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# Three- or Four-Section Displays for Permissive Left Turns? Some Evidence from a Simulator-Based Analysis of Driver Performance

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## Citation Details

Hurwitz, David; Monsere, Christopher; Marnell, Patrick; and Paulsen, Kirk, "Three- or Four-Section Displays for Permissive Left Turns? Some Evidence from a Simulator-Based Analysis of Driver Performance" (2014). *Civil and Environmental Engineering Faculty Publications and Presentations*. 228.  
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# **Three- or Four-Section Displays for Permissive Left Turns? Some Evidence from a Simulator-Based Analysis of Driver Performance**

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Submitted for publication in the Transportation Research Record: Journal of the Transportation Research Board

Revise date: March 15, 2014

Length of Paper:

Word Count (7,232): Abstract (234) + Text (3,998) + Tables (4) + Figures (8)

## **ABSTRACT**

Many jurisdictions are using the flashing yellow arrow (FYA) to control protected/permissive left turns (PPLTs). For cost and other reasons, some jurisdictions have or are considering implementing FYA with a three-section vertical head, displaying the flashing yellow indication in the same signal face as the protected green arrow. The current Manual on Uniform Traffic Control Devices (MUTCD) permits three-section operation only in height-restricted locations for permissive turns. This paper summarizes the comparison of driver performance with respect to three- and four-section FYA signal configurations gathered in a high-fidelity, motion-based driving simulator with mobile eye-tracking equipment. The experiment controlled for the effects of the opposing traffic, the presence and walking direction of pedestrians, and the signal head arrangement. A 24-intersection simulated environment was created and 27 subjects completed the course, producing 620 permissive left-turn maneuvers for further analysis. Driver performance was measured by 1) average total eye-glance durations at specific areas of interest and 2) the position of the pedestrian in the crosswalk when the driver initiated the left turn. No statistical differences were identified between the average fixation duration when the FYA was presented with a three- or four-section signal head. The pedestrian's position in the crosswalk when the driver began the left turn was not statistically different for three of the four pedestrian walking directions presented. Overall, it would seem that measureable driver performance is not sensitive to the vertical positioning of the FYA display in the permissive interval.

## INTRODUCTION

When a separate lane is provided for left-turning vehicles, the interval during which drivers turn can be described as either protected or permissive. In a protected interval, the left-turning driver has the exclusive right-of-way and will face no other (legal) conflicts. In permissive operation, the driver may turn only after yielding to other conflicting movements such as pedestrians, vehicles or bicycles. Permissive intervals have historically been communicated to drivers with various traffic-signal indications such as a circular green, flashing circular red, flashing circular yellow and a flashing yellow arrow (FYA). Research funded by the National Cooperative Highway Research Program (NCHRP) demonstrated that the FYA indication was the most effective of these displays for communicating permissive left turns by most measures (1, 2). Subsequently, the FYA display was included in the 2009 edition of the *Manual on Uniform Traffic Control Devices* (MUTCD) (3).

To implement the FYA in protected/permissive operation for left turns (PPLT), the 2009 MUTCD requires the use of the four-section signal face (4D.20.03). As jurisdictions deploy the FYA, some have or are considering a three-section vertical head — displaying the flashing yellow indication in the same signal face as the protected green arrow — for cost or other reasons. Three-section signal faces are currently allowed for permissive-only (4D.18.03), protected-only (4D.19.03), flashing red operations (4D.18.05) or when height or lateral restrictions prevent the use of a four-section display in PPLT (4D.20.03 (H)). The requirement of four sections for protected-permissive operation would seem to suggest better driver task performance with this arrangement. However, research confirming this suggestion is limited. In the original FYA display research (1, 2), driver performance with respect to the number of sections in signal head displays was not examined and no other published research on this topic has been identified. A search of the TRB Research in Progress database identifies NCHRP 20-07-Task 283 is currently underway to study shared yellow signal faces in the FYA by Dr. Noyce at the University of Wisconsin-Madison.

This paper compares driver performance with respect to three- and four-section FYA signal configurations gathered in a high-fidelity, motion-based driving simulator with mobile eye-tracking equipment for drivers making permissive left turns. A 24-intersection simulated environment was created and 27 subjects completed the course making 620 permissive left-turn maneuvers. Driver performance was measured by average total eye-glance durations at specific areas of interest per intersection approach and turning maneuver (left-turn pavement bay markings, the signal indication, the pedestrian and vehicle waiting area, and the pedestrian signal heads) during the permissive operation. The experiment controlled for the effects of the opposing traffic, the presence and walking direction of pedestrians, and the number of faces in the signal head.

