Three- or Four-Section Displays for Permissive Left Turns?

Some Evidence from a Simulator-Based Analysis of Driver Performance

David S. Hurwitz, Christopher M. Monsere, Patrick Marnell, and Kirk Paulsen

Many jurisdictions are using the flashing yellow arrow (FYA) to control protected and permissive left turns. 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* permits the operation of a three-section vertical head only for permissive turns in locations where heights are restricted. This paper summarizes a comparison of driver performance with 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 from the (*a*) average total eye glance durations at specific areas of interest and (*b*) the position of the pedestrian in the crosswalk when the driver initiated the left turn. No statistically significant differences between the average fixation duration when the FYA was presented with a three- or four-section signal head were identified. The pedestrian's position in the crosswalk when the driver began the left turn was not statistically significantly different for three of the four pedestrian walking directions presented. Overall, measurable driver performance does not seem to be sensitive to the vertical positioning of the FYA display in the permissive interval.

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 faces no other (legal) conflicts. In the 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 circular green, flashing circular red, flashing circular yellow, and flashing yellow arrow (FYA) indications. Research funded by NCHRP demonstrated that, by most measures, the FYA indication is the most effective of these displays for the communication of permissive left turns (*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 the protected or permissive operation for left turns (PPLTs), the 2009 MUTCD requires the use of the four-section signal face (Standard 4D.20.03). As jurisdictions deploy the FYA, some have or are considering the use of a three-section vertical head that displays the FYA 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 operations (Standard 4D.18.03), protected-only operations (Standard 4D.19.03), or flashing red operations (Standard 4D.18.05) or when height or lateral restrictions prevent the use of a four-section display in PPLTs [Standard 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 according to the number of sections in the 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 found that NCHRP 20-07/Task 283 is being conducted by D. Noyce at the University of Wisconsin–Madison to study shared yellow signal faces in the FYA display.

This paper compares driver performance with 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 making 620 permissive left-turn maneuvers completed the course. Driver performance was measured from average total eye glance durations at specific areas of interest (AOIs; left-turn pavement bay markings, the signal indication, the pedestrian and vehicle waiting area, and the pedestrian signal heads) per intersection approach and turning maneuver 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 and then describes the methodology and simulator equipment

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used in the research. The analysis of the data and a discussion of the results follow. 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 the challenges to driver behavior of different aspects of permitted left-turn phasing. Knodler and Noyce have suggested that the circular green 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 (*4*). At the time that Knodler and Noyce performed their research, several types of indications were used for permissive left-turn movements in the United States (e.g., a flashing red arrow, flashing circular yellow, flashing circular red, and FYA). These indications were developed to improve driver comprehension and safety during PPLT operations (although 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 tested 34 drivers at the Arbella Human Performance Laboratory Driving Simulator Laboratory at the University of Massachusetts, Amherst (*5*). They collected 991 responses from indication scenarios to understand the difference in driver comprehension of five different permissive left-turn signal indications (circular green, FYA, flashing red arrow, flashing circular yellow, and flashing circular red) in three configurations (five-section vertical, five-section horizontal, and five-section cluster). As measured by the correct driver responses, the circular green, FYA, and flashing circular yellow indications provided relatively equal responses (the difference was 1%) but outperformed the flashing red arrow and flashing circular red indications by an average of 28.2% (*5*).

In subsequent work, Noyce et al. 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 (*6*). They found no statistically significant difference ($\alpha = .05$) in the 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. also explored traffic conflicts associated with PPLT signal displays and found no statistically significant difference in conflict rates ($\alpha = .05$) (*1*). The rates were very low for the different PPLT signal displays, which limited the ability to make conclusions about the differences in the safety effects of the displays.

These preliminary works by Knodler and Noyce (*4*) and Noyce et al. (*6*) provided evidence that the FYA indication could be used to replace the flashing circular red and flashing red arrow for permitted left-turn movements. In 2003, Brehmer et al. published NCHRP Report 493, which comprehensively evaluated PPLT alternatives by the use of numerous experimental techniques (*1*). 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*).

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

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 examination of the comprehension of traffic signal indications (*8*). To date, no literature has specifically examined this influence for traffic signals. However, it is generally accepted that the visual search task is governed by cognitive factors (*9, 10*). In general, the work of Megaw and Richardson suggests that while searching for targets, subjects often begin the visual search at the upper left of the display (*11*), but others argue that the search initiates at the center of displays.

