AN EVALUATION OF THE FLASHING YELLOW ARROW PERMISSIVE INDICATION FOR USE IN SIMULTANEOUS INDICATIONS

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ABSTRACT

The recently completed National Cooperative Highway Research Program (NCHRP) Project 3-54 was a comprehensive, national research study to evaluate operational advantages and safety aspects of various left-turn controls at signalized intersections. After a series of studies that included evaluations of driver-based human factors, driver comprehension, and intersection operations, the NCHRP 3-54 research team concluded that a flashing yellow arrow (FYA) permissive indication provided a viable alternative to the circular green (CG) permissive indication. Therefore the research team recommended the FYA permissive indication be included in the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) as an acceptable and perhaps recommended indication for permissive left-turns. The NCHRP recommendations suggested the FYA be implemented in an exclusive signal display centered over the left-turn lane, which differs from many existing protected-permissive left-turn (PPLT) signal displays currently in use.

The most common application of PPLT signal displays is the use of a shared signal head (centered over the lane line between the left-turn lane and adjacent through lane) to meet MUTCD requirements of two signal heads per major approach movement. As a result, the implementation of the FYA in this display would require the FYA be displayed simultaneously with the through movement indication of circular green, circular yellow, or circular red. There was a need to research driver comprehension of the FYA permissive indication when it is used in a simultaneous display.

This research evaluated driver comprehension of the resulting simultaneous displays using a dynamic driving simulator experiment, follow-up computer-based static evaluation as well as an independent static evaluation completed in both Amherst, Massachusetts and Madison, Wisconsin. A comparison of seven different permissive left-turn scenarios featuring the CG and/or FYA permissive indications was completed. In total, 264 drivers participated in the research, evaluating 3,457 permissive left-turn scenarios. In the driving simulator, the simultaneous indications in the retrofit display (simultaneous indication display) did not improve nor reduce driver's understanding of the display. In a follow-up static evaluation, *yield* responses ranged from a low of 65 percent for the CG permissive indication in a five-section cluster configuration to a high of 89 for the proposed retrofit display. Therefore, there is evidence to suggest that the simultaneous indications in the retrofit display may improve driver's comprehension of the permissive indication.

Keywords: Protected / Permissive Signal Control, Left-Turns, Driving Simulation, Traffic Operations, Signal Phasing

INTRODUCTION

Improving safety for the traveling public has been a consideration in the design and operation of transportation facilities for years. Nevertheless, the desire to improve the capacity of our roadway system to accommodate rapidly growing traffic volumes often outweighs the sometimes conflicting safety improvements. The Intermodal Surface Transportation Efficiency Act (ISTEA) legislation in 1992 fundamentally changed the transportation delivery process by making safety improvements a key component of all transportation programs including those focused on capacity. One significant safety program with ISTEA and the following Transportation Equity Act for the 21st Century (TEA-21) legislation in 1998 was signalized intersection safety. Perhaps the most significant safety elements in signalized intersection operation are simultaneous movements which cross paths; specifically, left-turn movements.

The recently completed National Cooperative Highway Research Program (NCHRP) Project 3-54 was a comprehensive, national research study to evaluate operational advantages and safety aspects of various left-turn controls at signalized intersections. Specifically, the research evaluated all elements of protected/permissive left-turn (PPLT) signal phasing. PPLT signal phasing was a concept developed to improve operational efficiency at signalized intersections by providing a protected 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*).

PPLT research (sponsored by NCHRP) was based on several identified problems (*2*). The recurring major issue, targeted by traffic engineers and drivers alike, was the permissive indication. Permissive left-turn opportunities were communicated to the driver through a circular green (CG) indication. Unlike for a through movement, the CG meant that drivers wishing to complete a left-turn must first yield to oncoming traffic and accept a gap in the opposing traffic stream. Some argued that the CG permissive indication was adequate while others argue that a *unique* indication was needed because drivers, particularly those in a left-turn lane, may interpret the CG as a protected indication, resulting in a situation with high crash potential. For this reason, the permissive indication became the primary focus of NCHRP project 3-54 (*2*).

After a series of studies that included evaluations of driver-based human factors, driver comprehension, and intersection operations, the NCHRP 3-54 research team concluded that a flashing yellow arrow (FYA) permissive indication provided a viable alternative to the CG permissive indication. Therefore the research team recommended that the FYA permissive indication should be included in the Federal Highway Administration's (FHWA) Manual on Uniform Traffic Control Devices (MUTCD) as an acceptable and perhaps recommended indication for permissive left-turns. Since 1938, the MUTCD has been the leading document in providing guidance regarding the use of traffic signal displays (*3*). Changes to the MUTCD are recommended to the FHWA by the National Committee on Uniform Traffic Control Devices (NCUTCD). Initial review by the NCUTCD of the NCHRP research recommendations, including adoption of the FYA permissive indication into the MUTCD, resulted in several additional research statements. This research effort was established to specifically address one of the research questions posed by the NCUTCD as described in the sections below.

PROBLEM STATEMENT

With respect to PPLT signal phasing, the MUTCD does not require a separate signal head for left-turn control. The MUTCD also indicates that, "if a shared signal face is provided, it shall be considered an approach signal face...during the permissive left-turn movement, all signal faces on the approach shall display CIRCULAR GREEN signal indications." A shared signal face is located in a position over the lane line between the left-turn lane and adjacent through lane, such that signal display is shared by motorists in each of these lanes. To meet MUTCD requirements that no less than two signal faces be provided for the major movement of the approach, the most common installation of PPLT signal phasing has become a five-section cluster arrangement and an accompanying three-section vertical arrangement. In this setup, the five-section cluster arrangement is located in a shared location and the three-section vertical is located over the adjacent through lane. An example of this PPLT signal display is pictured in Figure 1.

The MUTCD requirement to display a CG signal indication on all signal faces on the approach during the permissive left-turn movement creates a problem with the implementation of the FYA permissive indication. In a shared signal face, the FYA must be simultaneously displayed with the CG (in the five-section display) to assure that two indications are provided for the through movement. To overcome this problem, an additional signal display is required that can operate as a separate signal face. The cost and logistics of installing this additional display may prevent some for implementing the FYA permissive left-turn indication.

In an attempt to ease the implementation of the FYA permissive indication for practitioners, there is a need to evaluate driver comprehension of the FYA permissive indication in the most common application of PPLT signal phasing. That is, the proposed display would incorporate the shared five-section cluster arrangement and adhere to MUTCD requirements by providing simultaneous through and left turn indications.

In the PPLT signal display presented in Figure 2, the permissive indication would display a FYA permissive indication presented simultaneously with a circular green (CG), yellow (CY) or red (CR) indication. Furthermore, both the protected green arrow and FYA indications would be cleared with a solid yellow arrow in the signal section directly above the bi-modal section. This is a preferred alternative as it uses a change of indication and location to alert drivers. It should be noted that this signal display is intended to be only a temporary implementation until the separate left-turn signal face recommended by the NCHRP research team could be installed.

