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Measuring drivers' visual attention in work zones

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Abstract

Assessing driver sensory and cognitive processes, and the effect of temporary traffic control devices upon those processes in work zones, can be somewhat difficult. Measuring vehicle speed, lane position, acceleration, braking, turning, etc. through in-vehicle instrumentation is easily accomplished, but understanding driver visual attention is much more challenging. For example, during construction projects, drivers often have difficulty identifying appropriate gaps for turning in order to access businesses, particularly at night. In addition, driveways are often delineated with channelizing drums that appear the same as all the other drums in the work zone. Researchers at the Texas A&M Transportation Institute performed a study of driver eye-tracking in work zones to determine if drivers could more easily locate specific business driveways if alternative driveway delineation treatments were used. The evaluation was performed using paid participants driving instrumented vehicles equipped with dash-mounted eye-tracking equipment. Primary measures of effectiveness (MOE) were: participants' glance distributions at various viewing regions during driveway approaches and average glance durations at driveway treatments. Overall, the data showed that drivers' visual attention was different when the alternative delineation treatments were used, evidenced by a statistically significant increase in the number of treatment glances at the alternative treatments. There was little difference in the durations of the treatment glances during the daytime, probably due to the prevalence of other visual cues that are readily visible in the daytime. But glance durations at the alternative treatments were longer at night, indicative of the success of the treatment in attracting attention to the actual driveway location. Overall, while differences in the MOE were less pronounced during the day, the alternative channelizing treatments generally performed better than the standard drum treatment at night.

Keywords: Work zone; Business driveway; Delineation; Channelizing; Cones; Drums; Longitudinal channelizing barricade; LCB; Longitudinal channelizing device; LCD

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1. Introduction

Work zones are temporary in nature, change frequently, and often require traffic to depart from normal driving paths via the use of temporary traffic control devices, including channelizing devices. Thus, work zones can present a more complex driving environment than one would experience under normal driving conditions. These complex driving conditions place a greater demand on driver visual processing, and can often result in more frequent scanning (i.e., increased frequency of eye movements or glances and decreased fixation lengths).

Locating business driveways in work zones can present challenges to drivers, particularly at night, as driveways are typically delineated with the same channelizing drums found throughout the work zone. The use of closely spaced drums to better delineate driveways is sometimes encouraged [1], but their close proximity can further contribute to a cluttered appearance which may make driveway detection more difficult for drivers [2]. Researchers at the Texas A&M Transportation Institute performed a study of driver eye-tracking in work zones to determine if drivers could more easily locate specific business driveways if alternative driveway delineation treatments were used.

2. Methodology

The primary objective of this research was to evaluate alternative business driveway channelizing treatments in real work zones in Texas using a human factors study. To accomplish this, the researchers used an instrumented vehicle with eye-tracking equipment to assess drivers' visual behavior when identifying driveways in cluttered urban work zones and making turns into the correct gap between channelizing devices to reach that driveway. Eye-tracking equipment can be used to record the frequency and duration of driver glances at various regions within the field of view during the driving task. The researchers associated more frequent and longer glances directly at the driveway channelizing treatments to improved delineation and increased driver focus on the driveway itself. Less frequent and shorter glances at the treatments meant that more time was spent searching for, but not yet identifying, the driveway treatments. The researchers hypothesized that the alternative driveway channelizing treatments would produce more frequent and longer duration glances directly at the treatment than the standard treatment.

2.1. Treatments

The researchers used nine different driveways in two active Texas work zones for the study. The standard delineation treatment was in use at these driveways. At these same driveways, the researchers also deployed two alternative treatments which were different in appearance than the standard drums used throughout the work zone. The alternative treatments consisted of combinations of 18-inch longitudinal channelizing devices (LCD) and 42-inch cones. These devices were distinctly different from drums in their size, shape and nighttime retroreflectivity patterns. The treatments are shown in Figures 1, 2 and 3.