In addition, surveys show that the engineering community has the perception 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*). Many forms of color blindness exist, 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, respectively), as well as blue and yellow color deficits (tritanopia). No common form of color blindness affects both green and yellow vision.

TABLE 1 Colors Perceived with Dichromatism (*8*)

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

[a]Cone cell, a photoreceptor cell in the retina; L = responds to long wavelengths, peaks at red; M = medium wavelength, peaks at green; S = short wavelength, peaks at blue.

METHODOLOGY

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

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 in the comparison of the three- versus four-section vertical displays, 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. The total duration of driver fixation during permitted left-turn maneuvers at signalized intersections operating the FYA does not differ between the four-section vertical and the three-section, dual-arrow vertical configuration.
2. 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 does not differ between the four-section vertical and the 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 rear-view mirror. The two side mirrors have liquid crystal displays. The vehicle cab instruments are fully functional and include a steering control loading system to accurately represent steering torques on the basis of vehicle speed and steering angle. The simulator software can record performance measures such as speed, position, braking, and acceleration at a sampling rate of 60 Hz. Figure 1 shows views from outside (Figure 1*a*) and inside (Figure 1*b*) the simulator.

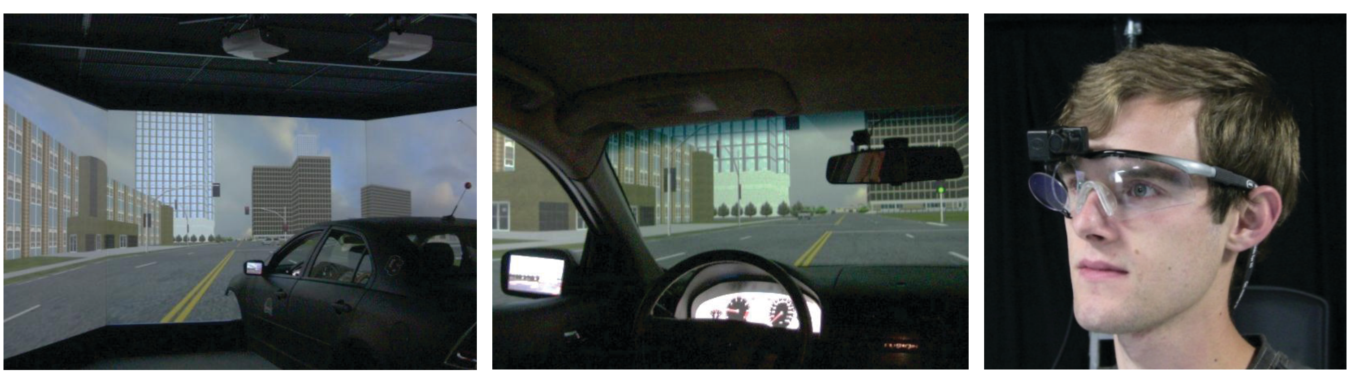
A driving simulator may be validated in an absolute (*12*) or relative (*13–15*) manner on the basis of the differences in any number of performance measures, such as speed or lateral position, observed. For a simulator experiment to be useful, it is not required that absolute validity be obtained; however, it is necessary that relative validity be established (*12*). Drivers' stopping behavior at traffic signals, perception reaction time, and deceleration rates have previously been validated in the OSU driving simulator (*16, 17*).

Eye Tracking

Eye-tracking data were collected by use of a Mobile Eye-XG platform from Applied Science Laboratories (Figure 1*c*). The advanced Mobile Eye-XG system allows the subject to have unconstrained eye movement and unconstrained head movement and has a sampling rate of 30 Hz and an accuracy of 0.5 to 1.0 degree. The subject's gaze is calculated on the basis of 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. A fixation consists of a focus on a point for a short period of time, and a saccade consists of movement of the eye when it jumps 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 ms. Saccades are not recorded directly but are calculated on the basis of 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 toward, 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



(a) (b) (c)

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

TABLE 2 Independent Variables and Levels

	Independent Variable		
Level	Crossing Pedestrians (variable name)	Number of Opposing Vehicles	FYA Signal Configuration
1	No pedestrians (ped area)	None	Three-section dual-arrow vertical
2	One pedestrian walking toward subject (ped toward)	Three	Four-section vertical
3	One pedestrian walking away from subject (ped away)	Nine	na
4	Four pedestrians (two pedestrians on each side walking toward and away from subject) (ped both)	na	na

NOTE: ped = pedestrian; na = not applicable.

sequence for the FYA for drivers in the simulated environment is shown in Figure 2. The simulator was configured so that all drivers were presented with the FYA on arrival at the intersection.