The resulting study question is as follows:

What is the (left-turner) driver's comprehension of the flashing yellow arrow when used in a five-section display, which is a shared display with the adjacent through lane? More specifically, what is driver's comprehension with the flashing yellow arrow in a five-section head when it is used as one of the two required heads, thus requiring the through movement indication to be displayed simultaneously with the flashing yellow arrow? Additionally, how does this comprehension compare to current the CG standard as well as the FYA in an exclusive signal head as recommended in NCHRP 3-54?

EXPERIMENTAL DESIGN

The intent of this research was to quantify driver comprehension of FYA permissive indications when it appears as part of a simultaneous indication (dual display). The research comprised three primary tasks, including a dynamic driving simulator experiment, a follow-up static evaluation, and an independent static evaluation administered in both Massachusetts and Wisconsin. The details of these evaluations and a description of the driving simulator and static evaluation instrument used are discussed in the following sections.

Signal Displays for Evaluation

The study was focused on driver's comprehension of the simultaneous indications in the five-section cluster display (the dual displays). The dual display scenarios included the FYA permissive indication displayed simultaneously with the adjacent through indications, which was either a CR, CY, or CG indication. Nevertheless, additional displays were included in the experiment to provide comparison information, variability in what drivers observed, and to counterbalance the objective functions. One additional display evaluated was the current PPLT display recommended by the MUTCD featuring a shared face application of a five-section cluster configuration with only CG indications on all signal faces. Additionally, three PPLT signal displays were evaluated including a FYA permissive indication in a four-section vertical configuration located exclusively over the left-turn lane; these displays differed only by the adjacent through movement indication, either CG, CY, or CR. A reasonable assumption of the research was that drivers were not familiar with the FYA prior to their participation in the experiment, given that the CG permissive indication in a five-section cluster is the predominant display used in both study locales of Massachusetts and Wisconsin. The permissive displays evaluated in the experiment are represented in Figure 3.

Driving Simulator Experiment

The initial methodology of evaluation was a dynamic driving simulator experiment completed in the Human Performance Laboratory at the University of Massachusetts – Amherst (UMass). The UMass driving simulator, pictured in Figure 4, is a full-scale, fixed-base fully-interactive dynamic driving simulator. Drivers are capable of controlling the steering, braking, and accelerating similar to the actual driving process; the visual roadway adjusts accordingly to the driver's actions. Three separate images are projected to create the "visual world" on a large semi-circular projection screen creating a field-of-view subtending 150-degrees.

Development of Simulated Environment

A virtual network of intersections was created for use in the HPL driving simulator. Each driver participating in the experiment completed a course consisting of multiple driving modules, each containing 14 total intersections. Figure 5 presents a simulated screen capture from the experiment. Each driving module was a continuous loop with multiple starting positions. Varying the starting positions provided appropriate counterbalancing to assure that each PPLT scenario was equally likely to be presented first to drivers. The rational for including the additional intersections which required drivers to complete a protected left-turn maneuver, proceed straight, or turn right was provide experimental variability and reduce the probability of drivers keying in on the nature of the evaluation. For this task, the dependent variables at the experimental intersections included drivers' comprehension of the permissive signal displays presented previously in Figure 3.

Operational Characteristics of Simulation

The operational characteristics within the simulation were consistent at all intersections requiring drivers to complete a left turn. All experimental signal displays within the simulation rested in either a red (circular or arrow) or a protected left-turn (green arrow) indication as drivers approached the intersection. The signal displays then changed to the test indications once the driver was approximately 30 meters prior to the intersection stop bar. The exception to this was the two scenarios featuring an adjacent circular yellow (scenario numbers 4 and 7 in Figure 3). For these two scenarios the displays rested in the given permissive indication and changed to the test indication, which was either a FYA/CY indication or FYA in a four-section vertical configuration with adjacent through movement of CY. Because the preceding indication was permissive it was not reasonable to assume that the opposing traffic would be queued, which provided justification for analyzing these two scenarios separately.

Each PPLT signal display was evaluated with opposing traffic at the intersection. The opposing traffic required drivers to simultaneously evaluate the PPLT signal display, traffic movement, and opposing gaps to complete a safe permissive left-turn maneuver. This methodology replicates the decision process required during actual operation of a motor vehicle within the roadway system, and may provide insight regarding the cues drivers use during the completion of a permissive left-turn maneuver.

All gaps in opposing traffic were consistently applied at intersections which drivers were required to make a permitted left-turn maneuver. Two vehicles were always positioned at the stop bar in the two through lanes opposing the left-turn driver. The remaining four were positioned further upstream in a specified gap sequence. Gaps were set at three and seven seconds in a series of 7-3-7-7; therefore, opposing vehicles crossed the intersection seven, 10, 17, and 24 seconds behind the two initially queued opposing vehicles. The critical gap concept was used to select the gap sizes. For permissive left-turns the critical gap would refer to the minimum time between opposing major-stream vehicles through which an average left-turn driver would complete their maneuver. The Highway Capacity Manual indicates a critical gap value of 5.5 seconds for permissive left-turn maneuvers in the design of a four-lane roadway (*4*). Therefore, a three second gap was selected because it was small enough that a majority of driver’s will not accept it, and a seven second gap was selected because it was generally acceptable to most drivers. Providing a consistent sequence of three and seven second gaps prevented gap selection from being a significant variable in the PPLT analysis.

Simulation Experimental Procedure

Participants driving the simulator vehicle were instructed to drive as they would drive their own vehicle. Specifically, don’t drive overly conservative nor drive extremely aggressive. Drivers successfully completing a practice course, free of simulator sickness, were permitted to continue with the simulator experiment. Following the practice course, drivers complete two driving modules. As noted, each module contained 14 intersections, eight of which require left-turn maneuvers. The sequential order in which drivers observe the experimental scenarios varied from driver to driver. This method provided a desired level of randomness to the signal displays evaluated and reduce the effects of learned behavior during the experiment. The driving portion of the experiment, including the practice module, required an average of 15 minutes.

Recording Driver Responses

With respect to driver comprehension, driver's responses at each PPLT signal display scenario was manually recorded. Correct responses were noted accordingly and incorrect responses were further classified as fail-safe or fail-critical. A fail-safe response is one in which the driver did not correctly respond to PPLT signal display arrangement/permissive indication combination, yet did not infringe on the right-of-way of opposing traffic. A fail-critical response was an incorrect response in which the driver incorrectly responded to the PPLT signal display and impeded the right-of-way of opposing traffic, thus creating the potential for a crash. Research team members manually recorded simulation results, including responses at each intersection and other driving related factors such as indecision, unnecessary braking, or any pertinent verbal comments made.

