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16. Abstract

This report documents the efforts and results of a two-year research project aimed at improving driveway delineation in work zones. The first year of the project included a closed-course study to identify the most promising driveway delineation alternatives for further study. In the second year of the research project, the researchers performed a human factors study of alternative business driveway channelizing treatments in real work zones. The purpose of the research was to determine the effectiveness of alternative business driveway channelizing treatments over standard drum treatments. The alternative treatments included combinations of 18-inch tall low-profile longitudinal channelizing devices and 42-inch tall cones (i.e., grabber cones). Using paid participants who drove a instrumented vehicles, the researchers used driver eye-tracking equipment to compare differences in drivers' visual attention while approaching business driveways with the various channelization treatments deployed. Other measures of effectiveness (MOEs) considered were detection distance, percentage of missed driveways, driver perception/recall of treatments, and driver preferences. 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.

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IMPROVED BUSINESS DRIVEWAY DELINEATION IN URBAN WORK ZONES

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of the FHWA or TxDOT. This report does not constitute a standard, specification, or regulation. This report is not intended for construction, bidding, or permitting purposes. The engineer in charge of the project was LuAnn Theiss, P.E. #95917. The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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Finally, the longitudinal channelizing devices used in this research were provided by Trinity Highway Products. The authors appreciate their contribution to this successful research project.

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CHAPTER 1: INTRODUCTION

STATEMENT OF THE PROBLEM

Turning into and out of driveways in confined or dense urban work zones can present significant challenges to drivers, especially during nighttime conditions when other visual cues about the driveways may be masked in the dark. These challenges can lead to erratic behaviors by drivers such as stopping in a travel lane or making a sharp turn without proper turn signal indications, and adversely affect safety and mobility in the work zone. This project focused on identifying alternative work zone delineation strategies at driveways using various types of work zone channelization devices, evaluating these strategies in both controlled and field conditions, and developing guidance for the effective use of the high-performing channelizing strategies at these driveways.

BACKGROUND

The Texas Department of Transportation (TxDOT) sponsored this research to improve safety and operations at Texas work zones. Approximately 38 percent of work zone crashes in Texas occur on non-freeway facilities in urban areas; the most common type of crash in those work zones are rear end collisions that typically account for 30–40 percent of all crashes. To better understand the problems associated with work zone driveway delineation, the researchers first examined existing work zone driveway delineation practices in Texas, then looked at practices and supporting research from other states.

Existing Work Zone Driveway Delineation Practices

TxDOT does not currently have a standard for delineating driveways in work zones. The channelizing devices and signs used for driveway delineation are identified in the *Texas Manual on Uniform Traffic Control Devices* (TMUTCD) (*1*) and in the *Standard Highway Sign Designs for Texas* manual (*2*).

Channelizing Devices

TxDOT policy allows for the mixing of channelizing device types within work zones. Channelizing device types include cones, tubular markers, vertical panels, drums, barricades, and longitudinal channelizing devices (LCD) (*1*). Figure 1 shows these devices.