Subject Recruitment and Sample Size

Participants in this study were recruited from OSU's student body and individuals from the surrounding community of Corvallis, Oregon. Participants were required to possess a valid driver's license, to be able to be calibrated with the eye tracker, and to be physically and mentally capable of legally operating a motor vehicle. Participants also needed to be deemed to be 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, college-aged students were overrepresented. The mean age of the 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. The mission of the Institutional Review Board is to ensure compliance with the *Code of Federal Regulations* issued by the U.S. Department of Health and Human Services for the conduct of research with human subjects.

Scenario Layout and Intersection Control

Open-source simulator software, including Internet Scene Assembler, Simcreator, and Google Sketchup, was 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 as follows:

- 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?

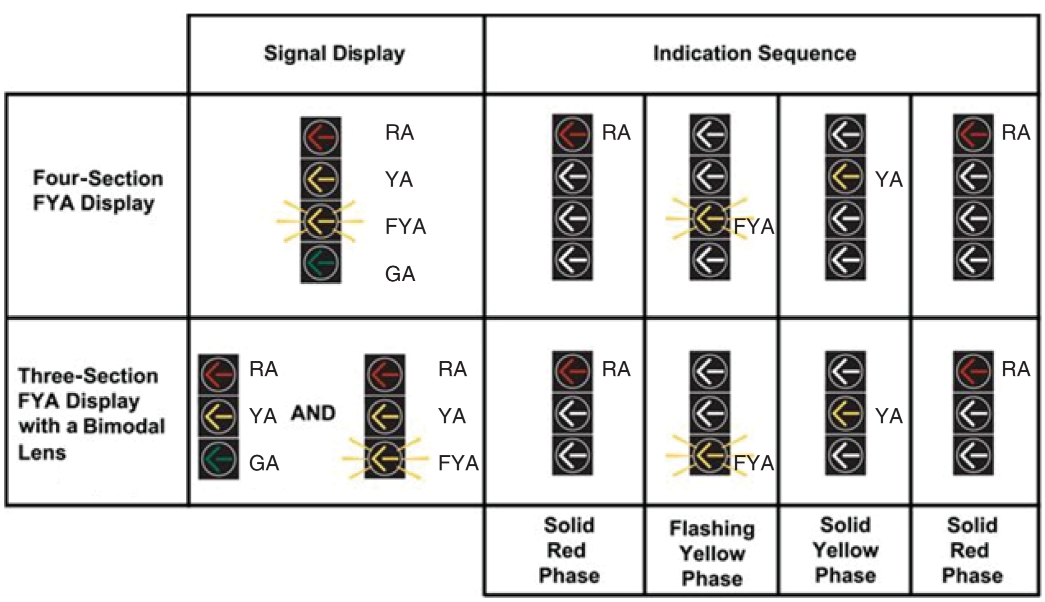


FIGURE 2 Sequence of FYA presentation for drivers arriving at each simulated intersection (RA = red arrow; GA = green arrow).

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-min experimental drive.

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

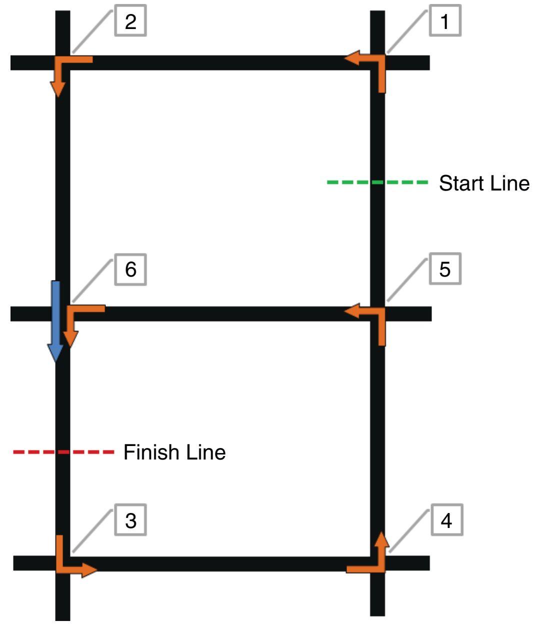


FIGURE 3 Grid layout of experimental intersection.

