DRIVER COMPREHENSION OF THE CIRCULAR YELLOW INDICATION: IMPLICATIONS OF REGIONAL VARIABILITY

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ABSTRACT

It has been postulated for some time that the indecision zone contributes to the occurrence of rear-end and right-angle crashes at signalized intersections. Much effort has been expended on the identification of situational factors that influence a driver's behavior when presented a circular yellow indication (CY), and the construction of boundary descriptions for the region that the indecision zone occupies on the approach to the intersection. The notion that drivers comprehend the appropriate message from the CY is accepted without question. However, before the indecision zone can be fully understood or defined by transportation professionals, the assumption that drivers are correctly interpreting the intended message of the CY needs to be validated. This collaborative research effort between Oregon State University and the University of Massachusetts Amherst evaluated both the situational and literal comprehension of 130 drivers in Massachusetts (65 drivers) and Oregon (65 drivers) to acquire information on driver comprehension of the CY. Driver comprehension of the CY was categorized by three factors: identification of the intended message, the signal immediately following the CY, and the duration of the CY. Additionally, predictive behavior was analyzed for three factors: being the lead or following vehicle, approaches with one or two through lanes, and relative distance from the stop bar. Statistically significant differences were determined between drivers in Massachusetts and Oregon regarding both comprehension and predictive behavior. Correct driver response occurred at a rate far lower than desirable. Thus, the results of study could contribute to improved educational and design procedures.

INTRODUCTION

A myriad of research has postulated that the dilemma and/or indecision zone contributes to rear-end and right-angle crashes at signalized intersections (*1*). This body of knowledge has concentrated on the identification of situational factors that influence a driver's decision to proceed though the intersection or stop at the stop bar (*2*, *3*), and/or the construction of boundary descriptions for the region that the indecision zone occupies on the approach to the intersection (*4, 5, and 6*). The transportation engineering community must revisit the assumption that driver's are correctly interpreting the intended message of the CY. Clearly, the difficulties drivers experience in making decisions when presented with the CY while approaching a signalized intersection cannot be separated from the driver's comprehension of the message that the indication is conveying. If the driver does not understand the message being presented, then the response to that message may vary substantially. This collaborative research effort between Oregon State University and the University of Massachusetts Amherst sought to acquire information on driver comprehension of the CY in order to better understand if the correct messages were interpreted by the driver. A series of quantifiable research questions are developed in the next section to address the overarching research goal.

Research Questions

The underlying assumption by the traffic engineering community that drivers are correctly interpreting the intended message of the CY needs to be evaluated in an effort to quantify this assumption's operational effects on real-world behavior. To adequately address this postulate the following null hypotheses were tested through this collaborative research effort described herein:

- $H_{O\ Meaning}$: 85 percent of drivers will correctly identify the messages stipulated by the Manual on Uniform Traffic Control Devices (MUTCD) for the CY in all signal configurations.
- $H_{O\ Sequence}$: 85 percent of drivers will correctly identify the signal to appear immediately after the CY for all signal configurations.
- $H_{O\ Duration}$: 85 percent of drivers will correctly identify the duration recommended by the MUTCD for the CY.

The overarching theory of the proposed research was examined by evaluating the three identified research questions associated with driver comprehension and behavior upon exposure to the solid yellow indication. To build the argument for these research questions and to set the stage for the experimental design in the sections that follow we have included a brief survey of the literature (which is in no way intended to be comprehensive) relevant to the standards for the CY in the MUTCD and the enforcement policies in Oregon and Massachusetts. Discussion on the use of static evaluation as an experimental means of assessing driver comprehension of a traffic signal is also presented.

Standards of Practice

In order to determine if drivers are correctly interpreting the intended messages of the CY indication it is necessary to establish a convention for what those messages are. The MUTCD is the generally accepted authority on the application of traffic signs, signals, and pavement markings within the United States. The MUTCD defines the meaning of a CY as the following: *A Yellow signal indication shall be displayed following every CIRCULAR GREEN or GREEN ARROW signal indication. The exclusive function of the yellow change interval shall be to warn traffic of an impending change in the right-of-way assignment. The duration of a yellow change interval shall be predetermined* (*7*).

Therefore, the place in the phasing sequence occupied by the yellow indication is required as well as the meaning of the indication. However, there is no required method for the calculation of the length of the CY. The only guidance provided by the MUTCD on the calculation of the change interval is the statement that: *A yellow change interval should have approximately 3 to 6 second duration. The longer intervals should be reserved for use on approaches with higher speeds* (*7*).

It seems that the impact of traffic laws and enforcement practices regarding the CY indication could also contribute to correct driver comprehension of the CY indication. For this purpose traffic laws were briefly examined in the U.S. with particular attention to the enforcement laws associated with Oregon and Massachusetts.

Yellow Indication Traffic Laws

As emphasized by Awadallah, there is a lack of uniformity in the legal requirement for the driver's interaction with the CY indication (8). Parsonson found that the law is implemented as either permissive or some form of restrictive and that these two categories each respectively encompass approximately half of the states (9). These designations can be described as follows:

1.) *Permissive yellow law*, which allows drivers to enter the intersection (typically considered as crossing the stop bar with the front vehicle axle) at any point while the yellow indication is displayed, therefore providing the vehicle permission to be in the intersection during the red indication as described in the Uniform Vehicle Code (*10*), or

2.) Restrictive yellow law, which either does not allow the driver to enter or be in the intersection on red or requires the driver to stop on yellow unless it is not safe to do so.