The paper begins by reviewing the relevant background and literature, then describes the methodology and simulator equipment used in the research. The analysis of data and discussion of results follows. The paper concludes with observations about the information gained from this work and a discussion of the limitations of the work.

## PRIOR RESEARCH

Numerous research efforts spanning nearly 20 years have examined challenges regarding driver behavior to different aspects of permitted left-turn phasing. Knodler et al. (4) have suggested that the circular green (CG) indication, which is also used to give the right-of-way in the through and right-turning lanes, may lead to poor driver comprehension because the same indication provides different messages depending on the movement being performed by the driver. At the time of Knodler's research, several types of indications were used for permissive left-turn movements in the U.S. (e.g., the flashing red arrow (FRA), flashing circular yellow (FCY), flashing circular red (FCR), and the FYA). These indications were developed to improve driver comprehension and safety during PPLT operations (though they clearly lacked uniformity). The use of different indications to communicate the same message to drivers was

identified as a significant issue. Therefore, research was undertaken to determine a single permissive left-turn indication that could be uniformly adopted. In 2000, Smith and Noyce (5) tested 34 drivers at the Arbella Human Performance Laboratory Driving Simulator Lab at the University of Massachusetts Amherst. They collected 991 responses from indication scenarios to understand the difference in driver comprehension of five different permissive left-turning signal indications (CG, FYA, FRA, FYC, and FRC) in three configurations (five-section vertical, five-section horizontal and five-section cluster). Measured by correct driver responses, the CG, FYA and FYC indications provided relatively equal responses (difference of 1%), but outperformed the FRA and FRC indications by an average of 28.2% (5).

In subsequent work, Noyce et al. (6) collected saturation flow rate, start-up lost time, response time, and follow-up headway data from 24 intersections in eight U.S. cities with different PPLT displays. They found no statistically significant difference ( $\alpha = 0.05$ ) in saturation flow rate or start-up lost time between different types of PPLT signal displays across the country. They concluded that any minor differences observed could be attributed to the different traffic operations and driver behaviors in each geographical area studied. Brehmer et al. (1) also explored traffic conflicts associated with PPLT signal displays and found no statistical difference in conflict rates ( $\alpha = 0.05$ ). The rates were very low for the different PPLT signal displays, which limited the ability to make conclusions about the difference in safety of the displays.

These preliminary works by Noyce and Knodler provided evidence that the FYA indication could be used to replace FCR and FRA for permitted left-turn movements. In 2003, Brehmer et al. published NCHRP Report 493, which comprehensively evaluated PPLT alternatives with numerous experimental techniques. This extensive work resulted in a recommendation to incorporate the FYA in future editions of the MUTCD as an allowable alternative display to the circular green during PPLT operation, but only as an exclusive signal display for the left-turn lane (1).

With respect to the number of signal faces for permissive left turns, the past work is sparse. No research was found to determine the specific operational and safety effects of using a three-section bimodal arrow versus four-section signal configurations. Knodler et al. did include work about signal head arrangements in their continued research on PPLT signal displays. Using a driving simulator, they observed that when presented with a five-section cluster signal configuration, in which both the left-turn FYA and the through-movement circular yellow are located in the same signal house, some drivers would completely stop in the left-turn lane during the through yellow. However, with a four-section vertical exclusive left-turn signal configuration and a separate signal for the through lane, an additional 1% of drivers stopped during the permissive left-turn phase (7).

More broadly, the functional difference between the three-section and four-section signal configuration is that each indication in the sequence has its own lens in the four-section head. Noyce postulated that the visual search task is critical to examining traffic signal indication comprehension (8). To date, no literature has specifically examined this influence with regards to traffic signals. However, it is generally accepted that the visual search task is governed by cognitive factors (9, 10). In general, the work of Megew and Richards suggests that while searching for targets subjects will often begin the visual search in the upper left of the display, but others argue that the search initiates at the center of displays (11).

In addition, surveys show there is a perception in the engineering community that the four-section configuration is preferable to the three-section configuration “because of the inability of certain color blind males (2% of male population) to distinguish between green arrow and FYA in the same section of a three-section FYA head” (8). There are many forms of color blindness and only monochromacy can be described as a complete lack of color vision (8). In the more common forms of color blindness, dichromatism or trichromatism, some color vision remains (8). Table 1 shows the color differences

associated with various forms of dichromatism and the estimated demographics affected. These include forms of red and green color deficits (protanopia and deuteranopia) as well as blue and yellow color deficits (tritanopia). There is no common form of colorblindness that affects both green and yellow vision.