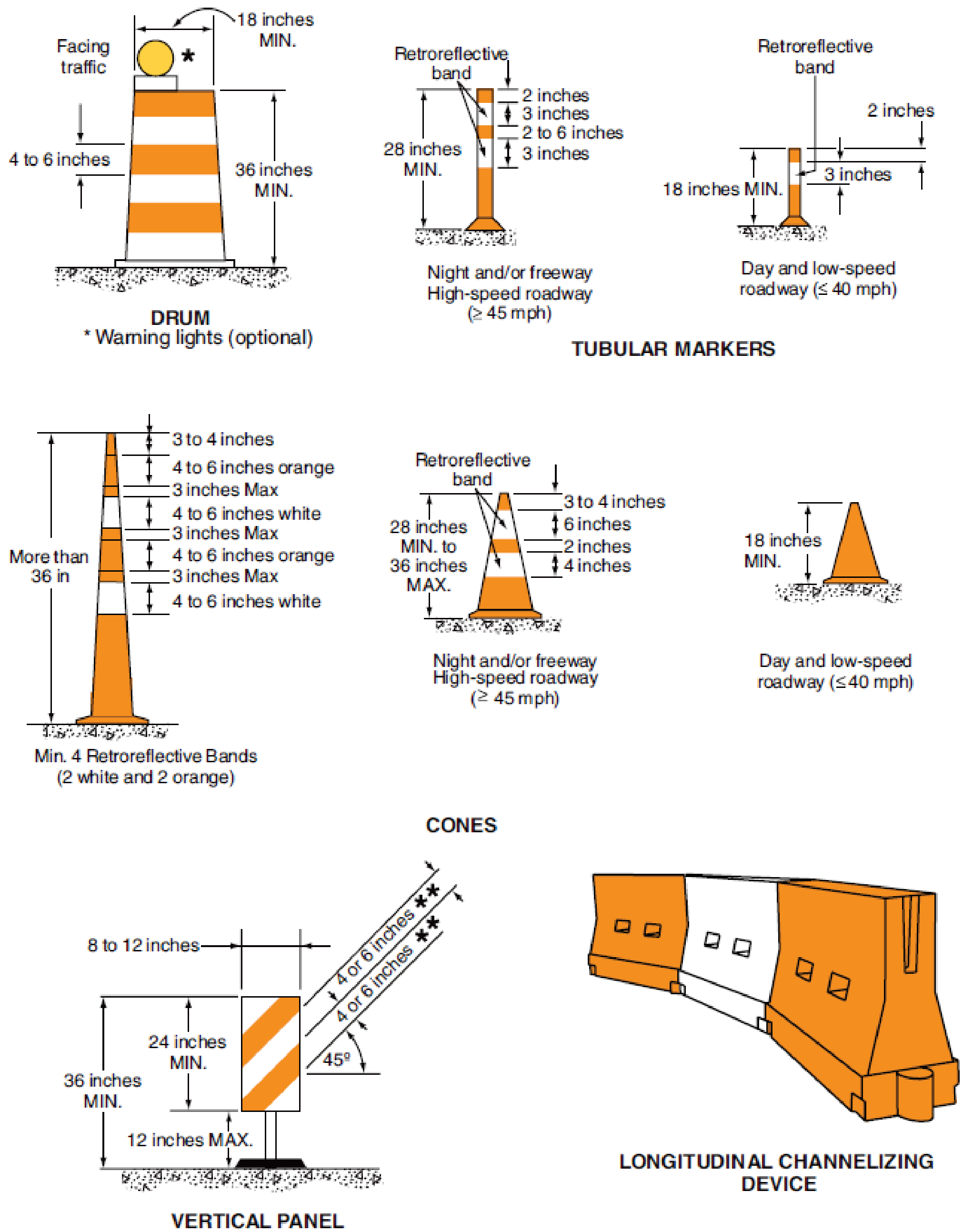

Figure 1. Channelizing Devices Shown in TMUTCD Figure 6F-7 (*1*).

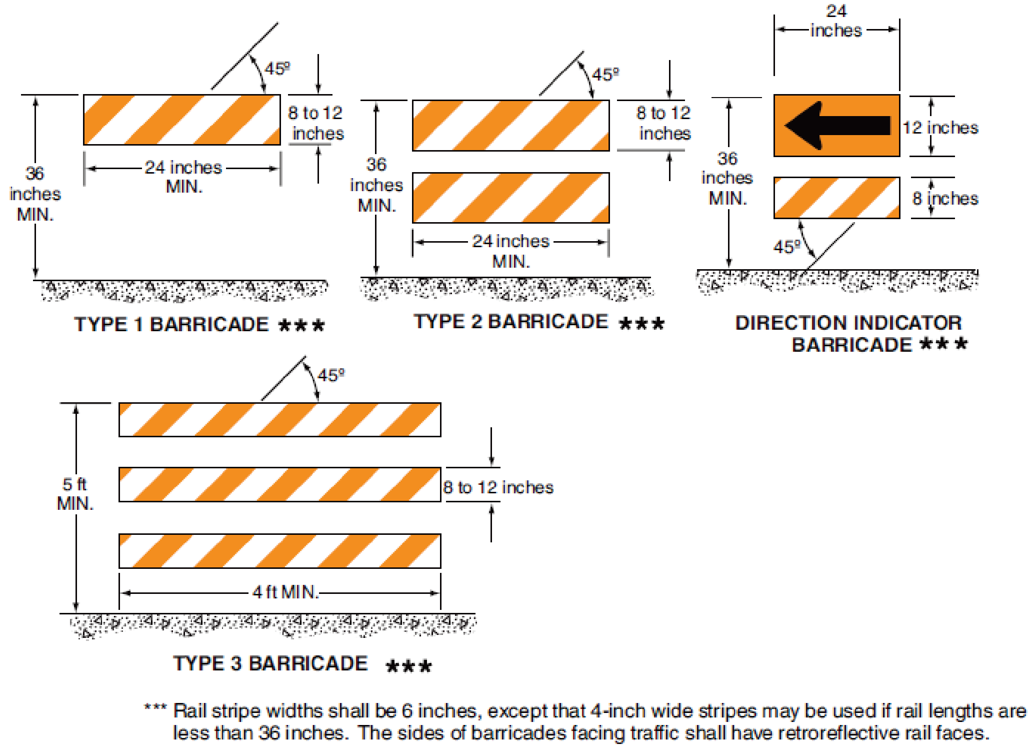

Figure 1. Channelizing Devices Shown in TMUTCD Figure 6F-7 (*1*) (continued).

Drums are the most common type of driveway delineation used in TxDOT work zones. Figure 2 shows a driver's view from a business driveway in a Texas work zone. In this case, the driver is able to look between the channelizing drums to see approaching traffic, but one can easily see that a closer spacing of these large channelizing drums in the vicinity of a business driveway may create negative impacts that far outweigh any improved delineation benefit.

Figure 2. Driver's View from a Passenger Car in a Driveway in a Texas Work Zone (*3*).