DATA ANALYSIS AND RESULTS

Because of simulator sickness, eight subjects did not complete the experiment, and data collection errors rendered the data for three subjects unusable. Data for the remaining 27 subjects (14 male and 13 female subjects) were processed and analyzed. Of the 648 possible permissive left-turn maneuvers performed by the 27 subjects, 28 left turns were removed because of calibration failures resulting in a loss of usable eye-tracking data, leaving 620 left turns

(a)

(b)

(c)

(d)

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

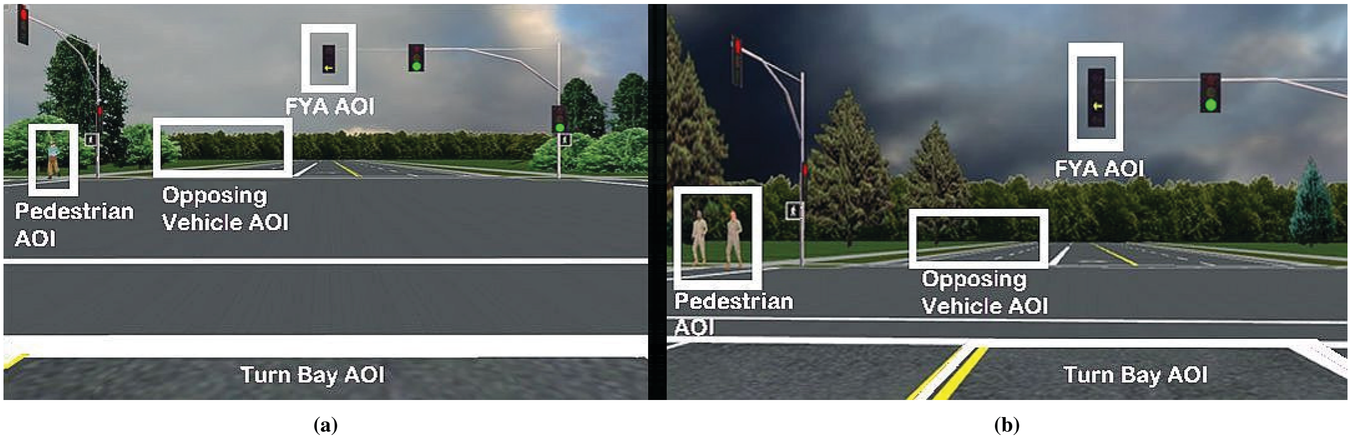


FIGURE 5 Example AOIs for (*a*) three-section signal head and (*b*) four-section signal head.

for analysis. Driver performance was measured by (*a*) the average total eye glance durations at specific AOIs and (*b*) 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 definition of 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-s 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 the length of fixation on each AOI and the configuration of the signal head. Table 3 presents the numerical results and the 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 an α-value of .05.

The largest average fixation duration was on the opposing vehicles, for which the average fixation durations were 5.46 and 5.20 s, respectively, for the three- and four-section displays. This difference was not statistically significantly ($p = .37$). This fixation duration was followed by that for the pedestrian areas when four pedestrians were walking from both directions: 2.84 s for the four-section arrangement and 3.03 s for the three-section arrangement (the difference was not statistically significant, i.e., $p = .59$). The turn bay (in which the driver was searching for a reference position) had average fixation durations of 2.36 and 2.43 s ($p = .68$). Depending on the signal arrangement, the rank orders of the next

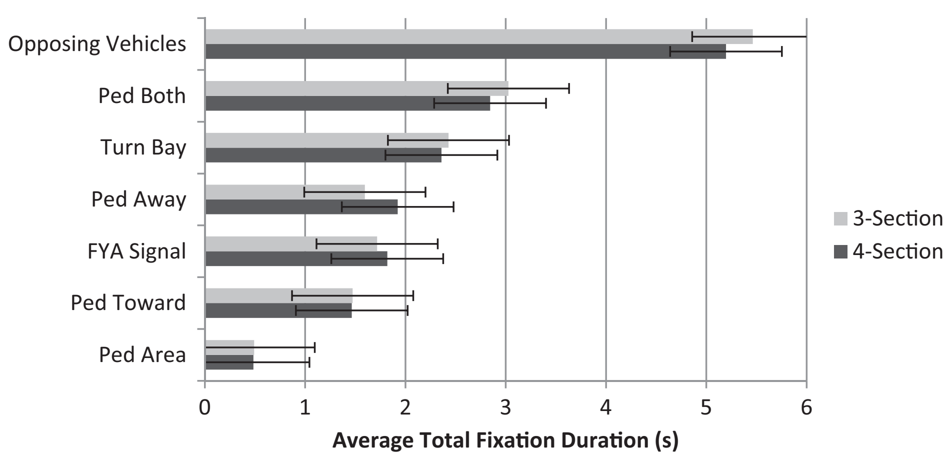


FIGURE 6 ATFDs at all intersections, by FYA signal configuration.