## **METHODOLOGY**

This research was conducted in a high-fidelity driving simulator. To build the environment, candidate locations were identified from FYA installations in Washington County, OR, so that the simulator work could be field validated. The geometry and background of the simulated intersections closely matched those in the field by approach widths, lane configurations, signal-head configurations, and adjacent land use.

This research was focused on driver behavior at permissive left turns during the start and duration of the permissive interval. In this context, this research does not address all possible driver performance issues for the three- vs. four-section comparison, and guidance for further work is provided in the paper's conclusion. The following two null hypotheses were developed to address the critical need for research to justify the use of three-section or four-section vertical displays for the FYA:

1. **H<sub>0</sub>**: There is no difference in the total duration of driver fixations during permitted left-turn maneuvers at signalized intersections operating the FYA with a four-section vertical or a three-section, dual-arrow vertical configuration.
2. **H<sub>0</sub>**: There is no difference in the location (measured as lane number) of the pedestrian in the crosswalk when the driver initiates a permitted left-turn maneuver at signalized intersections operating the FYA with a four-section vertical or a three-section, dual-arrow vertical configuration.

### **Driving Simulator**

The Oregon State University (OSU) Driving Simulator is a high-fidelity simulator, consisting of a full 2009 Ford Fusion cab mounted on top of a pitch motion system. The pitch motion system accurately models acceleration and braking. Three projectors produce a 180-degree front view and a fourth projector displays a rear image for the driver's center mirror. The two side mirrors have LCD displays. The vehicle cab instruments are fully functional and include a steering control loading system to accurately represent steering torques based on vehicle speed and steering angle. The simulator software can record performance measures such as speed, position, braking and acceleration at a sampling rate of 60Hz. Figure 1 shows views from a) outside and b) inside the simulator.

A driving simulator may be validated in an absolute (13) or relative (14-16) manner based on observed differences in any number of performance measures, such as speed or lateral position. For a simulator experiment to be useful it is not required that absolute validity be obtained; however, it is necessary that relative validity be established (13). Drivers' stopping behavior at traffic signals, perception reaction time, and deceleration rates have previously been validated in the OSU driving simulator (17,18).

### **Eye Tracking**

Eye-tracking data were collected using the Mobile Eye-XG platform from Applied Science Laboratories (Figure 1c). The advanced Mobile Eye-XG allows the subject to have unconstrained eye movement and unconstrained head movement, generating a sampling rate of 30 Hz and with an accuracy of 0.5 to 1.0 degree. The subject's gaze is calculated based on the correlation between the subject's pupil position and the reflection of three infrared lights on the eyeball. Eye movement consists of fixations and saccades. Fixations are points that are focused on during a short period of time and saccades are when the eye moves to another point. The Mobile Eye-XG system records a fixation when the subject's eyes have

paused in a certain position for more than 100 milliseconds. Saccades are not recorded directly but are calculated based on the dwell time between fixations. In this paper, driver saccades were not analyzed.

### **Experimental Factors**

Three experimental factors were tested: approaching vehicular volume, pedestrian volume and walking direction, and signal configuration type. Within the simulated environment, subjects were presented with combinations of the independent variables. These combinations are summarized in Table 2: Left-turning drivers faced zero, three or nine oncoming vehicles; with one pedestrian walking towards, one pedestrian walking away, or two pedestrians walking from both sides simultaneously; and a four-section vertical configuration or a three-section vertical configuration with a dual-arrow lens. These options resulted in 24 combinations of cases to be analyzed. The presentation sequence for the FYA for drivers in the simulated environment is shown in Figure 3. The simulator was configured so that all drivers were presented the FYA upon arrival at the intersection.

### **Subject Recruitment and Sample Size**

Participants in this study were recruited from OSU's student body and the surrounding community of Corvallis, OR. Participants were required to possess a valid driver's license, able to be calibrated with the eye tracker, and be physically and mentally capable of legally operating a motor vehicle. Participants also needed to be deemed competent to provide written informed consent. This study targeted an enrollment of 30 participants with a balance of gender (which was not screened until the quota for either males or females had been reached, at which point only the gender with the unmet quota was allowed to participate). In total, 38 drivers participated in the test. Given the demographics of the recruitment base, there was an overrepresentation of college-aged students — the mean age of subjects was 25.8 years. Subjects were given \$25 for their participation. The research design was reviewed and approved by the OSU Institutional Review Board (IRB). The mission of the IRB is to ensure compliance with the Code of Federal Regulations by the U.S. Department of Health and Human Services regarding the conduct of research with human subjects.