Depending upon the type, location, and duration of the work, many work zone driveways have no delineation and motorists simply select a gap in the main lane channelizing devices and turn into the business driveway. In other cases, the radii of the work zone driveways may be delineated with channelizing devices. Figure 3 shows 42-inch tall cones delineating a single driveway in a rural setting. In this scenario, the driveway is visible from a considerable distance.

Figure 3. Single Driveway with 42-Inch Tall Cones in a Rural Area.

Figure 4 shows the same work zone driveway delineation treatment at several closely-spaced driveways. In this case, the 42-inch tall cones appear somewhat scattered and the proper turning gap may be more difficult to select, even in a rural area.

Figure 4. Multiple Driveways with 42-Inch Tall Cones in a Rural Area.

Type 1 and type 3 barricades are frequently used in work zones for delineating business driveways. In addition to delineating, these devices are also used for closing roadways and serve to close off the portion of the roadway where driving is prohibited. Figure 5 shows type 3 barricades alongside a business driveway in a work zone from the perspective of a driver exiting the driveway. The primary concern of using type 3 barricades in this application is that they can block the view of oncoming traffic for motorists exiting the driveway.

Figure 5. Type 3 Barricades in a Texas Work Zone.

LCDs are relatively new channelizing devices and their application to work zones is less familiar. Texas A&M Transportation Institute (TTI) researchers recently completed a study of LCDs for TxDOT (*3*). This research project sought to determine if the use of LCDs could improve work zone channelization in various applications such as driveways. LCDs are manufactured and sold without any retroreflective material. Retroreflectivity is required for nighttime use on state roadways, so the researchers tested various types of delineation enhancements using 32-inch tall LCDs in a closed-course environment. Effective delineation would have to provide a retroreflective surface when LCDs are placed in a longitudinal position with respect to the driver's line of sight. The researchers found that placing retroreflective delineator tabs (similar to those used on concrete barrier) at 6-ft spacing on LCDs would provide sufficient delineation for nighttime use.

This research project also included closed-course human factors studies for driveway applications in a daytime setting. In this study, drivers encountered various configurations of driveway delineation techniques, including standard drums at 60-ft spacing, standard drums at 30-ft spacing, and continuous 32-inch tall LCDs. The spacings were applied in the upstream and downstream tangent sections of the main road, with standard drums in the radii of the driveways. Drivers were asked to identify the point at which they could see the driveway opening. The 30-ft drum spacing resulted in the shortest average detection distance (145 ft), with a few participants mentioning that they thought the devices were spaced too closely, limiting their field of vision.

Average detection distance was slightly longer (183 ft) with the LCD driveway delineation, while average detection distance for the 60-ft drum spacing was the longest (260 ft). The drivers were also asked their opinions of the driveway delineation. Table 1 summarizes the results.

Table 1. Participant Opinions from Project 0-6103 Driveway Study (*3*).

Device Evaluated	Advantages	Disadvantages
Channelizing Drums	• Easy to see the driveway opening • Could see between the drums • Drivers more familiar with drums	• Hard to see the driveway opening because all drums looked alike • Drums can become misaligned or go missing
LCDs	• Easy to see the driveway opening • Contrast in devices helps with driveway detection • Solid line indicates something is changing or happening	• Hard to see on the other side of the 32-inch LCDs • Looks intimidating, like concrete barrier

The researchers had concerns that taller LCDs may present undesirable sight distance conditions, so they evaluated the impacts to side-street drivers of using of LCDs placed longitudinally along the edge of the travel way by using intersection sight triangle computations. Aware of the challenges associated with looking around channelizing devices in a work zone to see oncoming vehicles, the researchers assessed their ability to look over the devices on a flat and level grade. Vertical sight distance depends upon driver eye height, the height of the critical object that the driver is trying to see (i.e., the approaching vehicle), the height of any obstructing objects located between the driver and the critical object (such as LCDs), and the relative distances between these three heights. Headlamp height of oncoming passenger cars is assumed to the critical object height for the approaching vehicle during nighttime conditions. The researchers found that passenger car headlamps would not be visible to side-street drivers behind 32-inch tall (or taller) LCDs and recommended that shorter LCDs (21 inches or less) be used in this application.

Overall, this LCD research produced key findings that are of benefit to the current TxDOT research project:

- Motorist opinions verified that the use of different devices indicates a change in the work zone and that this provides a perceived benefit.
- LCDs have a different appearance, particularly at night.

- The connectivity of LCDs can potentially increase positive guidance in work zones.
- An upper height limit for LCDs in driveway applications should be 21 inches to ensure adequate vertical sight distance for side-street drivers.

The use of LCDs to delineate driveways in work zones has potential merit, but no field studies have been conducted to validate their effectiveness.

Signs

TxDOT's *Standard Highway Sign Designs for Texas* manual (*2*) includes several types of blue driveway signs that can be used for demarcation of business driveways. Figure 6 shows these signs.