Thorough review of the driver training literature as well as conversations with several state police officers contributed to the verification that the existing law in both Oregon and Massachusetts most closely resembles a restrictive law. With an appreciation for both the nationally accepted standard from the MUTCD as well as the local enforcement policies for both experimental sites, the next most critical information to uncover was an argument for an appropriate experimental mechanism to evaluate driver behavior described in the next section.

Driver Comprehension and Behavior

It is important to establish a working definition for driver comprehension as it will be referred to within this document. The manual for Human Factors and Traffic Safety defines driver comprehension as “the ease with which the driver can understand the intended message.” With this definition in mind, it is clearly important for the driver to immediately understand the message of any traffic control device because any delay or misinterpretation can result in driver error (*11*).

A plethora of driver comprehension and behavior studies have been conducted within the field of transportation. Two recent research areas have focused upon driver comprehension of signalization concepts and speed perception and identification, both of which are relevant to the study of CY comprehension.

Specifically, Hurwitz concentrated on determining the fidelity with which drivers could perceive their speed in real world, driving simulator, and static environments (*12*). This project provided preliminary evidence in the understanding of the driver speed perception and selection process as well as providing a viable data set to compare driver performance across multiple experimental mediums. The results lead the authors to the conclusion that certain types of speed-related research could be effectively examined in driving simulator and static environments.

The series of studies compared both field validation and driving simulator studies with static evaluation and found significant agreement with the results (*13, 14, 15, 16, and 17*). When considered in total, this sampling of research studies provides strong preliminary evidence that effective driver behavior research can be accomplished through static evaluation and be very valuable to the study of transportation. The methodology described in the next section draws from the literature and illustrates the experimental approach conducted in this research effort.

METHODOLOGY

The current study was aimed at evaluating the degree to which drivers comprehend the intended meaning of the solid yellow indication, and what if any impact that comprehension had on drivers’ predicted behavior when approaching high-speed signalized intersections. Additionally, because the published laws and enforcement were similar, it was postulated that differences identified between responses from drivers in Oregon and Massachusetts could be attributed to regional variability in behavior.

The first section of the evaluation focused primarily on driver comprehension of the solid yellow indication. Here comprehension was examined in terms of the following 3 distinct dimensions:

- Do drivers understand the message being conveyed,
- Do drivers know what signal display comes next in the sequence, and
- Can drivers approximate the typical duration of yellow indications.

It is critical that the simple messages intended to be conveyed by traffic control devices are in fact comprehended by the motoring public. To evaluate if the correct messages were being comprehended by drivers when presented the CY and yellow arrow (YA), the following five scenarios were presented:

- 5 section cluster displaying a
    - Circular yellow indication (CY)
    - Shared turn signal with yellow arrow and circular green indication (YA + CG)
    - Shared turn signal with yellow arrow and circular yellow indication (YA + CY)
- 3 section vertical displaying a
    - Circular yellow indication (CY)
    - Yellow arrow indication (YA)

In each of the five scenarios the following five possible responses were provided:

- *Red light is coming next,*
- *Preceding movement is ending,*
- *Stop and wait for the appropriate signal,*
- *You are required to yield, and*
- *You have the right of way*

Figure 1 is an example of a comprehension question examining the drivers understanding of the message being conveyed by a CY indication in a 5 section cluster signal display.

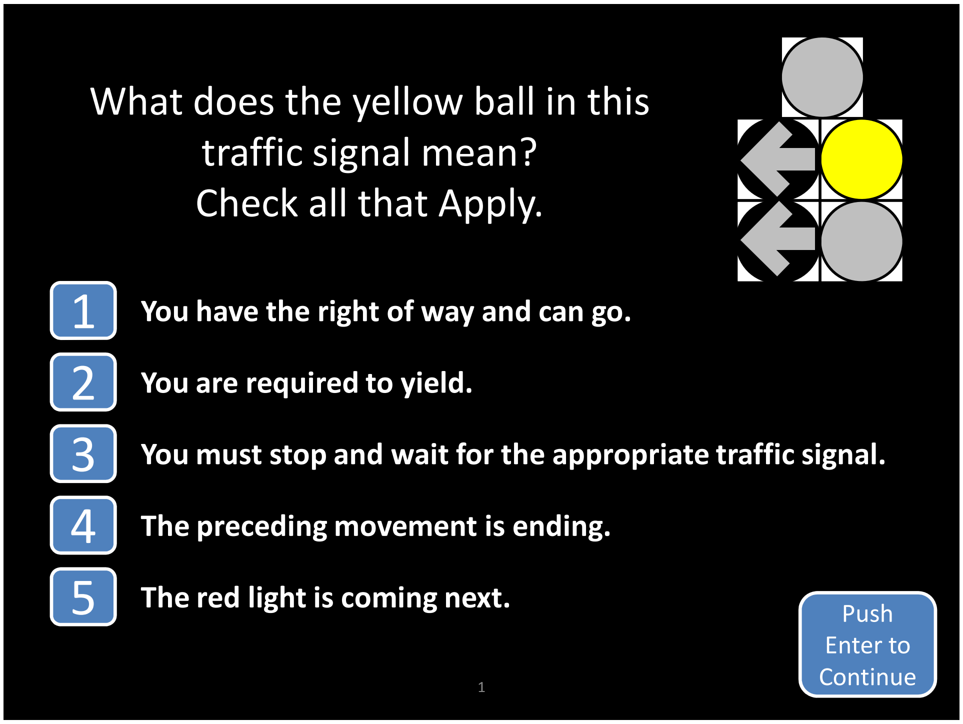

FIGURE 1 Example of a Computer-Based Predictive Behavior Evaluation Scenario.