### **Scenario Layout and Intersection Control**

Open-source simulator software, including Internet Scene Assembler, Simcreator and Google Sketchup, were used to create a virtual environment that could be projected around the driver. The driving scenario was split into four trials of six intersections each in an effort to reduce the chances of simulator sickness. At the breaks, the researchers introduced one distractor question between each trial. The distractor questions were:

- Did you find that the posted speed limit was appropriate for the road driven?
- How did the presence of bike lanes affect your driving behavior?
- What are your thoughts on the digital dashboard configuration?

Subjects were directed to conduct a total of six left-turn movements in each trial. The sequence of intersections can be seen in Figure 3. Drivers completed 24 independent left-turn maneuvers during a 15-minute experimental drive.

All intersection approaches consisted of five lanes: two 12-foot through lanes in each direction, 4-foot bike lanes, and an exclusive 12-foot left-turn bay. The left-turn signal head was positioned on a mast arm along with the through vehicle head. The second though head was post-mounted on the right side with the pedestrian head. A screen capture of a driver's viewpoint at four scenarios with different levels of pedestrian activity is shown in Figure 4. The intersection approaches had a posted speed limit of 45 mph. Tangent sections between intersections measure approximately 1,650 feet.

## DATA ANALYSIS AND RESULTS

Due to simulator sickness, eight drivers did not complete the experiment and data-collection errors rendered three subjects' data unusable. Data were processed and analyzed for the remaining 27 subjects (14 male and 13 female). Out of the 648 possible permissive left-turn maneuvers performed by the 27 subjects, 28 left turns were removed due to calibration failures resulting in a loss of usable eye-tracking data, resulting in 620 left turns for analysis. Driver performance was measured by 1) average total eye-glance durations at specific areas of interest, and 2) the position of the pedestrian in the crosswalk when the driver initiated the left turn.

### Average Total Fixation Duration

After the experiment, driver fixations for each subject were analyzed by defining Area of Interest (AOI) polygons with the ASL Results Plus software that was provided with the ASL Mobile Eye-XG equipment. To determine the AOIs, researchers watched each approach video and drew AOI polygons on individual video frames in a sequence separated by intervals of approximately five to 10 frames. For reference, a 30-second approach and turning maneuver was analyzed for each driver. Examples of the different AOIs are shown in Figure 5, in which the driver is at a stop line waiting for an appropriate moment to make a left-turn maneuver. Once the researcher manually moved each AOI, an "anchor" was created within the software. The distance and size differences of the AOIs between these anchors were interpolated by the software. Once the AOIs were coded for each individual video file, the software was used to output spreadsheets of all of the fixations and their corresponding AOIs. Fixations outside of coded AOIs were not used for further analysis.

Figure 6 graphically shows the results of the Average Total Fixation Duration (ATFD) sorted in descending order by length of fixation on each AOIs and configuration of the signal head. Table 3 presents the numerical results and results of the statistical comparison. Two-sample, two-sided Welch's  $t$ -tests were used to determine whether the ATFDs on specific AOIs varied when subjects completed left turns at locations with the three-section or four-section configurations. Significance was assumed at  $\alpha=0.05$ .

The largest average fixation duration was on the opposing vehicles — an average of 5.46 and 5.20 seconds, respectively, for the three- and four-section displays. This difference was not statistically significantly ( $p=0.37$ ). This was followed in duration by the pedestrian areas when four pedestrians walking from both directions — 2.84 for the four-section and 3.03 seconds for the three-section arrangement (not a statistically significant difference,  $p=0.59$ ). The turn bay (driver searching for reference position) had average durations of 2.35 and 2.43 seconds ( $p=0.68$ ). Depending on the signal arrangement, the rank order of the next two AOIs were different. For the four-section head, the AOI for the pedestrian walking away from the subject (1.92 seconds) was followed by the AOI for the signal head itself (1.82 seconds). For the three-section head the order was reversed — 1.71 seconds for the signal head followed by the pedestrian walking away (1.60 seconds). Neither of these were different ( $p=0.13$ ,  $p=0.48$ ). Average fixation durations for the single pedestrian walking toward the subject were nearly identical for both arrangements (1.46 and 1.47 seconds) and not statistically different ( $p=0.97$ ). The AOI with the lowest duration was the AOI where pedestrians would be if no pedestrians were present (0.49 seconds for both,  $p=0.93$ ).

### Position of the Pedestrian

The eye-tracking video clips were manually analyzed to capture the position of pedestrians in the crosswalk when the drivers initiated their permitted left-turn maneuvers. Initiation of the permitted left was determined by looking at the driver's hands on the steering wheel. This view was readily available from the eye-tracking video. Pedestrian position was assigned to one of six *Pedestrian Location Numbers* (PLNs), as show in Figure 7. These lanes are on the approach receiving the left-turning vehicle. Due to



the nature of the head-mounted eye tracker, it was not always possible to see the pedestrian in the video. PLNs were only included in the data analysis if the scene camera provided a clear line of sight to the pedestrian. Approximately 455 out of the 620 turning maneuvers were available for this analysis.