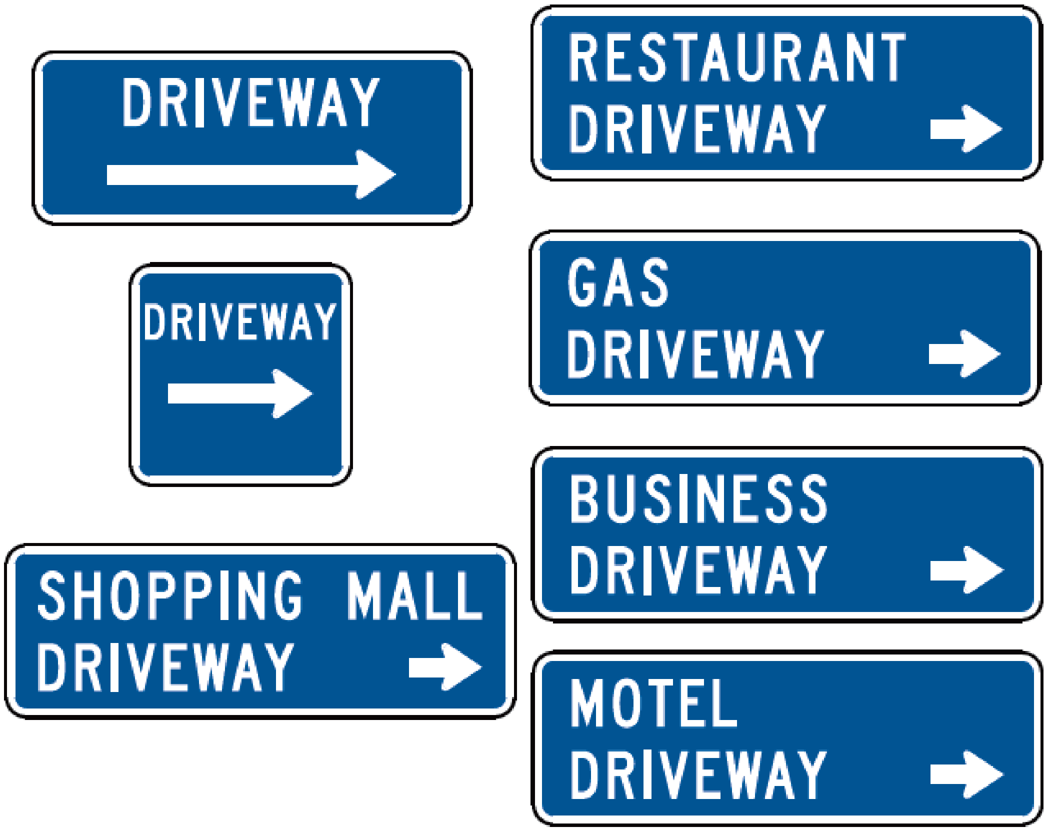

Figure 6. D70 Driveway Signs in the Standard Highway Sign Designs for Texas Manual (2).

Because these signs are different from the orange color that is used on channelizing devices and other work zone signs, they do offer some additional conspicuity. However, when used at work zones with many densely spaced driveways and businesses, they can quickly create a cluttered and confusing appearance. Figure 7 shows similar signs in an urban work zone in Florida.

Figure 7. Blue Driveway Signs in a Florida Work Zone.

The effectiveness of these signs in terms of affecting driveway detection and turning behavior has not been researched. The researchers found inconsistent placement of these signs with respect to the driveway location in various work zones. The use of driveway signs results in an additional expense to TxDOT and the contractor; however, they are popular with local businesses.

Other Work Zone Driveway Delineation Research

Other states have sponsored research into improving delineation of decision points (i.e., exit ramps and driveways) in work zones. Some of those efforts are documented in this section of this report.

Florida

Florida Department of Transportation (FDOT) is currently sponsoring research to improve work zone driveway delineation (*4*). Although the research was originally intended to evaluate the use of blue-striped channelizing drums, FDOT chose instead evaluate LCDs because they conform to *Manual on Uniform Traffic Control Devices* (MUTCD) channelizing device requirements (i.e., colors) and are already approved for use in the national manual. Figure 8 shows an example application of LCDs used for driveway delineation. This particular device was chosen because (a) it is only 18 inches in height and should not create sight distance restrictions, and (b) when connected together, the LCDs form a continuous line to improve positive guidance. The results of this research have not yet been published.

Figure 8. Example Application of Low-Profile LCDs for Driveway Delineation.

Georgia

Georgia Department of Transportation is currently sponsoring research to investigate the improved delineation methods for work zone diverges on limited access roadways (i.e., exit ramps). The treatments include drums at 10-ft spacing, drums at 40-ft spacing, and concrete barriers. The study is limited to developing and evaluating candidate treatments in a driving simulator and making recommendations for further study in actual field conditions (*5*). The results of this research have not yet been published.