The second component of the static evaluation concentrated on the predictive behavior of drivers when provided an image taken from a vehicle approaching a signalized intersection. The following three variables were examined as to their impact on predictive driver behavior:

- Number of approach lanes (one or two lane approaches),
- Approximate distance from the stop bar (near (50 ft), mid (100 ft), or far (200ft)), and
- Vehicle position in the approaching platoon (lead or following vehicle).

Figure 2 provides an example of a predictive behavior scenario depicting a lead vehicle on a single lane approach near the stop bar.

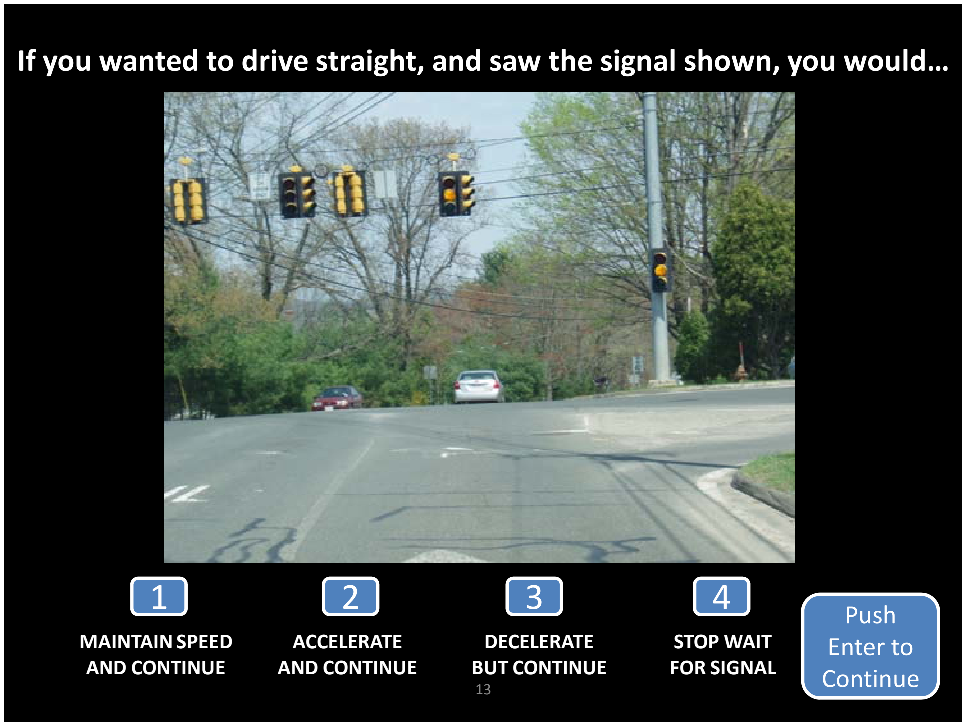

FIGURE 2 Example of a Computer-Based Predictive Behavior Evaluation Scenario.

The static evaluations were administered via computer monitors and the scenarios were counterbalanced to minimize the potential for confounding errors. Once the data was collected, it was transcribed into a spreadsheet application, so that further statistical analysis could be conducted.

DATA ANALYSIS AND RESULTS

The static evaluation was designed to examine driver comprehension and predictive behavior when exposed to the CY indication. Driver comprehension of the CY was evaluated with regard to the meaning conveyed, the sequencing, and the duration of the indication, while predictive behavior was evaluated with regard to several factors including number of approach lanes, distance from the stop bar, and position in the platoon of approaching vehicles.

An effort was made to balance driver demographics across the major dimensions of gender, age, and driving experience as well as to replicate similar demographics between both experimental locations. Table 1 displays the demographics of 130 drivers 65 from Oregon and 65 from Massachusetts who participated in the static evaluation.

TABLE 1 Subject Demographics

States	Gender		Age (in years)			Miles Driven Last year (in thousands)		
	Male	Female	< 25	25 to 45	> 45	< 10 K	10K-20K	> 20 K
Oregon	62%	38%	42%	38%	20%	57%	38%	5%
Massachusetts	45%	55%	28%	45%	28%	41%	40%	19%

Meaning of the CY Indication

The data collected from the five possible comprehension scenarios described in the methods section has been aggregated and displayed in Figure 3. The vertical axis represents the five possible scenarios which the driver was presented. The horizontal axis represents the percent of drivers who selected all possible correct answers for each scenario. Also displayed are 95% Confidence Intervals (C.I.).