2.2. Study locations

The study was performed at two different work zones. The first work zone was located in McKinney, Texas. US Highway 75 was being widened and there were numerous business driveways located along the frontage road. At this work zone, the contractor was using business driveway signs to better distinguish driveway locations. The second work zone was located in Houston, Texas. Interstate Loop 610 was being widened and several business driveways were located along the frontage road. There were no driveway signs at this work zone. Limitations in the field precluded execution of a fully randomized experimental design. However, the researchers did change the treatments each day over the twelve days of data collection in order to partially randomize the treatment order.

Fig. 1. Treatment 1: 18-inch LCD with 42-inch cones.

Fig. 2. Treatment 2: 42-inch cones with 18-inch LCD.

Fig. 3. Treatment 3: standard 36-inch drums.

2.3. Data collection

Paid participants were recruited for the study. Upon arrival, each participant completed visual screenings for acuity, contrast sensitivity, and color blindness to ensure minimum acceptable levels prior to the driving portion of the study. After completing consent paperwork, each participant drove one of two GPS-instrumented 2009 Ford Explorers through the work zone where the treatments were deployed. The vehicles were equipped with a faceLAB™ eye-tracking system, which was used to record driver glances via calibrated in-vehicle dash-mounted infrared video transmitters and cameras. The transmitters emitted a very low level of light and did not impact the driving task. The left and right cameras recorded pupil information for each eye, respectively, which was used to estimate the location of the driver's glances. In addition, a forward scene camera was also mounted behind the vehicle's rear-view mirror and was used to capture the view out the front of the vehicle. The forward scene view was then overlaid with the eye movement of the participant to gauge where within the road scene each participant's attention was drawn. All of this information was recorded by equipment located in the back seat of the vehicle. Two researchers were in the vehicle with the participant at all times. One researcher provided driving instructions for the participant, while the other operated the data collection equipment.

At a designated point upstream of the treatment driveway, the participant was asked to notify the researchers when they could identify the driveway opening for a specific business, then make the turn into that driveway. While the eye-tracking equipment was running continuously during each participant's drive, only the eye-tracking data collected during the period of time between the driver's verbal identification of the driveway and completion of the turn into that driveway were of interest to the researchers. Figure 4 shows a screen shot of one participant's eye-tracking data when they glanced at a driveway sign.

2.4. Data analysis

Researchers recorded data for 243 driveway views (81 subjects for three driveway approaches with each driveway having a different treatment). However, when reducing and analyzing the eye-tracking data, the researchers found that some data was not usable. In some cases, the eye-tracking equipment did not properly record either frame numbers or the forward scene view. In other cases, the eye-tracking equipment was not able to remain properly calibrated over the duration of the participant's drive-through. Finally, traffic queues from a downstream intersection occasionally spilled back into the treatment area and affected the participants viewing time and ability to reach the driveway at a normal speed. Once these data files were eliminated, the researchers had daytime data for 15 participants viewing Treatment 1, 21 participants viewing Treatment 2, and 21 participants viewing Treatment 3. In addition, the nighttime data included for 40 participants viewing Treatment 1, 41 participants viewing Treatment 2, and 42 participants viewing Treatment 3.

Fig. 4. Example of a participant's glance at a business driveway sign.

2.5. Measures of effectiveness

The researchers sought to answer many questions using the data collected. The first question was, “Is the participant’s visual attention drawn more frequently to the correct driveway region when one of the alternative treatments was used?” To answer this question, the researchers used the distribution of the number of glances for each treatment. The second question was, “Do the participants spend more time looking at the correct driveway region when the alternative treatments were used?” To answer this question, the researchers computed the total glance durations of each participant at each treatment. The underlying hypothesis was that the amount of time spent looking at the driveway instead of looking around to double-check whether they are truly looking at the driveway is indicative of improved delineation of the driveway. The channelizing treatment providing higher relative frequencies of glances to the driveway opening and/or longer glance times at the driveway would be considered “better.” In summary, the researchers identified the following measures of effectiveness (MOE) to evaluate the data collected:

- Participant glance distributions
- Average total glance durations

3. Participant glance distribution results

Using the eye-tracking data, the researchers first categorized individual glances for each participant into four main regions in the visual field, which included:

- Driveway signs (if present)
- Treatment (i.e., driveway opening)
- Lane-keeping
- Non-lane-keeping

These regions are shown in Figure 5. Categorization of glances at driveway signs and at treatments was rather straightforward. Lane-keeping glances were considered to be any glances used for the purpose of lane positioning and/or spacing. This included glances at edge lines, glances at non-treatment edge line channelization, glances at the roadway within the edge lines, as well as glances to judge the distance to a vehicle ahead in the same or adjacent lane. Non-lane keeping glances were any glances that did not fall into the previous three categories.