Pennsylvania

Pennsylvania Department of Transportation (PennDOT) has sponsored research investigating the use of green and yellow stripes on channelizing devices to enhance delineation of exit ramps and driveways in work zones (*6*,*7*,*8*,*9*). The study focused on enhanced delineation of freeway exit ramps and urban arterial driveways and included an expert evaluation, full-scale test track simulation in a closed-course setting, and field studies in nine active work zones. As shown in Figure 9, the experimental devices were placed on the tangent sections both upstream and downstream of the driveway in the urban arterial evaluation.

Figure 9. Green and Yellow Striped Channelizing Drums Used in PennDOT Research.

The results showed that the devices appeared to make the exits easier to locate. However, approval of the use of these devices would require that a new (non-uniform) color combination be introduced into temporary traffic control zones.

Kansas

In an FHWA Pooled Fund Study performed under the Midwest Smart Work Zone Deployment Initiative, the use of green/orange/white reflectorized sleeves (or wraps) was evaluated in exit ramp applications. The study did not include driveways on urban arterials. The primary measure of effectiveness used in the evaluation was average speed. The researchers found no differences in average speeds when the colored wraps were used and concluded that they had no negative impacts on traffic operations. In addition, the researchers recognized that work zone had optimum geometric design conditions and that the colored devices might have better application in work zones with visibility issues. At least one work zone intrusion occurred during the study, causing damage to one of the colored channelizing devices (*10*).

Oregon

Oregon Department of Transportation (ODOT) performed an evaluation of blue "Temporary Business Access" signs with blue tubular markers at business access points in one work zone, while another work zone had the signs alone (without tubular markers). Figure 10 shows one of the driveways studied.

Figure 10. Blue Delineation of Business Driveway in Oregon.

The researchers found no difference in traffic count data at the locations with blue signs and tubular markers, while the traffic count data at the other location (with signs only) was inconclusive for unknown reasons. The study primarily used telephone surveys of motorists and businesses to determine the usefulness of the signs and markers. Sixty-two percent of the 381 area motorists surveyed noticed the blue signs and markers, while 78 percent of that group felt that these devices helped them locate the driveways into the businesses. Half of the 12 businesses that had the blue signs and markers at their business entrance stated that they thought the blue signs and markers helped customers locate their business driveway. The research report summary indicates that no negative impacts were found, and the authors recommended continued use of the blue signs and tubular markers (*11*). ODOT implemented the use of the blue signs and markers, including language and the photo shown in Figure 11, in their *Traffic Control Plans (TCP) Design Manual* (*12*).

Figure 11. Enhanced Delineation for Business Entrances in Oregon TCP Design Manual.

Texas

In the late 1980s, research performed by Hawkins et al. (*13*) for TxDOT addressed motorists' understanding of work zone signing that was used during the reconstruction of FM 1960, a major urban arterial in Houston, Texas. Researchers conducted in-person motorist surveys designed to ascertain general knowledge about work zone signing, identify confusing or problematic areas of the signing, and obtain general motorist opinions regarding work zone problems other than signing. One category of questions presented to 205 survey participants asked about locating and accessing destinations adjacent to FM 1960. About half of the respondents (49.5 percent) answered yes to the question: "Do you have trouble finding certain places you want to go because of construction?" This construction project involved over 360 business driveways. Some of the business owners adjacent to FM 1960 had placed directional signing in the work zone that included the business name, logo, and directional arrow indicating the location of the access drive to their business. A majority of the survey participants (53.5 percent) favored the placement of these signs.

The study also included a review of crashes by location. Results showed that approximately one-third of all crashes occurred at or near driveway access points. The researchers also recommended that that larger turning radii be used at driveways to make it easier for motorists to make turns. This could potentially reduce turning encroachments into adjacent lanes, thereby reducing potential vehicle conflicts. Turning encroachments occur more frequently in situations where the width of travel lanes is reduced. The researchers also noted that the presence of channelizing devices may create sight distance restrictions and recommended that individual driveways be checked to ensure that they are visible to drivers from the roadway and that drivers in the driveway can adequately see traffic on the roadway. Interestingly, a low-profile concrete barrier was under development at TTI during the same time that the FM 1960 study was being performed. The researchers noted that one of the primary advantages of the 20-inch tall barrier was that the reduced height significantly improved visibility for drivers.

There is no question that state departments of transportation are concerned with driver identification of exit ramps and driveways in work zones. Research records show that they have sought ways to improve delineation in these areas, often by trying to incorporate the use of non-standard colors, supplemental signing, etc. Although a variety of options have been evaluated, the common theme is that there is likely a benefit to providing channelization that is different in appearance and can be seen by drivers far enough upstream so that they can perceive and react appropriately when they need to access businesses in work zones. It is possible that providing a different channelization appearance could be accomplished by using treatments that consist of uniform devices without the need for non-uniform colors.

Summary

Improving driveway delineation in urban work zones is a concern for many transportation agencies. Based on the number of studies performed in other states, it is apparent that TxDOT is not alone in facing this challenge. There may be some promising driveway delineation techniques that use different combinations of standard devices with uniform colors, but field evaluation using operational data is still needed to validate their effectiveness.