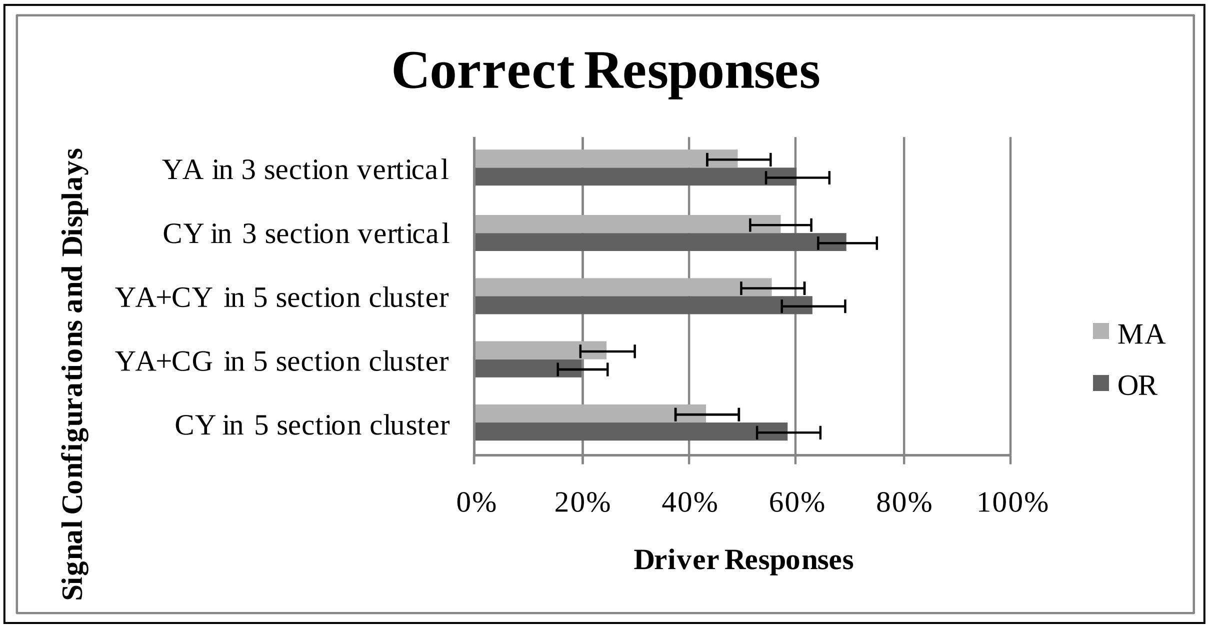

FIGURE 3 Driver Understanding of Signal Meaning in Massachusetts and Oregon.

The highest mean correct response rate (69% with a statistical confidence of 95%) occurred in OR for the CY indication when presented in a three section vertical signal head. As anticipated, the correct response rates dropped substantively for the presentation of the YA + CG in a 5 section cluster to 20% and 25% respectively for Oregon and Massachusetts. Regional variation appeared between Oregon and Massachusetts for the presentation of a lone CY in both a 3 section vertical and a 5 section cluster with a statistical confidence of 95%.

To further examine the correct and incorrect interpretations of signal display meaning, a series of one-way ANOVA tests were conducted. All 5 signal displays were tested in conjunction with one another. A statistically significant difference between the correct responses was identified for at least one of the signal displays ($P = 0.001$) in Massachusetts and ($P < 0.000$) in Oregon.

A post hoc Tukey test was then conducted for the purpose of confirming specifically where the differences in correct responses existed. From the results of this test it can be determined that the only statistically significant differences in the Massachusetts data exist between the understanding of the meaning of the YA+CG in a 5 section cluster and the following three signal displays; YA+CY in a 5 section cluster, CY in a 3 section vertical, and YA in a 3 section vertical. In all three comparisons, it was determined that fewer correct pairs of responses were reported in the YA+CG configuration at a 95% confidence level. However, the Oregon data showed that understanding of the meaning of the YA+CG in a 5 section cluster was different from all four alternative configurations at a 95% confidence level.

Signal Display Sequence after the CY Indication

The second component of comprehension examined was driver understanding of the allowable sequencing of traffic signal indications. Specifically, what signal display comes next in the sequence after that of the CY or YA? This sequencing question was tested in five scenarios with the same signal head configurations provided in the previous section on indication meaning. The vertical axis shows the possible responses which included five of the alternative signal displays that could theoretically be activated next in the sequence. The horizontal axis shows the percent of driver responses for each alternative signal display recorded in Oregon and Massachusetts. Drivers were only allowed to select one display per scenario. The results of the five scenarios are displayed in Figure 4.