Static Evaluations

Each driver completing the dynamic driving simulator experiment also completed a follow-up computer-based static evaluation immediately after driving in the simulator. Over 100 subjects in Madison, Wisconsin and Amherst, Massachusetts were recruited to complete the experiment. The static evaluation instrument presented drivers with various traffic signal displays in realistic background photos and allowed for the signal indications to flash as required. A sample computer-based static evaluation scenario presented in Figure 6. For each signal display drivers were asked to respond with one of four choices to the following question:

"If you want to turn left and you see the traffic signal lights shown, you would?"

- Go, you have the right-of way;
- Yield, then go if a gap in the opposing traffic exists;
- Stop, then go if a gap in the opposing traffic exists; or,
- Stop and wait for the appropriate signal.

As part of the static evaluation, drivers observed the PPLT scenarios presented in Figure 3, as well as additional scenarios at which the appropriate response would be different, including both protected green arrow scenarios, prohibited red indications, and solid yellow change indications. In total, each driver observed 29 scenarios as part of the static evaluation. The static evaluation instrument was designed such that the order in which the scenarios were presented was completely randomized across drivers, and it also allowed for all the driver responses to be downloaded to a spreadsheet file.

RESEARCH RESULTS

A total of 264 drivers participated in the experiment with 54 drivers participating in the dynamic driving simulator experiment and follow-up static evaluation and 210 drivers participating in the independent static evaluation. Of the 210 independent static evaluation drivers, 101 completed the experiment in Massachusetts and 109 completed it in Wisconsin. The driver demographics included an approximate split of males and females and comprised an extensive range of driver ages. Six drivers participating in the simulator experiment elected not to complete the simulation as a result of simulator induced discomfort or time constraints, yet all 54 managed to fully complete the follow-up static evaluation. In total, 553 PPLT scenarios were evaluated in the driving simulator, 594 PPLT scenarios were evaluated in the follow-up static evaluation, and 2,310 PPLT scenarios were evaluated in the independent static evaluation. A series of chi-square analyses were used to identify statistically significant differences. The appropriate statistical values are reported in parentheses throughout this section. Note that a p-value less than 0.05 indicates statistically significant differences at the 95 percent confidence level.

Driving Simulator Experiment

In the driving simulator experiment, five experimental scenarios were initially considered in the dual display analysis (all scenarios presented in Figure 3 except those with an adjacent circular yellow through indication). Driver simulator responses were classified as follows to allow comparison with the static evaluations:

- Go – the driver incorrectly perceived the right-of-way and either crashed or narrowly avoided a crash;
- Yield – the driver correctly yielded the right-of-way to opposing vehicles before selecting a gap in opposing traffic;
- Stop first – the driver stopped at the left-turn lane stop bar and waited for all opposing vehicles to pass before proceeding; Note: this response was also considered to be correct; or
- Stop and wait – the driver stopped at the left-turn stop bar and waited even after all opposing vehicles had cleared waited as if waiting for the signal to change. Drivers had to be instructed to proceed, but were instructed to continue doing that which they believed to be appropriate at future intersections.

Figure 7 presents the breakdown of driver responses from the driving simulator experiment. The percentage of *yield* responses ranged from 69 to 84 percent with no statistically significant differences across the five scenarios ($p = 0.303$). However, because drivers electing to *stop first* did not make an error and were instead only driving cautiously, the *yield* and *stop first* responses were combined and both considered correct. When these responses are combined the percentage of correct responses ranged from 94 to 98 percent, and again the differences between scenarios were not statistically significant ($p = 0.636$).

With respect to incorrect responses, only six drivers made a *go* response. *Go* responses were of primary interest as they demonstrate the most critical error in understanding. It should be noted that three of these responses occurred on the experimental scenario that presented a FYA permissive indication in a four-section vertical arrangement with an adjacent through movement green indication. One *go* response was recorded in each of the other displays except the CG only display.

Follow-Up Static Evaluation

Following the driving simulator experiment, drivers were presented with the same scenarios again in the form of a computer-based static evaluation. Figure 8 presents the breakdown of all four possible responses from the follow-up static evaluation completed by each of the 54 driving simulator participants. *Yield* responses ranged from a low of 65 percent to a high of 89 percent, and an initial chi-square analysis of the responses indicated statistically significant differences in the distribution of *yield* responses across the five displays ($p = 0.016$). Specifically, the scenario featuring a five-section-cluster arrangement simultaneously displaying a FYA/CG permissive indication had a significantly higher percentage of yield responses than all other displays except the FYA in a four section vertical configuration when the adjacent through movement indication was CG.

No statistically significant differences existed in the percentages of *stop first* responses (p = 0.53). Nevertheless, when *yield* and *stop first* responses were combined, with both considered as correct responses, the percent of responses ranged from 83 to 98 percent and statistically significant differences were again observed. The percentage of *yield* and *stop first* responses was significantly higher for the five-section cluster configuration with the simultaneous CG/FYA indications than for the five-section cluster with only the CG permissive indication.

Consistent with previous research, the scenario depicting only a CG permissive indication resulted in the highest percentage of *go* (fail-critical) responses (six responses representing 11 percent of all responses for that scenario). Four *go* responses were recorded at the scenario with a FYA permissive indication in a four-section vertical when the adjacent through movement was CG. The remaining scenarios each had between one and three *go* responses (less than six percent). Statistically the difference in go responses was not statistically significant (p= 0.296)

Independent Static Evaluation

A similar analysis approach was used for the independent static evaluation. The data were initially disaggregated by the location in which they were collected (Massachusetts or Wisconsin). A chi-square analysis indicated statistically significant differences in the responses given at each location. As a result, the Massachusetts and Wisconsin were not combined for analysis, rather the data sets were analyzed independently and significant differences between the two were identified.

Figure 9 presents the breakdown of driver responses for the 101 Massachusetts drivers. The distribution of responses for the five experimental displays differed significantly (p = <0.01). Collapsing the data and considering only the percentage of *yield* responses results in the identification of statistically significant differences across the experimental displays. Specifically, the permissive FYA displayed simultaneously with a CG resulted in significantly more *yield* responses than all other displays except the FYA in a four-section vertical configuration with adjacent CG indication (p = <0.01).

Although there were not statistically significant differences in the percentage of *stop first* responses by scenario among Massachusetts drivers (p = 0.278), there were statically significant differences when the *yield* and *stop first* responses were combined (p = 0.002). With respect to the combined *yield* and *stop first* responses, the CG/FYA display resulted in significantly more responses than both the CG display and simultaneous CR/FYA displays. Additionally, the scenario featuring a FYA in a four-section vertical resulted in a statistically higher percentage of yield and stop first responses than the scenario with only a CG permissive indication. As in the follow-up static evaluation, the scenario with only the CG permissive indication resulted in the highest percentage of *go* responses (13 percent). The other four scenarios had between five and seven percent *go* responses; however the difference across all five scenarios was not significantly different (p = 0.153). Isolating the *stop and wait* responses also resulted in statistically significant differences across the five displays. Specifically, the FYA/CR and CG scenarios both resulted in significantly more *stop and wait* responses than the FYA/CG scenario. The FYA/CR scenario also resulted in significantly more stop and wait responses than the scenario featuring a FYA in a four-section vertical with adjacent CG through movement.