CONTENTS OF THIS REPORT

This report describes the methodology and results of analyses conducted to evaluate various channelizing device applications to enhance identification of driveways in urban work zones. Chapter 2 contains the results of interviews with TxDOT personnel regarding driveway delineation practices. Chapter 3 describes the closed-course study used to the select candidate treatments for further evaluation. Chapter 4 describes the field evaluations of selected treatments in real work zones. Chapter 5 contains the recommendations regarding driveway configurations and conditions where alternative treatments may provide some benefits over standard driveway channelizing practices.

CHAPTER 2:
TXDOT INTERVIEWS

INTRODUCTION

In order to determine the state-of-the-practice regarding business driveway delineation in Texas work zones and the desired work zone configurations and conditions where alternative delineation treatments could be used, TTI researchers conducted telephone interviews with TxDOT personnel in 19 of the 25 TxDOT districts. Some of the most populated cities in Texas are included in the survey responses. A total of 20 responses were received, with two responses coming from the Abilene District.

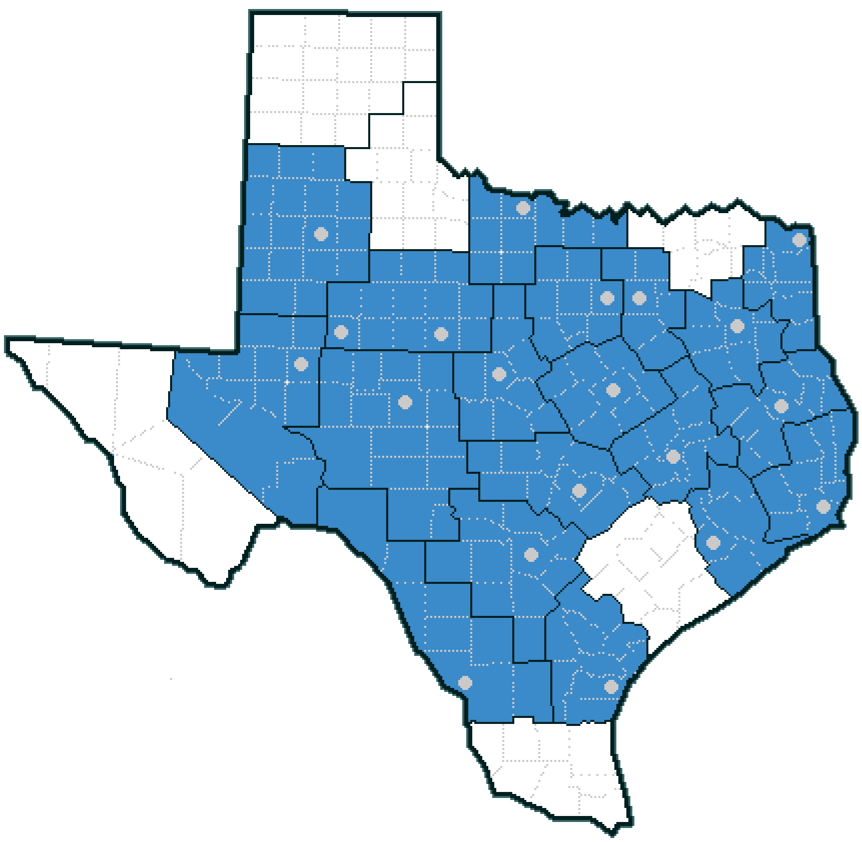

Figure 12. District and Office Locations Represented by Survey Responses.

The survey questions included the following:

- What problems have been encountered concerning driveways within work zones?
- What techniques are used in your area to improve work zone driveway delineation?

- What techniques from other areas of Texas or the United States have you seen or heard of?
- What suggestions do you have for improving work zone driveway delineation?

RESULTS

The survey results were tabulated and summarized. The first question asked the respondents to identify problems that they have encountered with driveways in work zones. Table 2 shows the results.

Table 2. Responses to Common Driveway Problems in Work Zones.

Problem Description	Total
Access density	15
Sight restriction	12
High traffic volume	6
Turning trucks	5
Driver confusion	4
Poor driveway geometry	3

According to the survey responses, access density and sight restriction are the two most common problems related to driveways in work zones reported in the survey. For access density, 15 out of 20 respondents (75 percent) indicated this was a problem. When driveways are located closely together, motorists often have difficulty determining which gap in the channelizing drums is the appropriate gap for turning into their intended destination. Sight restriction was identified by 12 out of 20 respondents (60 percent). This was not surprising, primarily due to the widespread use of drums, which can block motorist's view of roadway features and other traffic. Other problems identified by respondents included high traffic volume (30 percent), turning trucks (25 percent), driver confusion (20 percent), and poor driveway geometry (15 percent).