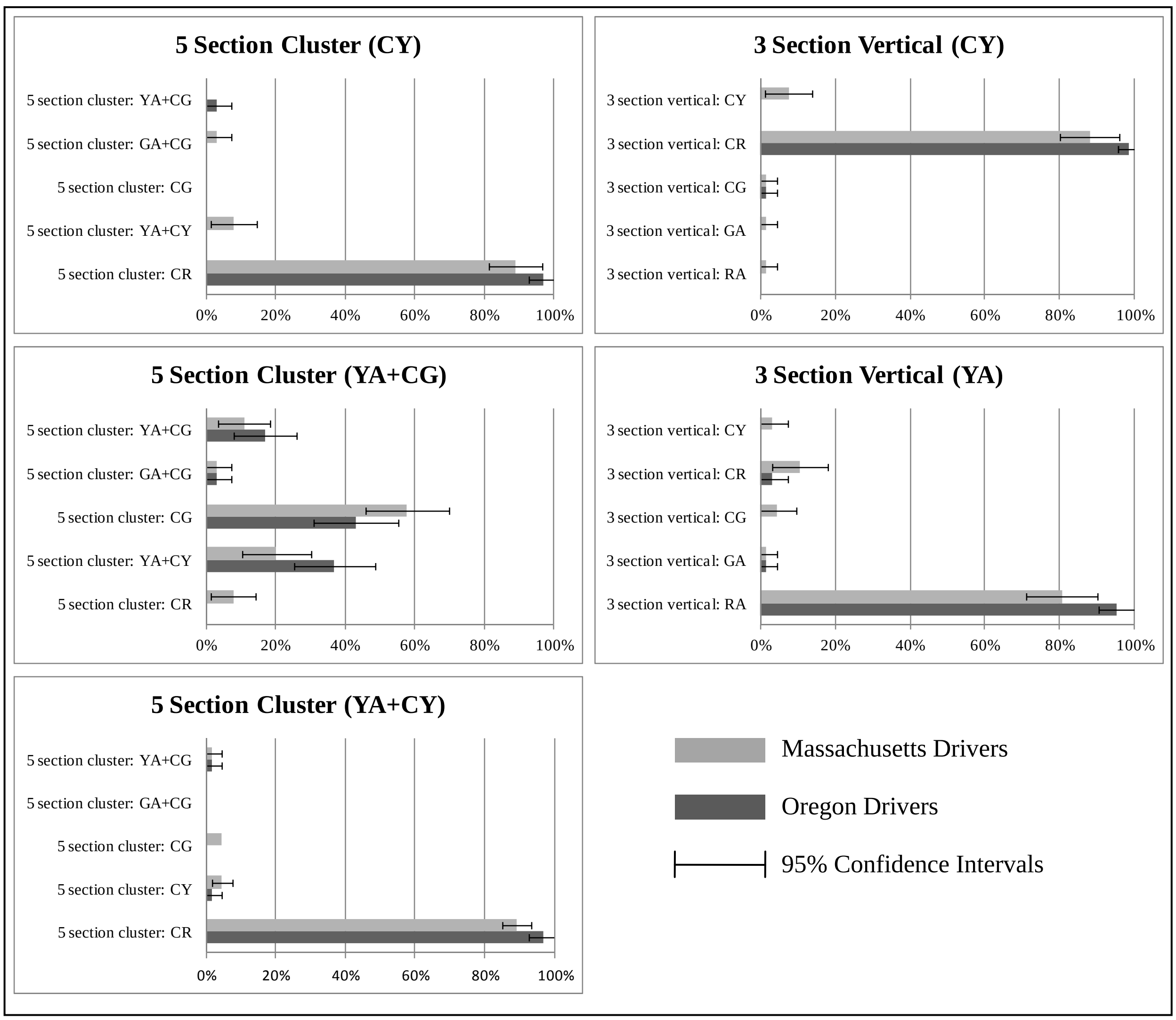

FIGURE 4 Driver Understanding of Signal Sequencing in Massachusetts and Oregon.

Examination of the 95% C.I. did not result in any statistically significant differences between the responses in Oregon and Massachusetts in any of the sequence scenarios. To expand upon the analysis of correctly predicting the next display in sequence, each of the 5 signal display scenarios were compared with one another using ANOVAs and Tukey post hoc comparisons in a similar manner to that of the meaning scenarios. First, it was determined through an ANOVA that a difference did in fact exist in the means of correct answers for the Oregon responses ($P < 0.001$) as well as the Massachusetts responses ($P < 0.001$). Upon closer examination it was determined that the YA+GC in the 5 section cluster display did yield fewer correct responses than each of the 4 alternative signal displays with statistical significance for both the Oregon and Massachusetts data.

Duration of the CY Indication

The third component of the comprehension section dealt with the understanding of the acceptable duration for the CY. Two scenarios were developed for this question; one representing a low-speed roadway posted at 30 mph and the other representing a high-speed roadway posted at 50 mph. Figure 5 shows the data collected from these scenarios in Massachusetts and Oregon. The vertical axis shows the aggregate alternative durations in seconds that drivers were allowed to select from. Originally drivers were allowed to select a range from 0 to 10 seconds increasing in one second intervals. The horizontal axis shows the percent of driver responses. The error bars represent 95% confident intervals.