As in the AOI analysis, the data were grouped by the number and direction of pedestrians. The following groups were defined: *Away Only*, *Both Away*, *Towards Only* and *Both Towards*. *Towards Only* and *Away Only* are the single pedestrians walking towards and away from the driver. *Both Towards* and *Both Away* are observations from the same pedestrian scenario but are lane positions of each walking pair. *Both Towards* is the measured PLN of the set of two pedestrians walking towards the driver when two pedestrians are also walking away from the driver. *Both Away* is the corresponding PLN of the sets of two pedestrians walking away from the driver in the same scenario. Figure 8 shows the average PLNs for different pedestrian groups by FYA configuration with the  $x$ -axis reversed to correspond graphically to Figure 7. The numerical results are presented in Table 4, including the results of Welch's two-sample, two-sided  $t$ -tests. Significance was assumed at  $\alpha=0.05$ .

When a single pedestrian was walking away from the left-turning driver (from position 6 to 0 in Figure 7), the average lane position when the driver initiated the left turn was 0.72 for the four-section arrangement and 1.08 for the three-section arrangement. This means that on average, pedestrians were 0.36 PLN closer to the destination curb in the presence of a four-section signal display as compared to the three-section display. This difference was statistically significant different ( $p = 0.01$ ). When there was a single pedestrian walking towards the driver (from 0 to 6 in Figure 7), the average position was 3.40 for the four-section and 3.103 for the three-section arrangement (meaning, on average, pedestrians cleared the legal receiving lane 2). There was no statistical difference between the arrangements ( $p=0.028$ ). When four pedestrians were present, the set of pedestrians walking towards the drivers reached PLN 4.89 and 4.72, respectively. While this was not statistically different by the signal head arrangement ( $p=0.67$ ), it was approximately 1.5 lanes further towards to the far curb than the *Towards Only* pedestrian (drivers need to wait for the other set of pedestrian walking away). For the set of pedestrians walking away from the driver, the PLN was 0.81 for the four-section and 1.06 for the three-section arrangement. This difference was not statistically significantly different ( $p=0.09$ ) and very similar to the PLN for the single pedestrian walking away from the driver.

## CONCLUSION

A clear knowledge gap exists in the traffic engineering profession with respect to the operational and driver safety impacts of presenting the FYA in a three-section or four-section vertical configuration. This is the first study to examine the visual search task of drivers with respect to three- and four-section FYA signal configurations using a high-fidelity, motion-based driving simulator with mobile eye-tracking equipment. The primary difference in our research between the signal arrangements is in the vertical position of the FYA display. In this context, we observed little difference in the visual search task of drivers. The analysis found no statistically significant difference in the average driver fixation duration between any of the independent control variable studied between the three- and four-section FYA displays. When considering the position of the pedestrians by lane number when the driver initiated a left turn, a statistically significant difference between the four- and three-section arrangement was only found for the case when a single pedestrian was walking away from the driver. The average difference was 0.36 lanes (4 feet) closer to the destination curb (the difference in average values for the away direction with multiple pedestrians was similar — 0.25 lanes — but not significant). Though these differences are measurable, this measure has yet to be mapped to crash potential or other currently accepted measures of safety. Overall, it would seem that measureable driver performance in this research is not sensitive to the vertical positioning of the FYA display in the permissive interval.

There are acknowledged limitations to this research. This study only examined driver interaction with the permissive portion of PPLT phasing. It is possible that driver performance differences between

the four- and three-section arrangements exist during the transitions between protected and permitted phasing. Future research should consider studying driver performance at this interval. To do so, gap acceptance or fail-critical/fail-safe approaches may be needed to provide critical insight. In addition, this research did not address the color deficiency issue. This may not be as important a research question as whether the difference between a solid arrow and a flashing arrow should be detectable by a person with monochromacy. Also, this research did not consider the bimodal use of the yellow arrow lens (for flash and clearance). In this study, the subject recruitment is biased towards a younger population. A larger, more diverse sample size that more closely match the driving population might produce different results. Finally, another key question that deserves future study relates to the sequence of the yellow change or red clearance interval (after the protected or permissive indication, or both).

## ACKNOWLEDGEMENTS

This project was funded by the Oregon Transportation Research and Education Consortium (OTREC) with matching funds from Washington County, OR, Oregon State University and Portland State University.