The second question asked about techniques or strategies used to improve work zone driveway delineation. Table 3 shows the results. Routine use indicates that these techniques were identified as routinely used, while special use indicates that these techniques may be used for special circumstances. The most common responses included the use of standard drums, generic "Driveway" or "Business Access" signs, driveway consolidation, 42-inch tall cones, and type 3 barricades. From the 20 respondents, 13 indicated that drums were their primary driveway channelizing device and two respondents indicated that they might use drums under certain circumstances, for a total of 15 (75 percent). Fourteen use blue business driveway signs either as a default or as needed (70 percent), 12 respondents actively consolidate driveways (60 percent), 11 use 42-inch tall cones (55 percent), and 10 use type 3 barricades (50 percent) by default or as needed. Other strategies were mentioned, but their use was not widespread.

Table 3. Responses to Driveway Delineation Strategies Used in Work Zones.

Driveway Improvement Strategy	Utilization			
	Routine	Special	Total	Percentage
Drums	13	2	15	75%
"Driveway" or "Business Access" sign	7	7	14	70%
Driveway consolidation	12	0	12	60%
42-inch tall cones	6	5	11	55%
Type 3 barricades	8	2	10	50%
Reduced channelizing device spacing	1	5	6	30%
Increased driveway delineation radius	1	5	6	30%
Meeting with business owners	4	1	5	25%
Purposefully different device than main lanes	1	3	4	20%
Vertical panels	2	1	3	15%
"Road Closed" Sign	2	0	2	10%
"[business name]" Sign	1	1	2	10%

Interestingly, several respondents mentioned techniques that were used specifically to address sight concerns: four districts reported using driveway signs, three districts reported using 42-inch tall cones or vertical panels because they are easier to see between, two districts reported increasing the number of channelizing devices along a driveway, and one district reported using low profile barrier along the main lane to increase driveway detection. The addition of signs, barriers, and channelizing devices is intended to provide more conspicuity to the driveway itself while the use of 42-inch tall cones or vertical panels is intended to reduce sight obstructions.

The third question asked about other delineation techniques that the respondents may have seen elsewhere. Of techniques seen out of area or out of state, only two have not already been discussed. One involved painting the curbs, but this was reported with a disclaimer on its potential effectiveness because many work zones will not involve curbs. The other is the use of a portable changeable message signs (PCMS) at the driveway itself. Providing a PCMS at every driveway would not be a very cost-effective strategy, but for large traffic generators needing access within a work zone, this tool may provide some benefit.

For the fourth question, the respondents were asked about their own ideas for improving driveway delineation in work zones. Proposed techniques suggested by the respondents included:

- Blue [business name] driveway signs.
- Temporary and continuous rail or barrier.
- A low profile barrier for higher speeds.
- Drums with driveway arrows.
- Raised pavement marker (RPM) edge line to delineate driveway radii.
- Markers on rural mailboxes.
- Meeting with businesses and using newspapers to communicate.
- PCMS to communicate closures in advance.

Including the business names on the driveway signs was suggested three times and has already been used in 2 of the 19 areas represented in the survey. A temporary and continuous rail or barrier was proposed. With regard to a temporary barrier, there are many types, but these concrete barriers are generally only used when positive protection is required. In addition, concrete barriers require end treatments for each section. The time and effort required to install them at locations with closely spaced driveways makes them an undesirable choice when positive protection is not required. However, LCDs could provide the same continuous rail appearance. LCDs are relatively new and protocols for their use are being developed. LCDs are currently being used to channelize traffic by only one of the 19 maintenance sections included in the survey. Drums with driveway arrows were described as adhesive driveway arrow signs affixed to the side of a standard drum. However, this application would be subject to misalignment and rotation issues and came from an area that does not currently use any driveway signs. The use of RPMs to delineate driveways is a good suggestion for locations with low access density and for projects that do not involve significant pavement work. RPMs may be of benefit in certain applications, but cannot be considered a universal tool. Also suggested for rural use is the application of reflective markers to mailboxes to help residents find their driveway at night.

Meeting with businesses was suggested twice and is currently used in 5 of the 19 respondent areas. This advance communication helps provide a better temporary traffic control and work zone design through an understanding of business needs and helps communicate proposed changes during construction for less confusion. Business owners may be better able to communicate the proposed changes to customers and avoid confusion during construction. Similarly, the use of PCMS and newspapers to help prepare drivers for the work zone was proposed. This is a common practice and its application to the closure of specific driveways can help avoid confusion if the information can be presented and processed in sufficient time. This may not prove to be cost-effective for low volume driveways, but could prove beneficial for large traffic generators.

TREATMENT SELECTION FOR CLOSED-COURSE STUDY

To obtain a final list of driveway delineation candidate treatments for the closed-course study, the researchers first created a list of all uniform channelizing devices. Within the scope and budget of the research project, it would be impossible to evaluate all of the combinations of color, size, shape, and patterns of channelizing devices available in the MUTCD. Only the most promising alternatives should be considered. In addition, it was not known if placing the devices in the radii of the driveway or along the main lane just upstream and downstream of the driveway would provide better information for motorists, so both options were considered. Table 4 was created as a tool for developing a list of potential candidate delineation treatments for further study. The researchers used an internal rating system to quantify the advantages or disadvantages of each application. Advantages of the candidate treatments were considered in terms of their ability to provide a noticeable change, increase visibility, reduce work zone confusion, and reduce driveway confusion. Disadvantages included limited use/application, increased/difficult maintenance, unfamiliarity of devices by motorists and workers, and reduced mobility for the workers. A value of ±3 indicates that the device may provide a significant advantage or disadvantage, while ±2 indicates a moderate impact, and ±1 indicates some impact, or slight impact. Blank cells indicate that the treatment would have no impact. The last column of the table provides a net total of the ratings for each application. The highest scores are shaded.