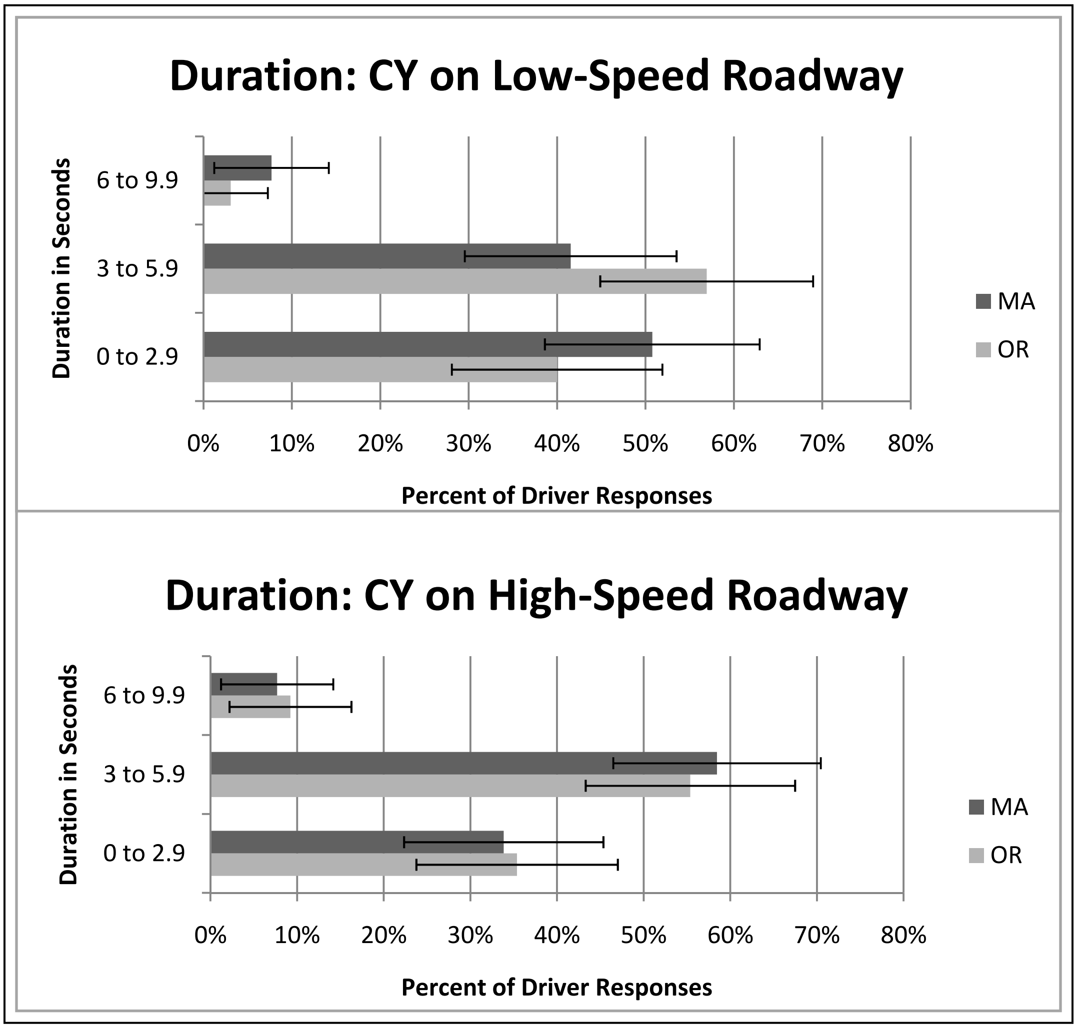

FIGURE 5 Understanding of CY Duration in Massachusetts and Oregon.

The top panel of Figure 5 displays the results for the driver predicted duration of a CY indication on a Low-Speed Roadway posted at 30 mph. A total of 42% of Massachusetts drivers and 57% of Oregon drivers provided responses within the MUTCD region of three to six seconds. While the responses of 8% of Massachusetts drivers and 3% Oregon drivers appeared in the region above six seconds. Lastly 51% of Massachusetts drivers and 40% of Oregon drivers had responses that appeared in the region below three seconds.

The bottom panel of Figure 5 displays the results for the driver predicted duration of a CY light on a High-Speed Roadway posted at 50 mph. A total of 59% of Massachusetts drivers and 55% Oregon drivers provided responses within the MUTCD region of three to six seconds. While the responses of 8% of Massachusetts drivers and 9% of Oregon drivers appeared in the region above six seconds. Lastly, 33% of Massachusetts drivers and 36% of Oregon drivers had responses that appeared in the region below three seconds.

It appears with a statistical significance of 95% that in both the high-speed and low-speed condition drivers in Massachusetts and Oregon were less likely to predict CY durations greater than the recommended 6 second duration.

A series of Chi-square tests were conducted to determine if there was any difference in the distributions of predicted duration in the high-speed and low-speed scenarios presented above. It was determined that no such differences could be assessed at a confidence level of 95% in either Oregon or Massachusetts.

Predictive Behavior

In the pursuit of understanding driver comprehension issues it has been established that predictive behavior may act as a surrogate measure for comprehension and correlates in many cases to results obtained in previous driving simulator experiments as well as prior field studies (*6*, *12*, *13*, *14*, *15 and 16*). For this reason predictive behavior was examined regarding the CY indication. Figure 6 displays the data from the predictive driver behavior evaluation. The vertical axis for each panel displays the alternative actions that the driver could select from, while the horizontal axis shows the actual driver responses for each alternative action. The left column shows the Oregon driver data while the right column shows the Massachusetts data. Drivers were only allowed to select one action per scenario. Each figure represents a given scenario at three different distances.