Figure 10 presents the breakdown of responses among Wisconsin drivers for each of the five experimental displays evaluated in the independent static evaluation. Analysis of the Wisconsin data resulted in the following:

- *Yield* responses – ranged from 50 to 72 percent resulting in statistically significant differences (p = 0.007);
- *Go* responses – percent of responses ranged from six percent to 15 percent, but was not statistically significant (p= 0.059).
- *Yield* and *stop first responses* - significant differences are present (p = 0.017).
- *Stop and wait* responses - two scenarios with an adjacent CR indication resulted in a higher percentage of *stop and wait* responses than both scenarios with a CG in a five-section cluster and the scenario featuring a simultaneous FYA/CG indication.

The percentage of *yield* responses for the FYA permissive indication displayed in a four-section vertical configuration with CG adjacent through indication resulted in significantly more *yield* responses than the scenario featuring the simultaneous FYA/CR indication in a five-section cluster. Upon combining the *yield* and *stop first* responses, still further significant differences are present (p = 0.017). Specifically, the CG permissive indication resulted in significantly more correct responses than the FYA/CR simultaneous indication in a five-section cluster.

A side-by-side comparison of responses between Massachusetts and Wisconsin respondents was completed. Considering yield responses there were no statistically significant differences between Massachusetts and Wisconsin responses for any particular PPLT scenario. When the *yield* and *stop first* responses are combined there was a statistically higher percentage of combined *yield* and *stop first* responses for the scenario featuring the dual FYA/CG among Massachusetts responses.

FYA Scenarios with Circular Yellow Adjacent Through Movement Indication

As previously discussed, two additional permissive scenarios were evaluated in the driving simulator and static evaluations. The displays contained a FYA permissive indication in either a five-section cluster of four-section vertical configuration and were accompanied by an adjacent through movement circular yellow (CY) indication. Recall, that in the simulator the traffic scenario for these two displays needed to be presented differently. As a result, fail-critical responses were not recorded and only anecdotal information regarding driver comprehension was recorded. For example, in the five-section cluster arrangement with simultaneous FYA/CY indication, two drivers stopped and had to be directed to proceed. By comparison, when the FYA was located in an exclusive four-section vertical signal head and the adjacent through indication was CY no drivers needed to be directed to proceed.

A better assessment of drivers' comprehension of these two displays occurred in the both the follow-up and independent static evaluations as presented in Figure 11. The percentage of *yield* responses was greater in each case for the scenarios with the four-section vertical configuration than for the dual display; however this difference was only statistically significant in the Massachusetts independent static evaluation (p = 0.007). As before, *yield* responses are correct, however, *stop first* responses may also be considered as correct responses. When both responses are considered correct there are no statistically significant differences between the two different configurations (five-section cluster versus four-section vertical) scenarios within each grouping. Approximately, four percent of drivers participating in the follow-up static evaluation and Massachusetts independent static evaluation responded *go* for these two scenarios, while over 14 percent of Wisconsin drivers responded *go;* however, this difference between Massachusetts and Wisconsin drivers was not statistically significant.

CONCLUSIONS AND RECOMMENDATIONS

The results presented led to the following conclusions:

- No statistically significant differences in the percentage of *yield* responses across all scenarios evaluated were found in the dynamic evaluation. Similarly, there were no statistically significant differences in the combined *yield* and *stop first* responses. The simultaneous indications in the retrofit display did not improve nor reduce driver's understanding of the display. Nevertheless, it is worth noting that drivers were not familiar with the FYA prior to their participation in the experiment, yet still had high levels of comprehension.
- In the follow-up static evaluation, *yield* responses ranged from a low of 65 percent for the CG permissive indication in a five-section cluster configuration to a high of 89 for the proposed retrofit display; and the difference in *yield* responses between these two scenarios was statistically significant at the 95 percent confidence level. However, there were no statistically significant differences across scenarios when the *yield* and *stop first* responses are both considered as correct. Therefore, the evidence suggests that the simultaneous indications in the retrofit display may improve driver's comprehension of the permissive indication.
- For the independent static evaluation, results varied geographically:
    - In Massachusetts, the proposed retrofit display with the permissive FYA displayed simultaneously with a CG resulted in significantly more *yield* responses than all other displays except the FYA in a four-section vertical configuration with adjacent CG indication. When both the *yield* and *stop first* responses are considered correct, statistically significant differences are still present among Massachusetts drivers' responses. Specifically, the proposed retrofit resulted in significantly more correct responses than both the scenario with the existing CG permissive indication and the scenario with FYA permissive indication in a five-section cluster displayed simultaneously with a CR through indication.
    - In Wisconsin, the percentage of *yield* responses for the FYA permissive indication displayed in a four-section vertical configuration with adjacent through CG resulted in significantly more *yield* responses than the scenario featuring the FYA permissive indication in a five-section cluster displayed simultaneously with a CR through indication. Upon combining the correct responses still further significant differences are present. Specifically the existing CG permissive indication resulted in significantly more correct responses than the FYA permissive indication in a five-section cluster displayed simultaneously with a CR through indication.

The research results in the following recommendations.

- The driver comprehension of the FYA permissive indication determined in this research is consistent with previous research findings and supports inclusion of the FYA permissive indication in the MUTCD. As a result, it is recommended that the FYA be unconditionally approved for use as a left-turn permissive indication in the MUTCD.
- Currently, the most common PPLT installation includes a shared PPLT signal display, which requires the adjacent through movement indication to be simultaneously displayed.

The FYA, when displayed as part of a dual indication display, was consistent with all other permissive indication combinations evaluated. Therefore, the conflicting message of the CR/FYA display suggests that the preferred implementation of the FYA be an exclusive signal head as recommended in NCHRP 493 (*2*).

- Although the research has addressed several specific questions related to the implementation of the FYA permissive indication as part of simultaneous indication, it is recommended that future research should continue to address remaining issues, including field evaluations of simultaneous indications including the FYA permissive indication, expanded analysis related to elderly drivers, and potential impacts of the FYA on driver comprehension of solid yellow arrow indications used in cluster configurations.

ACKNOWLEDGMENTS

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LIST OF FIGURES

Figure 1 Example of common PPLT signal display using a shared signal head.