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**TABLE 1: Colors Perceived with Dichromatism (from 8)**

Type	Missing Cone	Normal Vision Colors				
		Blue	Green	Yellow	Orange	Red
Protanopia (1% of white males)	L	Blue	None	Yellow	None	Black
Deutanopia (1% of males, 0.1% of females)	M	Blue	None	Yellow	Gray	Gray
Tritanopia (0.01% of people)	S	None	Green	None	Orange	Red

**TABLE 2 Independent Variables and Levels**

Level	Independent Variable		
	Crossing Pedestrians	Opposing Vehicles	FYA Signal Configuration
1	No pedestrians [ped area]	No vehicles	Three-section dual-arrow vertical
2	One pedestrian <i>toward</i> the subject [ped toward]	Three vehicles	Four-section vertical
3	One pedestrian <i>away</i> from subject [ped away]	Nine vehicles	-
4	Four pedestrians (two pedestrians each side walking <i>toward</i> and <i>away</i> the subject) [ped both]	-	-

**TABLE 3 Two-sample t-Test of ATFDs Comparing AOIs with Four- vs. Three-Section Signals**

<b>Area of Interest</b>	<b>Signal Configuration</b>						<b>Welch's t-test</b>
	<b>4-section</b>			<b>3-section</b>			<b>4-Section vs. 3-Section</b>
	<b>ATFD (s)</b>	<b><i>n</i></b>	<b>Std. Dev.</b>	<b>ATFD (s)</b>	<b><i>n</i></b>	<b>Std. Dev.</b>	<b><i>p</i>-value</b>
Opposing Vehicles	5.20	207	2.88	5.46	207	3.21	0.37
Ped Both	2.84	309	1.86	3.03	78	2.31	0.59
Turn Bay	2.36	207	1.69	2.43	308	1.88	0.68
Ped Away	1.92	76	1.39	1.60	74	1.28	0.13
FYA Signal	1.82	309	1.58	1.72	308	1.98	0.48
Ped Toward	1.47	78	1.63	1.47	74	1.34	0.97
Ped Area	0.49	56	0.4	0.49	60	0.43	0.93

**TABLE 4 Pedestrian Lane Number by FYA Signal Configuration**

<b>Pedestrian Direction</b>	<b>Signal Configuration</b>						<b>Welch's <i>t</i>-test</b>
	<b>4-section</b>			<b>3-section</b>			<b>4-section vs. 3-section</b>
	<i>Average PLN</i>	<i>n</i>	<i>Std. Dev</i>	<i>Average PLN</i>	<i>n</i>	<i>Std. Dev</i>	<i>p-value</i>
Both Towards	4.89	42	1.21	4.72	41	1.15	0.67
Toward Only	3.40	44	1.01	3.10	48	1.37	0.28
Both Away	0.81	76	0.78	1.06	74	0.84	0.09
Away Only	0.72	100	0.77	1.08	72	0.78	<b>0.01</b>





a



b



c

**FIGURE 1 Views from a) outside the simulator and b) from inside the OSU Driving Simulator and c) subject wearing eye-tracking device.**