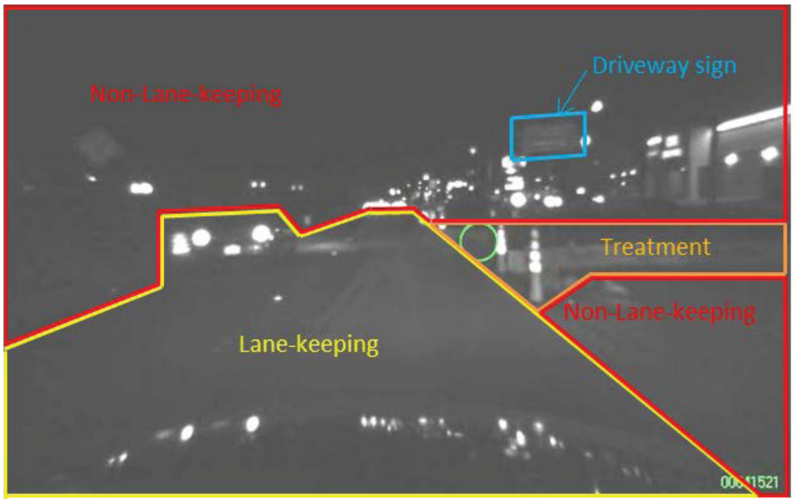

Fig. 5. Participant glance regions used in data reduction.

The researchers then determined the distribution of glances over the four glance region categories for each participant for each driveway approach and treatment tested. Because only the McKinney sites had driveway signs, the McKinney and Houston data had to be analyzed separately. In addition, daytime and nighttime data were analyzed separately. For each data group (McKinney daytime, McKinney nighttime, Houston daytime, and Houston nighttime), researchers conducted a series of Pearson's chi-squared test of independence (also known as the test of homogeneity) to assess whether the distribution of glances was independent of driveway location, and thus could be consolidated across all driveways in each group. Using an alpha value of .05, this test was successful in each of the data groups. Thus, all of daytime data for the McKinney driveways were merged together into one group, as were the data for the other groups. The researchers also tested to see if the McKinney daytime data and the Houston daytime data could be merged (which would suggest that the driveway signs had no impact upon daytime visual scanning for driveways). However, the driveway sign glances did cause the chi-square test to fail, so the McKinney and Houston data remained separate. For each data group, the treatment glance percentages are shown in Table 1.

Table 1. Test of proportion results for treatment glance distributions.

Location and Setup	Treatment 1	Treatment 2	Treatment 3	Glance Relationships[1]
McKinney – Daytime	23%	12%	4%	Trt 1 > Trt 2 > Trt 3
Houston – Daytime	18%	18%	8%	(Trt 1 = Trt 2) > Trt 3
McKinney – Nighttime	10%	15%	8%	Trt 2 > (Trt 1 = Trt 3)
Houston – Nighttime	18%	11%	8%	Trt 1 > Trt 3; Trt 1 = Trt 2; Trt 2 = Trt 3

[1] > indicates a significantly higher proportion of glances; = indicates no significant difference.

Interestingly, the treatment glances at Treatment 3 were significantly lower than both of the other treatments during the daytime. While Treatment 1 had the same distribution of treatment glances as Treatment 2 in Houston during the daytime, it had significantly more glances in McKinney during the daytime. At night, the treatment glances at Treatment 3 were generally lower than the other treatments as well. This suggests that drivers may have some difficulty identifying Treatment 3 at night.