<table>
<tr><th rowspan="2">Lens Color and Arrangement</th><th colspan="2">Left-Turn Indication[a]</th></tr>
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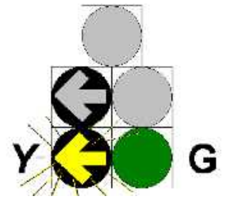
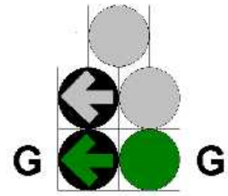
<tr><td></td><td></td><td>
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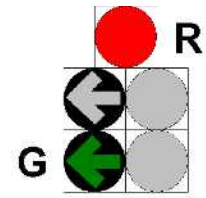</td></tr>
</table>

R = Red   Y = Yellow   G = Green   *Y* = Flashing Yellow

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

Figure 2 Potential retrofit application of the FYA using existing five-section cluster displays.

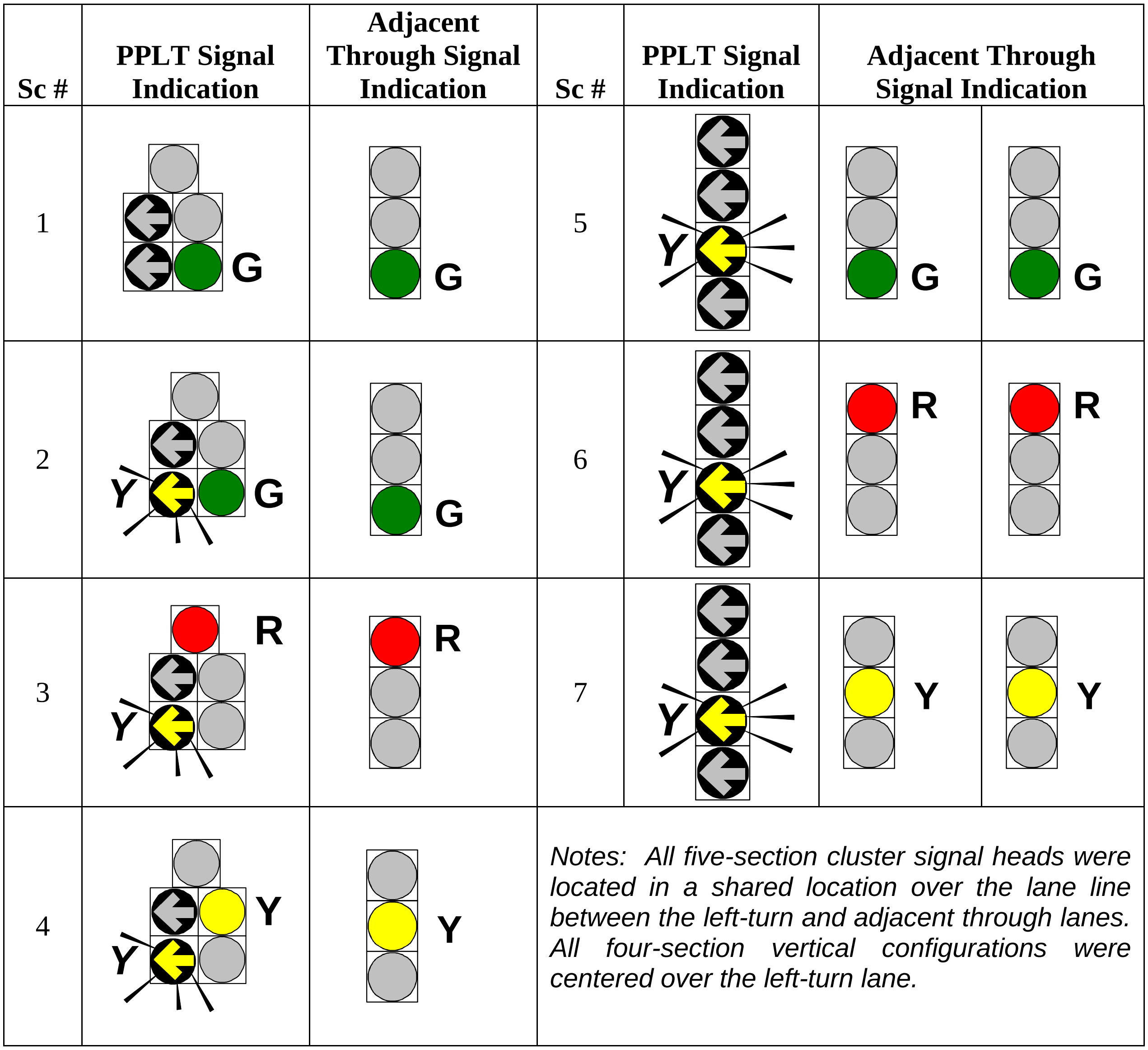

Figure 3 Permissive signal displays evaluated with dual displays.

Figure 4 UMass Human Performance Laboratory driving simulator.

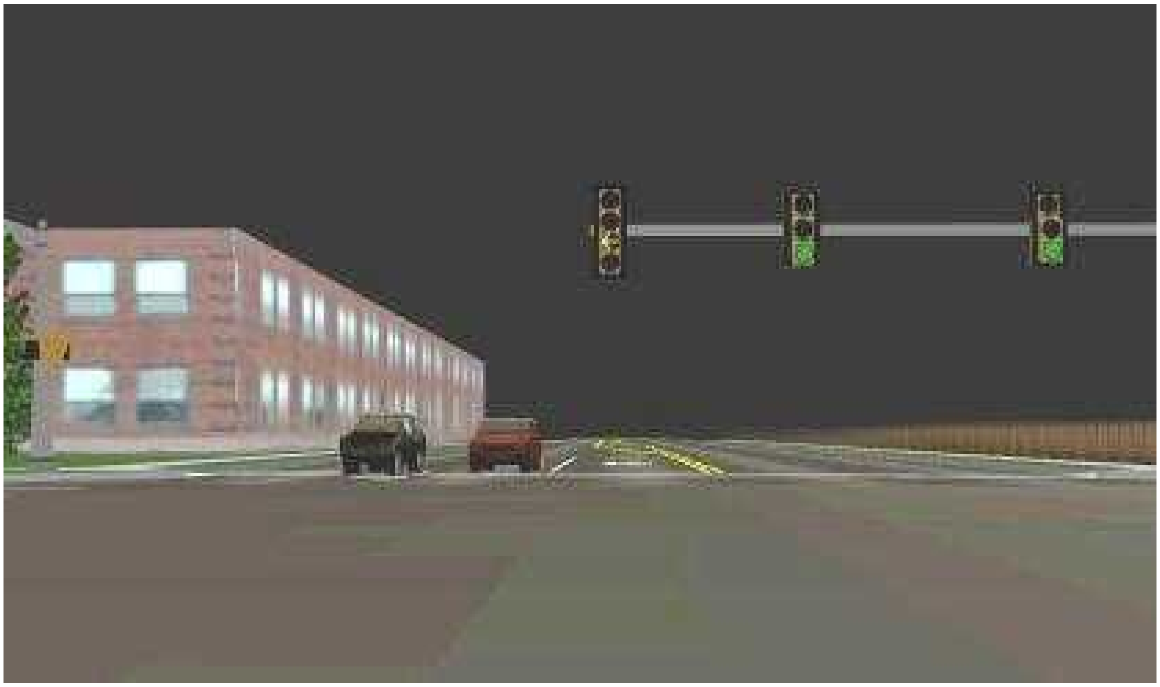

Figure 5 Sample screen capture from driving simulator experiment.

