1	32	84.4
	Flashing Red Ball	34	76.5	32	53.1
Total		**510**	**85.3**	**481**	**77.1**

Table 3 Observations and Percent Correct Responses by Age

Display	Permitted Signal Indication	< 24		25 - 45		>45	
		Observ.	Percent Correct	Observ.	Percent Correct	Observ.	Percent Correct
5-Section Vertical	Green Ball	34	94.1	24	87.5	8	100.0
	Flashing Yellow Arrow	34	97.1	24	83.3	8	100.0
	Flashing Red Arrow	34	52.9	24	79.2	8	12.5
	Flashing Yellow Ball	34	97.1	24	83.3	8	100.0
	Flashing Red Ball	34	61.8	24	83.3	8	66.7
5-Section Horizontal	Green Ball	51	90.2	36	97.2	13	92.3
	Flashing Yellow Arrow	34	94.1	24	91.7	8	100.0
	Flashing Red Arrow	34	55.9	24	79.2	8	25.0
	Flashing Yellow Ball	34	100	24	91.7	8	100.0
	Flashing Red Ball	34	70.6	12	87.5	8	37.5
5-Section Cluster	Green Ball	17	94.1	24	91.7	3	100.0
	Flashing Yellow Arrow	34	94.1	24	79.2	8	100.0
	Flashing Red Arrow	34	55.9	24	87.5	8	0.0
	Flashing Yellow Ball	34	91.2	24	87.5	8	87.5
	Flashing Red Ball	34	67.6	24	79.2	8	12.5
Total		**510**	**81.0**	**360**	**86.1**	**121**	**68.6**

Table 4 Observations and Percent Incorrect Responses for PPLT Displays

Display	Permitted Signal Indication	Fail-Safe		Fail Critical (non-serious)		Fail-Critical (serious)		Total
		Observ.	Percent	Observ.	Percent	Observ.	Percent	
5-Section Vertical	Green Ball	1	1.5	4	6.1	0	0.0	7.6
	Flashing Yellow Arrow	3	4.5	2	3.0	0	0.0	7.5
	Flashing Red Arrow	26	39.4	2	3.0	0	0.0	42.4
	Flashing Yellow Ball	4	6.1	1	1.5	0	0.0	7.6
	Flashing Red Ball	19	28.4	1	1.5	0	0.0	29.9
5-Section Horizontal	Green Ball	2	2.0	3	3.0	2	2.0	7.0
	Flashing Yellow Arrow	2	3.0	1	1.5	1	1.5	6.0
	Flashing Red Arrow	23	34.8	1	3.0	1	1.5	39.3
	Flashing Yellow Ball	2	3.0	0	0.0	0	0.0	3.0
	Flashing Red Ball	18	27.3	0	0.0	0	0.0	27.3
5-Section Cluster	Green Ball	0	0.0	2	6.3	0	0.0	6.3
	Flashing Yellow Arrow	4	6.1	3	4.5	0	0.0	10.6
	Flashing Red Arrow	25	37.9	1	1.5	0	0.0	39.4
	Flashing Yellow Ball	4	6.1	2	3.0	1	1.5	10.6
	Flashing Red Ball	22	33.3	1	1.5	0	0.0	34.8

Table 5 Fail Critical Demographics

Gender	Age	Education Completed	Annual Miles Driven	Five-Section PPLT Signal Display	Permissive Indication
Male	Under 24	Less than college degree	10,000 to 20,000	Cluster	Flashing Yellow Ball
Female*	Under 24	Less than college degree	Under 10,000	Horizontal	Green Ball
Female	Under 24	Less than college degree	Under 10,000	Horizontal	Flashing Yellow Arrow
Female	Under 24	Less than college degree	10,000 to 20,000	Horizontal	Flashing Red Arrow

*One female committed two fail-critical (serious) errors for the five-section horizontal arrangement with green ball permissive indication