3.1. Average total treatment glance durations

The researchers tabulated the total glance time for each treatment for each subject, and averaged those across each treatment type. The researchers used Statistical Analysis System 9.4 (SAS) to conduct a nested fixed effects analysis of variance (ANOVA) with the treatment orders nested within treatments to determine if the average total glance durations could be consolidated across the various treatment orders tested. SAS models were run for McKinney and Houston respectively, separated into day and night. The researchers used a type I sum of squares in the General Linear Model procedure (GLM). The alpha value was set to .05 for assessing whether the model was effective. All of the models found the nested factor (treatment order) not to be significant. Therefore, researchers were able to simply compare the treatment means generated for each of the models. A summary of the average total glance time data is shown in Figure 6.

The McKinney daytime model showed that the treatments did not produce a statistically significant difference in average total glance times for each treatment. However, the McKinney nighttime model showed that the treatments did produce a statistically significant difference in treatment glance times. The researchers used Tukey's honest significant difference (HSD) test to calculate how each treatment affected the results of the McKinney nighttime data. The results showed that Treatment 2 has the largest value in difference between means when compared to Treatments 1 and 3. There was no difference between Treatments 1 and 3. The Houston daytime model showed that the treatments did not produce a statistically significant difference in treatment glance times. Meanwhile, the Houston nighttime model was found to almost be significant (alpha equal to .0526). The Tukey's HSD test showed that Treatment 2 again had the largest difference between means when compared to Treatments 1 and 3. Once again, there was no difference between Treatments 1 and 3.

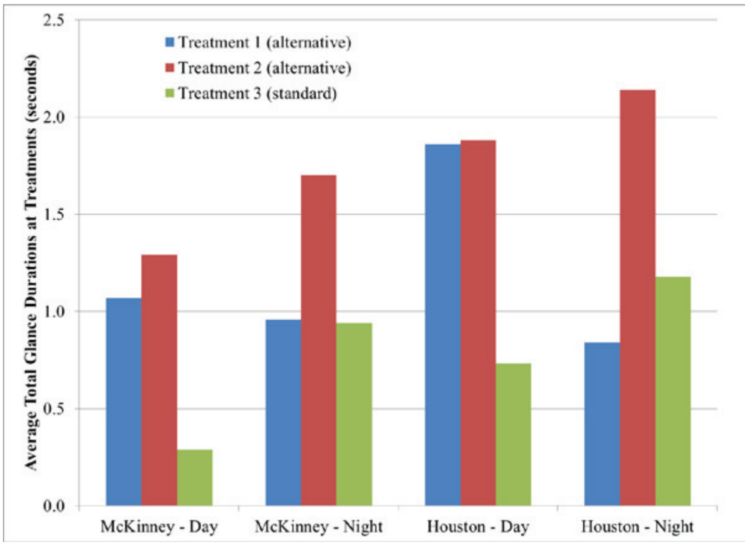

Fig. 6. Average Total Glance Durations at Treatments.

Although the McKinney and Houston nighttime data indicated that the treatment was the primary factor in time spent glancing at treatments, the daytime data showed an element of randomness and no demonstration of a significant effect caused by the treatment.

In further review of the treatment glance durations in Figure 6, the researchers hypothesized that longer treatment glances suggested improved attention-attraction capability of the alternative treatments to the actual driveway location. It was further hypothesized that this improved attraction of attention would assist the task of properly negotiating the driveway turn. Overall, the researchers found that glance durations were longer for Treatment 2 at night at both McKinney and Houston. The differences were not as pronounced in the daytime, likely because drivers use a host of other visual cues to detect driveway openings, many of which are not available in the dark of night.

4. Conclusions

Overall, the researchers found that deploying either Treatment 1 or Treatment 2 could provide some benefits over the existing practice of using Treatment 3. The study results indicated that drivers may have some difficulty identifying business driveways channelized with standard drums at night. The alternative treatments produced more frequent glances at the correct driveway opening, particularly at night. In addition, drivers focused longer on driveways with alternative channelizing treatments than those with standard drums.

The full report for the entire study is available online [2]. Other data showed that fewer study participants missed their intended driveway turn at night when alternative channelizing treatments were used in lieu of standard drums. The results also showed that participants were more likely to notice alternative channelizing devices when they were placed on the driveway radii, rather than along the main lane on either side of the driveway. Based on participant rankings, the standard drum treatment performed worse than both alternative business driveway channelizing treatments at night.

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