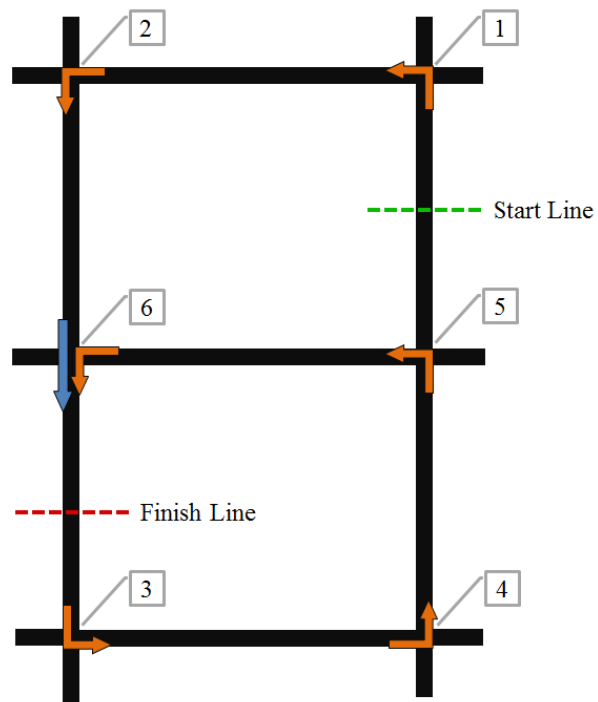
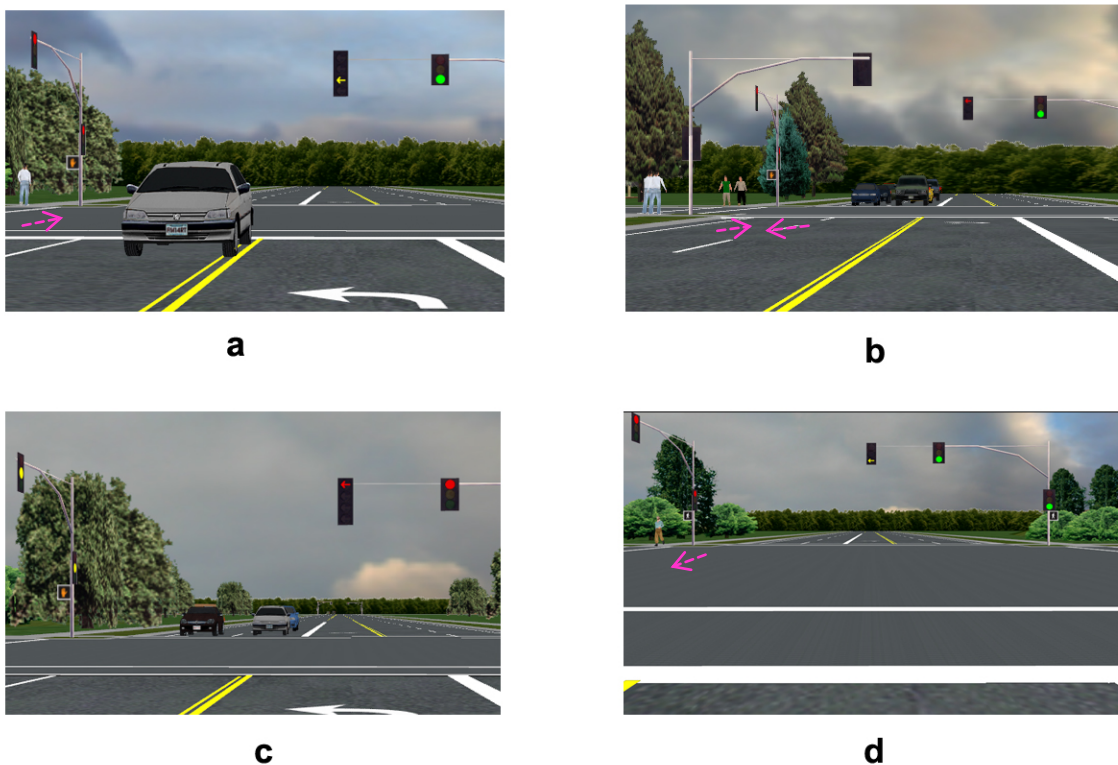
	Signal Display	Indication Sequence			
Four Section FYA Display	 RA YA FYA GA	 RA	 FYA	 YA	 RA
Three Section FYA with a Bimodal Lens	 RA YA GA           AND  RA YA FYA	 RA	 FYA	 YA	 RA
		Solid Red Phase	Flashing Yellow Phase	Solid Yellow Phase	Solid Red Phase

FIGURE 2 Presentation sequence of the FYA for drivers arriving at each simulated intersection.



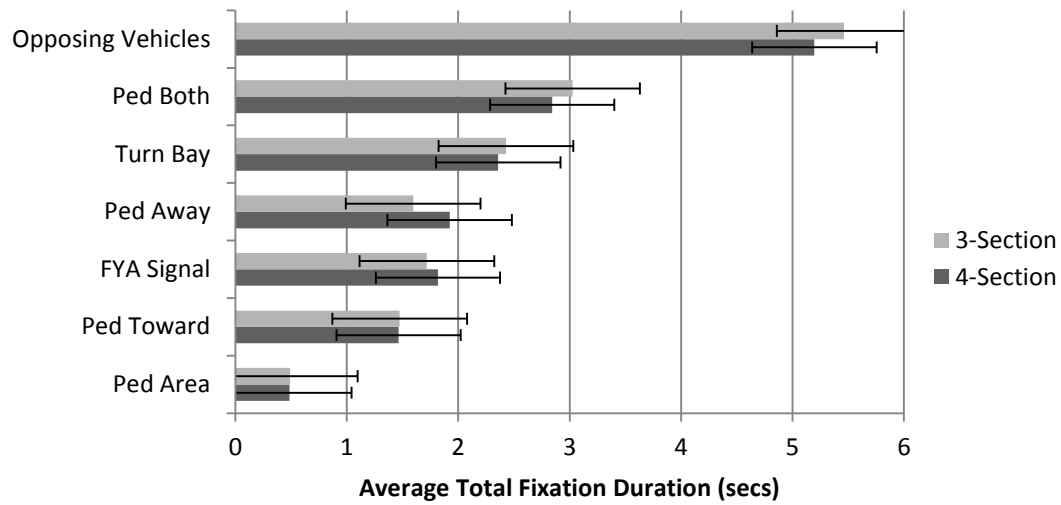
**FIGURE 3 Experimental intersection grid layout**