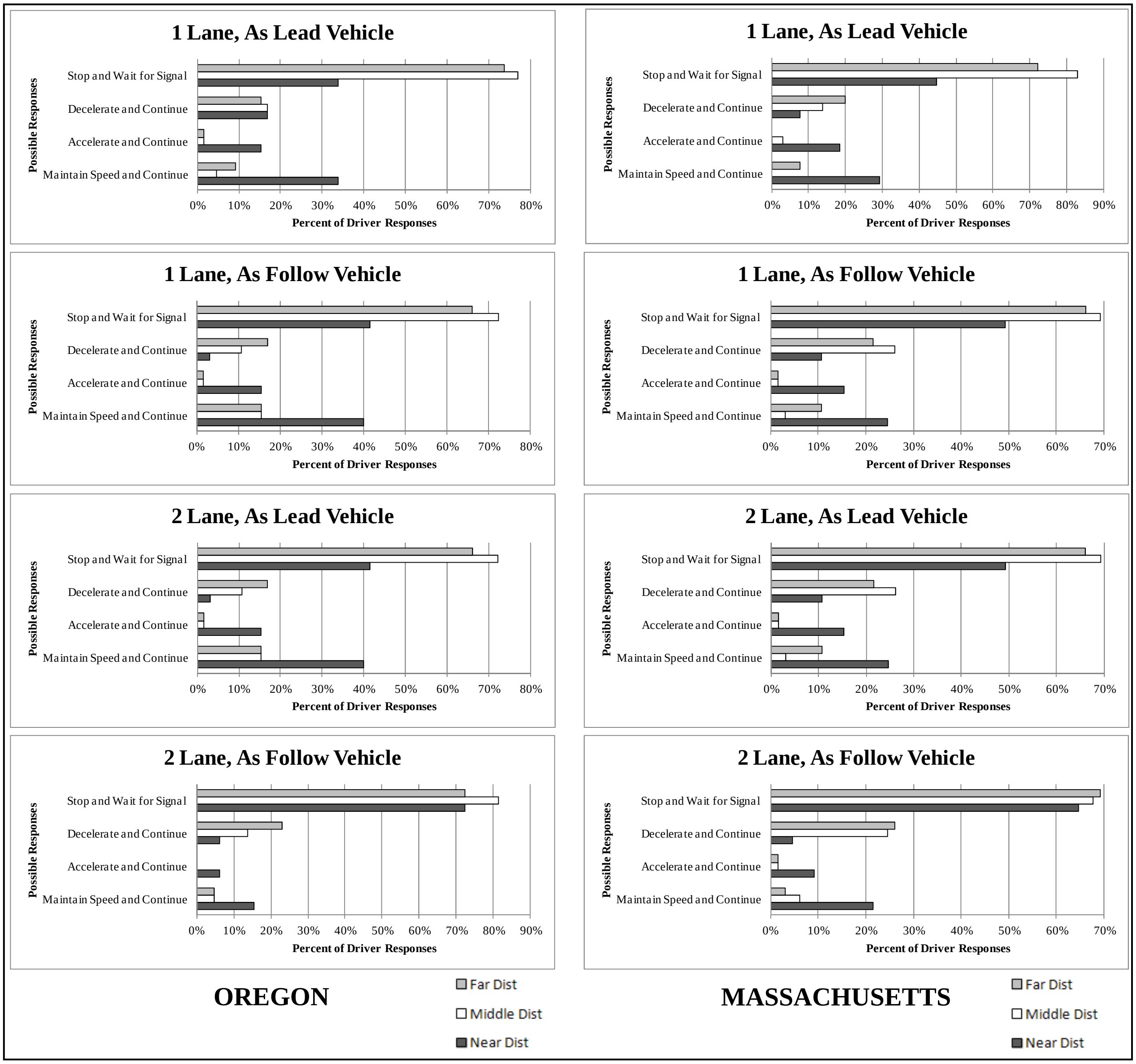

FIGURE 6 Predictive Driver Behavior in Oregon and Massachusetts.

To assist in the description of the results from the predictive behavior evaluation numerous Chi-square tests were conducted. Chi-square tests were conducted on the data for each of the four aggregate scenarios (one lane following vehicle, one lane lead vehicle, two lane following vehicle, two lane lead vehicle) all four were determined to have statistically significant differences in the distributions ($P < 0.001$) in Massachusetts and ($P < 0.0008$) in Oregon. The responses were further segmented across each of the four scenarios by distance near (50 ft), middle (100 ft), and far (200 ft). In Massachusetts statistical differences in distribution were identified for both the near ($P = 0.029$) and middle ($P = 0.006$) distances, but not the far distances ($P = 0.301$). A similar trend was identified in Oregon where statistical differences in distribution were identified for both the near ($P = 0.004$) and middle ($P = 0.015$) distances, but not the far distances ($P = 0.193$). Therefore, responses at the far distance were not impacted by scenario in Massachusetts or Oregon.

CONCLUSION AND RECOMMENDATIONS

Several conclusions regarding driver comprehension can be reached based on an examination of the results from this experimental procedure. With regards to the meaning of the CY, mean correct responses across all displays ranged from a low of 43% +/- 6% to a high of 69% +/- 5%. This was an unexpected result potentially contradicting the belief that drivers have a high comprehension rate for the solid yellow indication. One of the most interesting differences between the observations recorded in Massachusetts and Oregon was the identification of statistically significant differences in the correct responses to the meaning of the CY when displayed in a 3 section vertical and a 5 section cluster. In both of these scenarios Massachusetts drivers were less capable of identifying the correct answers. Anecdotally, it appeared that in debriefings with subjects in Massachusetts, they were very unaware of the legal requirements for interacting with the CY indication. This suggests a need for augmented education regarding legal definitions and standards of enforcement.

On average, drivers showed a high level of understanding (greater than 80%), when identifying what display would follow after the YA or CY. However, drivers showed significant difficulty in comprehending both the meaning and the appropriate sequencing of the five section cluster when presenting a YA+CG display. This adds to the existing concern about left turn indications presented on shared turn signal head and driver's inability to correctly comprehend them. This result appeared statistically significant in Massachusetts and Oregon.