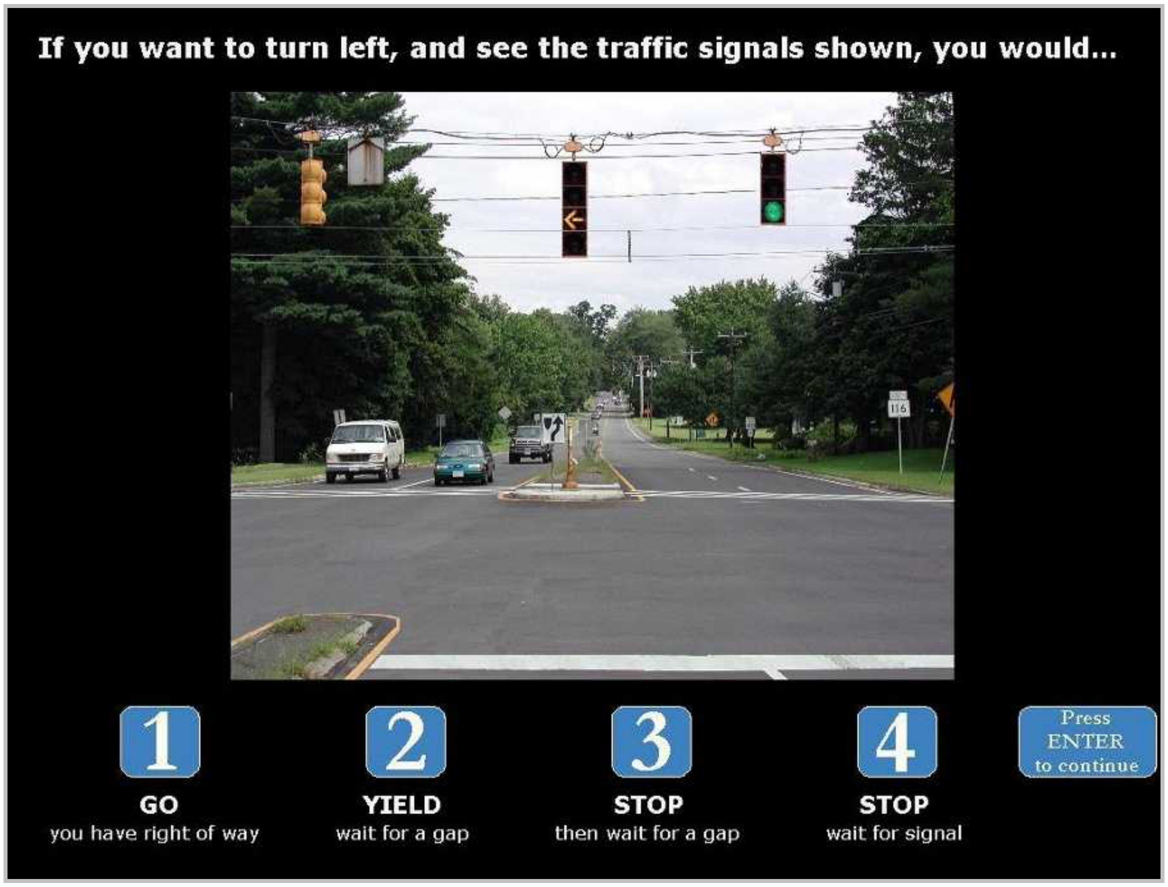

Figure 6 Sample from computer-based static evaluation.

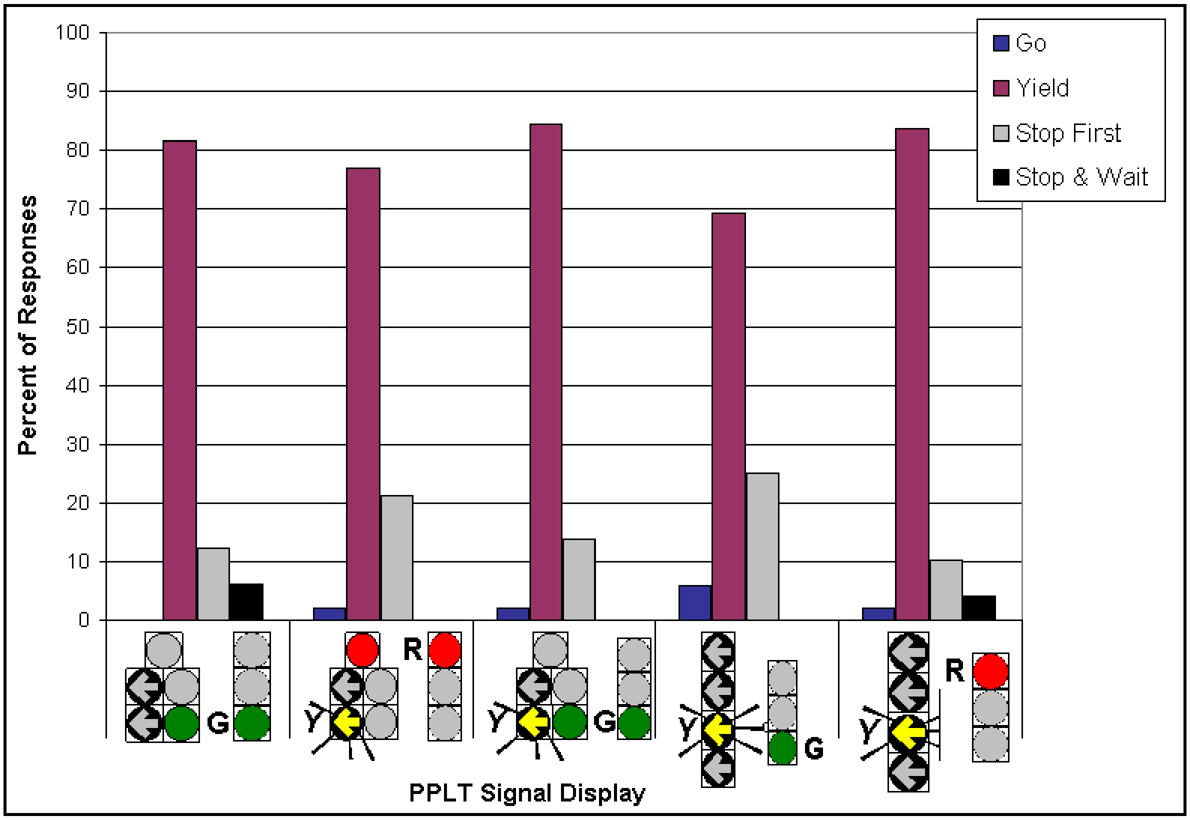

Figure 7 Breakdown of driver responses from driving simulator experiment.