TABLE 3 Two-Sample *t*-Test of ATFDs Comparing AOIs with Four- and Three-Section Signals

	Result, by Signal Configuration Display						
	Four-Section			Three-Section			
AOI	ATFD (s)	*n*	SD	ATFD (s)	*n*	SD	*p*-Value for Four-Section Display Versus Three-Section Display
Opposing vehicles	5.20	207	2.88	5.46	207	3.21	.37
Ped both	2.84	309	1.86	3.03	78	2.31	.59
Turn bay	2.36	207	1.69	2.43	308	1.88	.68
Ped away	1.92	76	1.39	1.60	74	1.28	.13
FYA signal	1.82	309	1.58	1.71	308	1.98	.48
Ped toward	1.46	78	1.63	1.47	74	1.34	.97
Ped area	0.49	56	0.4	0.49	60	0.43	.93

NOTE: The *p*-values were determined by Welch's *t*-tests; *n* = number of left turns; SD = standard deviation.

two AOIs were different. For the four-section head, the fixation duration of the AOI for the pedestrian walking away from the subject (1.92 s) was followed by that for the AOI for the signal head itself (1.82 s). For the three-section head, the order was reversed: a fixation duration of 1.71 s for the signal head, followed by a fixation duration of 1.60 s for the pedestrian walking away from the subject. Neither of these was statistically significantly different ($p = .13$ and $p = .48$, respectively). The average fixation durations for the single pedestrian walking toward the subject were nearly identical for both arrangements (1.46 s for four-section and 1.47 s for three-section) and not statistically significantly different ($p = .97$). The AOI with the lowest fixation duration was that where pedestrians would be but no pedestrians were present (0.49 s for both displays; $p = .93$).

Position of Pedestrians

The eye-tracking video clips were manually analyzed to capture the positions of pedestrians in the crosswalk when the drivers initiated their permitted left-turn maneuvers. Initiation of the permitted left turn was determined by examination of 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 shown in Figure 7. These lanes are on the approach receiving the left-turning vehicle. Because of the nature of the head-mounted eye tracker, it was not always possible to see the pedestrian in the video. PLNs were included in the data analysis only if the scene camera provided a clear line of sight to the pedestrian. Approximately 455 of the 620 turning maneuvers were available for this analysis.

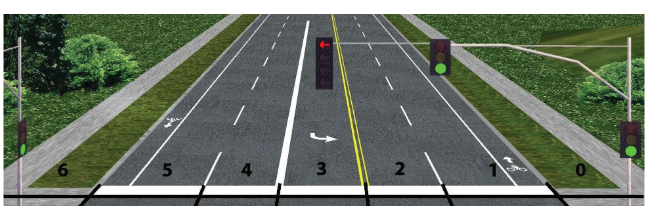


FIGURE 7 PLNs in receiving approach when driver initiates left turn.

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, Toward Only, and Both Toward. Toward Only and Away Only are single pedestrians walking toward and away from the driver, respectively. Both Toward and Both Away are observations from the same pedestrian scenario but are the lane positions of each walking pair. Both Toward is the measured PLN of the set of two pedestrians walking toward 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. In Figure 8, the *x*-axis is reversed to correspond graphically to Figure 7. The numerical results, including the results of Welch's two-sample, two-sided *t*-tests, are presented in Table 4. Significance was assumed at an α-value of .05.

When a single pedestrian was walking away from the left-turning driver (from Positions 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. These results mean that, on average, pedestrians were 0.36 PLN closer to the destination curb in the presence of a four-section signal display than they were in the presence of the three-section display. This difference was statistically significantly different ($p = .01$). When a single pedestrian was walking toward the driver (from Positions 0 to 6 in Figure 7), the average position was 3.40 for the four-section arrangement and 3.10 for the three-section arrangement (which means that, on average, pedestrians cleared the legal receiving Lane 2). No statistically significant difference was found between the arrangements ($p = .28$).