Only 42% (Massachusetts) and 59% (Oregon) of drivers were able to recognize the MUTCD recommended duration of a yellow indication on a low speed road (30 mph). If drivers cannot accurately predict the length of the CY indication, they will have significant difficulty in making the correct decision to stop or proceed through the intersection. Additionally, a small portion of drivers, 3% to 9%, overestimate the duration of the CY. This overestimate could contribute to vehicles entering the intersection late, thereby precipitating right-angle crashes. It should be noted that some of the difficulty in driver assessment for the CY duration is likely associated with the lack of consistent timing strategies in the U.S. This result should strengthen the argument for a need to establish consistent timing practices to aid in the driver comprehension of the CY.

It is important to note that this study only capture driver responses in two states with similar traffic enforcement laws. For these results to be more applicable to practitioners around the country it is necessary for driver responses to be observed in numerous other states with differing yellow enforcement laws.

The crucial impact of this research effort is to raise awareness to the issue that drivers do not appear to have as clear a comprehension for the CY as is expected by the designers and operators of signalized intersections. This fact should be considered in both current and future efforts to establish national standards for the timing of the CY. The variability in driver comprehension associated with different regions of the country cannot be discounted. This suggests either the necessity for additional training and education practices to improve driver understanding or the use of regional calibration factors in future timing practices. Additionally, consistency in the application of yellow enforcement laws should be considered for the purpose of improving driver response.

REFERENCES

1. Zimmerman, K., and Bonneson, J.A. Intersections Safety at High-Speed Signalized Intersections: Number of Vehicles in Dilemma Zone as Potential measure of Intersection Safety at High-Speed Signalized Intersections. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1897, Transportation Research Board, National Research Council, Washington, D.C., 2004, pp. 126-133.

2. Gates T.J., Noyce, D., and Larauente, L. Analysis of Dilemma Zone Driver Behavior at Signalized Intersections. Paper 07-3351. TRB, Washington, D.C., 2007.

3. Rakha, H., El-Shawarby, I., and Setti, J.R. Characterizing Driver Behavior on Signalized Intersection Approaches at the Onset of a Yellow-Phase Trigger. IEEE, 2007, 8(4), pp. 630-640.

4. Zeeger, C.V., and Deen, R.C. Green-Extension Systems at High-Speed Intersections. *ITE Journal*, Washington, D.C., 1978, pp. 19 – 24.

5. Chang, M.S., Messer, C.J., and Santiago, A.J. Timing Traffic Signal Change Intervals Based on Driver Behavior. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1027, Transportation Research Board, National Research Council, Washington, D.C., 1985, pp. 20-30.

6. Hurwitz, D.S. *Application of Driver Behavior and Comprehension to Dilemma Zone Definition and Evaluation*. Phd dissertation. University of Massachusetts Amherst, 2009.

7. Manual on Uniform Traffic Control Devices. FHWA, U.S. Department of Transportation, Washington, D.C., 2009.

8. Awadallah, F. A. A Legal Approach to Reduce Red Light Running Crashes. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2096, Transportation Research Board of the National Academies, Washington, D.C., 2009, pp. 102-107.

9. Parsonson, P. S. *NCHRP Synthesis of Highway Practice 172: Signal Timing Improvement Practices.* TRB, National Research Council, Washington, D.C., 1992.

10. *Uniform Vehicle Code*. National Committee on Uniform Traffic Laws and Ordinances, and Model Trafffic Ordinance, Evanston, Ill., 1992.

11. Dewer, R. and Olson, P. Human Factors in Traffic Safety Second Edition. *Lawyers & Judges Publishing Company*, Inc. Tucson, AZ, 2007, pp. 348-349.

12. Hurwitz, D.S., and Knodler, M.A. Static and Dynamic Evaluation of the Driver Speed Perception and Selection Process. In *Fourth International Driving Symposium on Human Factors in Driver Assessment, Training and Vehicle Design*. CD-ROM. 2007.

13. Knodler, M.A.Jr., Noyce, D.A., Kacir, K.C., and Brehmer, C.L. Potential Application of Flashing Yellow Arrow Permissive Indication in Separated Left-Turn Lanes. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1973, Transportation Research Board of the National Academies, Washington D.C., 2006, pp. 10-17.

14. Knodler, M.A.Jr., Noyce, D.A., Kacir, K.C., and Brehmer, C.L. Analysis of Driver and Pedestrian Comprehension of Requirements for Permissive Left-Turn Applications. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1982, Transportation Research Board of the National Academies, Washington D.C., 2006, pp. 65-75.

15. Knodler, M.A.Jr., Noyce, D.A., and Fisher, D.L. Evaluating Effect of Two Allowable Permissive Left-Turn Indications. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 2018, Transportation Research Board of the National Academies, Washington D.C., 2003, pp. 53-61.

16. Noyce, D.A., and Kacir, K.C. Driver Understanding of Simultaneous Traffic Signal Indications in Protected Left Turns. In *Transportation Research Record: Journal of the Transportation Research Board*, No. 1801, Transportation Research Board of the National Academies, Washington D.C., 2002, pp. 18-26.

17. Brehmer, C.L., Kacir, K.C., Noyce, D.A., and Manser, M.P. NCHRP Report 493: Evaluation of Traffic Signal Displays for Protected/ Permissive Left-Turn Control. TRB, National Research Council, Washington, D.C., 2003."