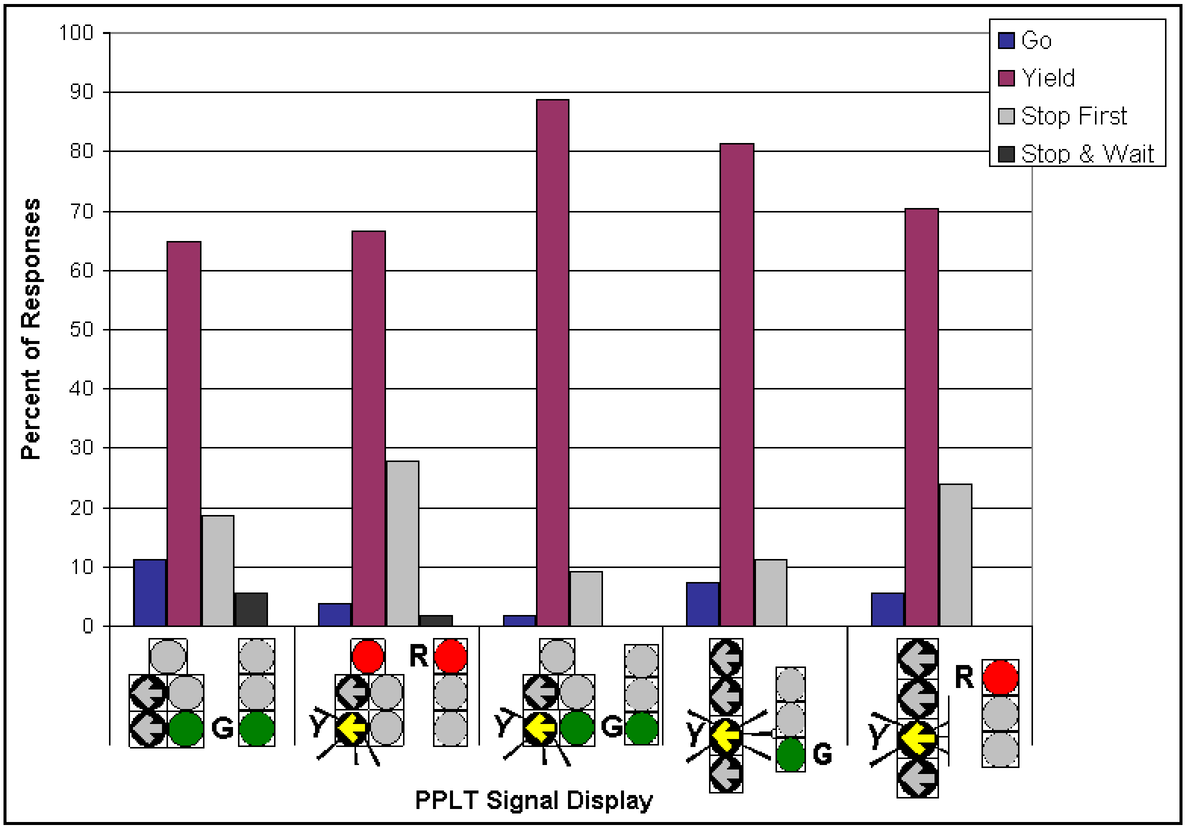

Figure 8 Breakdown of driver responses from follow-up static evaluation.

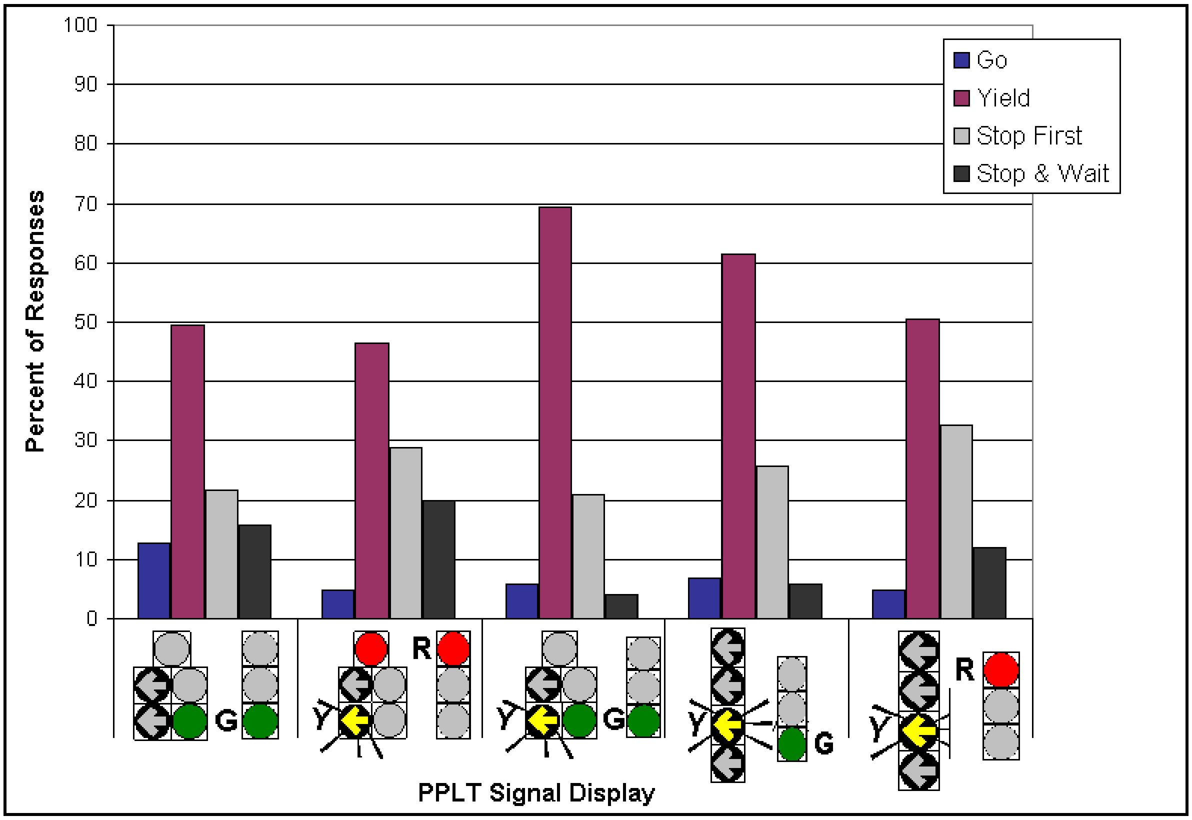

Figure 9 Breakdown of driver responses for static evaluation in Massachusetts.