When four pedestrians were present, the set of pedestrians walking toward the drivers reached PLNs of 4.89 and 4.72, respectively, for the four-section and three-section arrangements. Although these values were not statistically significantly different by signal head arrangement ($p = .67$), the PLN was approximately 1.5 lanes farther toward the far curb than the PLN for the Toward Only pedestrian (drivers need to wait for the other set of pedestrians walking away). For the set of pedestrians walking away from the driver, the PLNs were 0.81 for the four-section arrangement and 1.06 for the three-section arrangement. This difference was not statistically significantly different ($p = .09$) and similar to the PLN for the single pedestrian walking away from the driver.

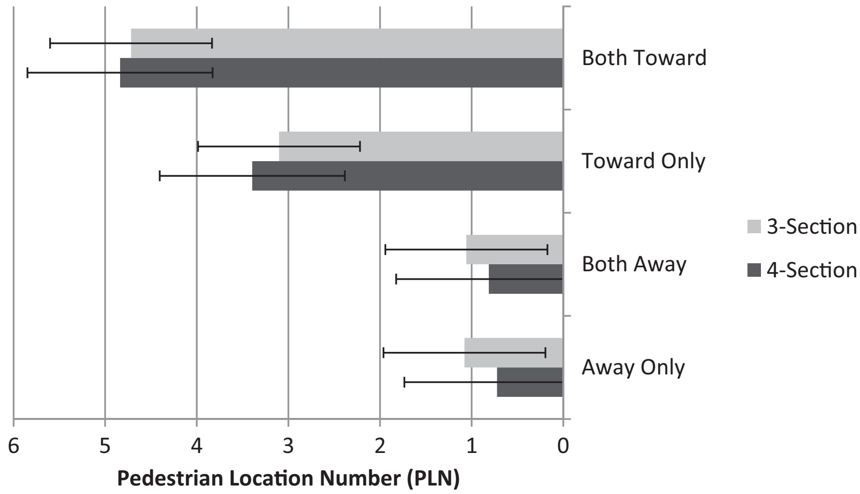


FIGURE 8 Average PLN when driver initiates left turn, by FYA signal configuration.

CONCLUSION

A clear gap in knowledge on the impacts of the presentation of the FYA in a three-section or four-section vertical configuration on operational and driver safety exists in the traffic engineering profession. This is the first study to examine drivers' visual search of three- and four-section FYA signal configurations by use of a high-fidelity, motion-based driving simulator with mobile eye-tracking equipment. In this research, the primary difference between the signal arrangements was in the vertical position of the FYA display. In this context, little difference in the visual search tasks of the drivers was observed. The analysis found no statistically significant difference in the average driver fixation duration between any of the independent control variables studied between the three- and four-section FYA displays.

When the positions of the pedestrians are considered by lane number, when the driver initiated a left turn, a statistically significant difference between the four- and three-section arrangements was found only for the case in which a single pedestrian was walking away from the driver. The average difference was 0.36 lane (4 ft) closer to the destination curb (the difference in average values for the away direction with multiple pedestrians was similar—0.25 lane—but the difference was not significant). Although these differences are measurable, this measure has yet to be mapped to crash potential or other currently accepted measures of safety. Overall, it seems that the driver performance measurable in this research is not sensitive to the vertical positioning of the FYA display in the permissive interval.

This research has limitations that the authors acknowledge. This study examined driver interactions only with the permissive portion of PPLT phasing. It is possible that differences in driver performance between the four- and three-section arrangements exist during the transitions between protected and permitted phasing. Future research should study driver performance at this interval. To do so, gap acceptance or fail-critical and fail-safe approaches may be needed to provide critical insight. In addition, this research did not address the color deficiency issue. This research question may not be as important as one evaluating 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). Furthermore, subject recruitment in this study was biased toward a younger population. A larger, more diverse sample that more closely matches 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).

TABLE 4 PLN by FYA Signal Configuration

	Result, by Signal Configuration Display						
	Four-Section			Three-Section			
Pedestrian Direction	Average PLN	*n*	SD	Average PLN	*n*	SD	*p*-Value for Four-Section Versus Three-Section
Both toward	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	0.01

NOTE: The *p*-values were determined by Welch's *t*-tests.

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