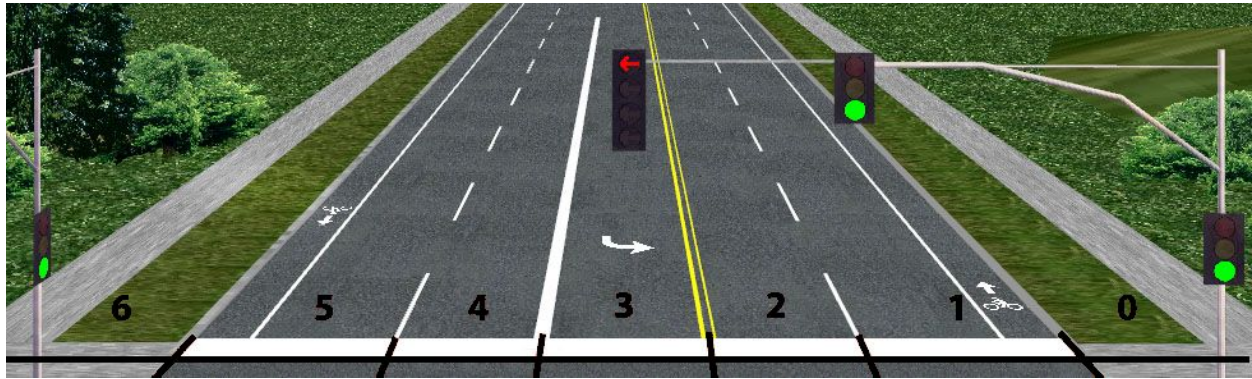
**FIGURE 4** Scenarios displaying a) 1 pedestrian walking away; b) four pedestrians, two walking in each direction; c) no pedestrians; and d) one pedestrian walking towards (dashed arrows indicate the pedestrian direction of travel).



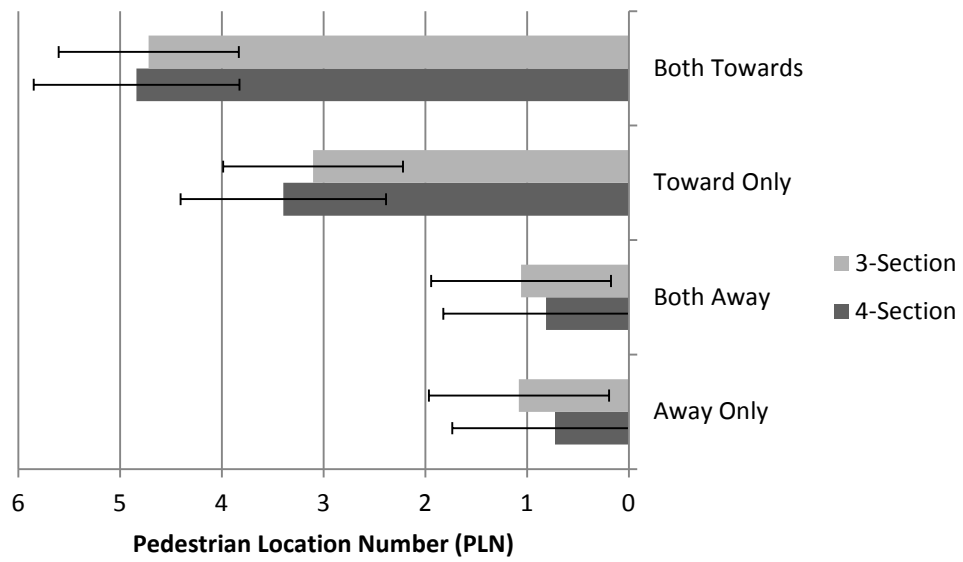
**FIGURE 5** Example AOIs a) three-section signal head and b) four-section signal head.



**FIGURE 6** Bar plot of ATFDs at all intersections, by FYA signal configuration.



**FIGURE 7** Pedestrian lane numbers in receiving approach when driver initiates a left turn.



**FIGURE 8 Average pedestrian lane number when driver initiates left turn, by FYA signal configuration**