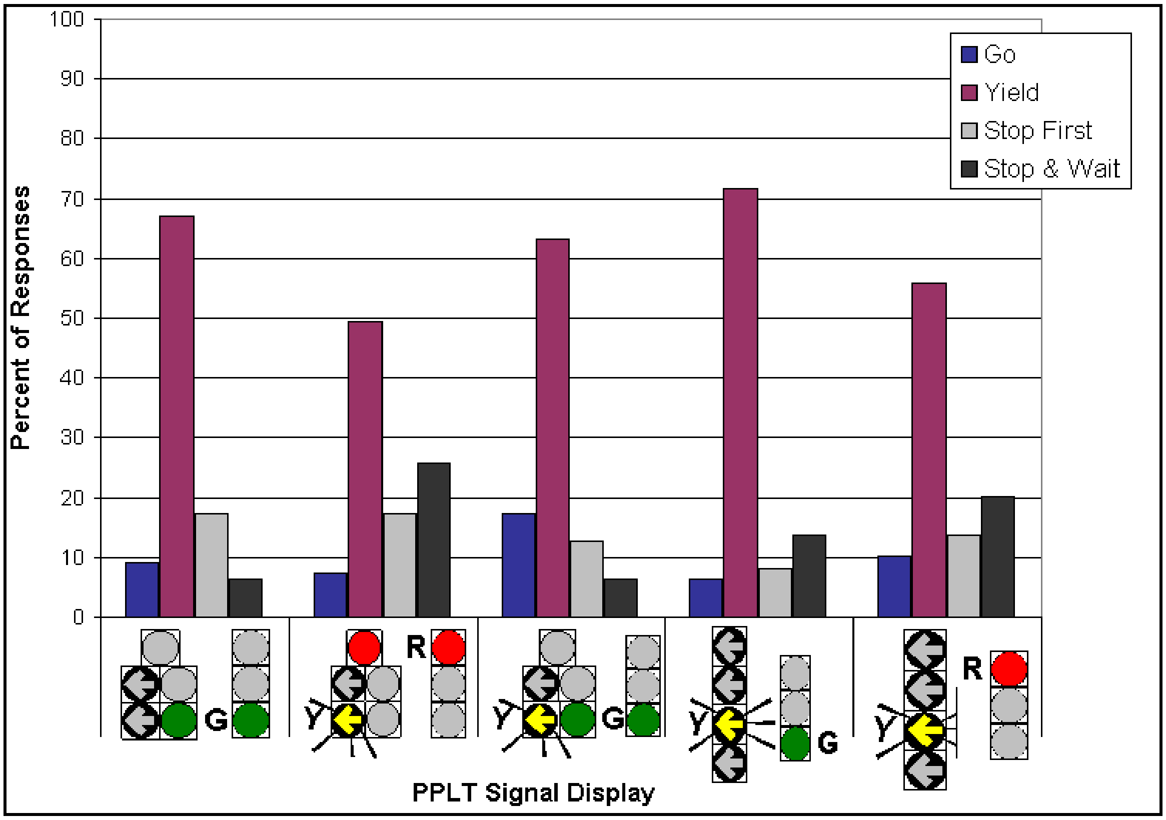

Figure 10 Breakdown of driver responses for static evaluation in Wisconsin.

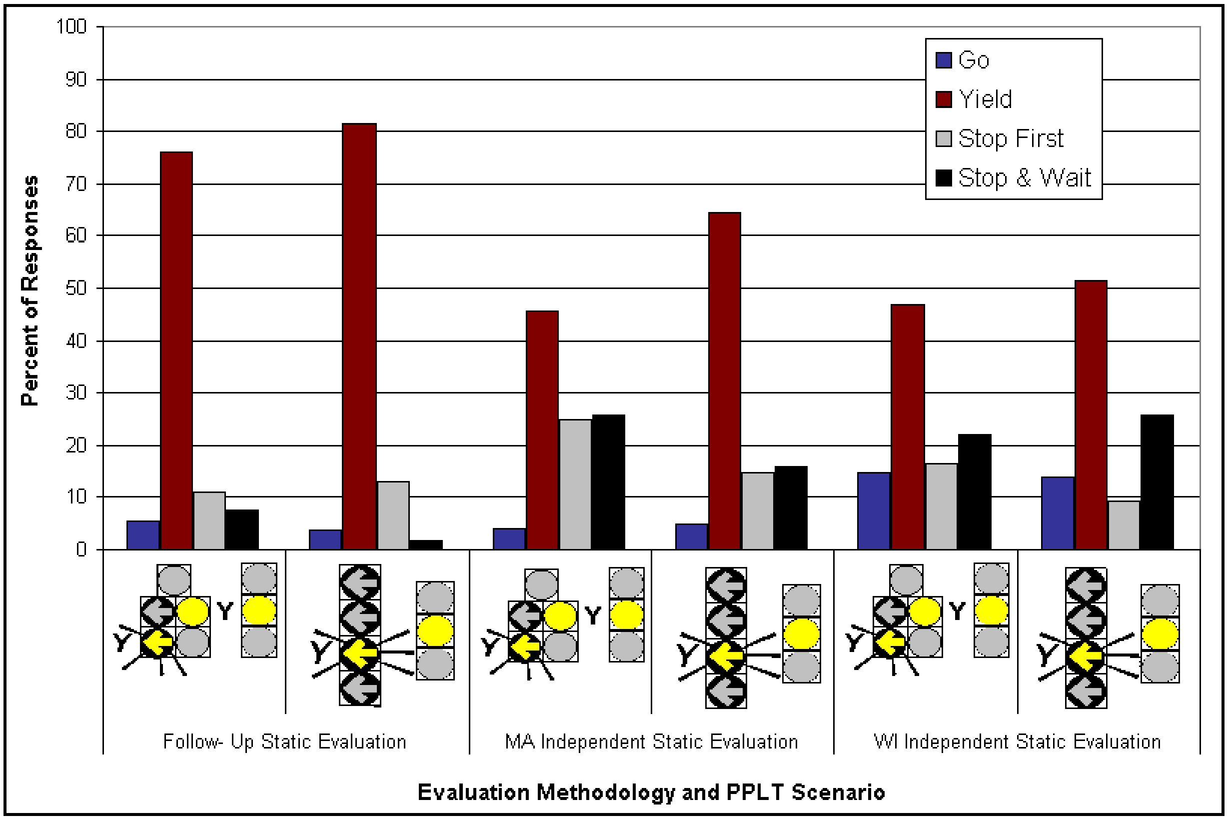

Figure 11 Driver responses for FYA and solid circular yellow scenarios.