Table 4. Advantages and Disadvantages of Various Candidate Delineation Techniques.

Rating ±3 = significant ±2 = moderate ±1 = some		Advantages				Disadvantages				Net Totals
		Noticeable change	Increased visibility	Less work zone location confusion	Less driveway location confusion	Limited use	Increased or difficult maintenance	Unfamiliar devices	Less mobility	
Driveway Delineators	Driveway signs	3			2					5
	STOP + street signs	2			1	−2				1
	Drums			1						1
	42-inch tall cones		2	1						3
	28-inch tall cones		3	1			−3			1
	36-inch vertical panels		2	1						3
	32-inch tall LCDs			3	3			−1	−2	3
	18-inch tall LCDs		3	3	3			−1	−2	6
	Type 3 barricades			3	2				−1	4
	Curb-mounted delineators		3	2	2	−2		−2	−3	0
	RPMs		3	1	1	−2	−1		−3	−1
Mainlane Delineators	Drums			2						2
	42-inch tall cones		1	2						3
	28-inch tall cones		2	1			-3			0
	36-inch vertical panels		1	1						2
	32-inch tall LCDs			2	2			−1	−1	2
	18-inch tall LCDs		3	3	2			−1	−1	6
	Curb-mounted delineators		3	2	2	−1	−1	−2	−2	1
	Buttons		3	1	1	−2	−1		−2	0
Other	Change in device spacing	1		2	1					4
	Change in device type	2		1	3		−2			4

The highest rated candidate treatments are the 18-inch tall LCDs, driveway signs, and type 3 barricades, but the remaining devices are certainly not without merit. In addition, any treatment(s) that employ a change in device spacing or type would still be a viable consideration. The treatments selected for further study are discussed in the following chapter.

SUMMARY

In summary, the TxDOT interviews revealed that common work zone driveway problems include the idea that driveways are too close and motorists have difficulty seeing features and other traffic in the work zone. Current mitigation practices focus on the use of different types of channelizing devices at driveways, although none of these have been field tested. Many of the proposed concepts for improving driveway delineation in work zones are aimed at the use of different channelizing devices and/or signs that would provide a different color, size, shape, or pattern near the driveway. The selection process for the closed-course study treatments resulted in a focus on main lane devices that do not block sight distance for traffic exiting or entering the driveway.

CHAPTER 3:
CLOSED-COURSE STUDY

INTRODUCTION

This chapter describes the closed-course human factors study that was used to determine which of the candidate treatments would be most appropriate for further study during the field evaluations in the second year of the project. The study protocol was approved by the Texas A&M University System Office for Research Compliance and Biosafety and was approved as Protocol IRB2013-0079.

TREATMENTS

Table 5 shows the treatments that were evaluated during the closed-course study.

Table 5. Driveway Treatments Used in the Closed-Course Study.

Treatment Number[1]	Main Lane		Driveway	
	Device	Spacing (ft)	Device	Spacing (ft)
C1	42-inch tall cones	40	42-inch tall cones	10
C2	42-inch tall cones	40	28-inch tall cones	5
C3	42-inch tall cones	40	18-inch tall LCDs	connected
C4	42-inch tall cones	40	36-inch tall type 1 barricades	single
C5	36-inch tall drums	40	36-inch tall drums	10
C6	18-inch tall LCDs	connected	42-inch tall cones	10
C7	18-inch tall LCDs	connected	28-inch tall cones	5
C8	18-inch tall LCDs	connected	18-inch tall LCDs	connected
C9	18-inch tall LCDs	connected	36-inch tall type 1 barricades	single

[1] C indicates a closed-course treatment number.

The 42-inch tall cones, often referred to as grabber cones, are frequently used in lane closures where lateral constraints are aggravated by the use of standard (36-inch tall) drums, which are up to 24 inches wide with ballasts. These cones, as well as the drums, were readily available from temporary traffic control providers in Texas. The researchers found only one LCD product available that is known to have a height of less than 21 inches and obtained a small supply from the manufacturer.

The main lane devices were placed along the roadway for approximately 250 ft upstream and downstream of each driveway (and on the same side of the roadway). For Treatments C1 through C5, the same mainline devices continued beyond the 250-ft sections on either side of the driveway. For Treatments C6 through C9, the areas beyond the 250-ft LCD sections consisted of 42-inch tall cones or drums, since the researchers only had a limited number of LCDs. The Appendix shows daytime and nighttime images of the treatments.

The course at the Texas A&M Riverside Campus consisted of five different treatment positions. Figure 13 shows the treatment positions with the designations A through E.

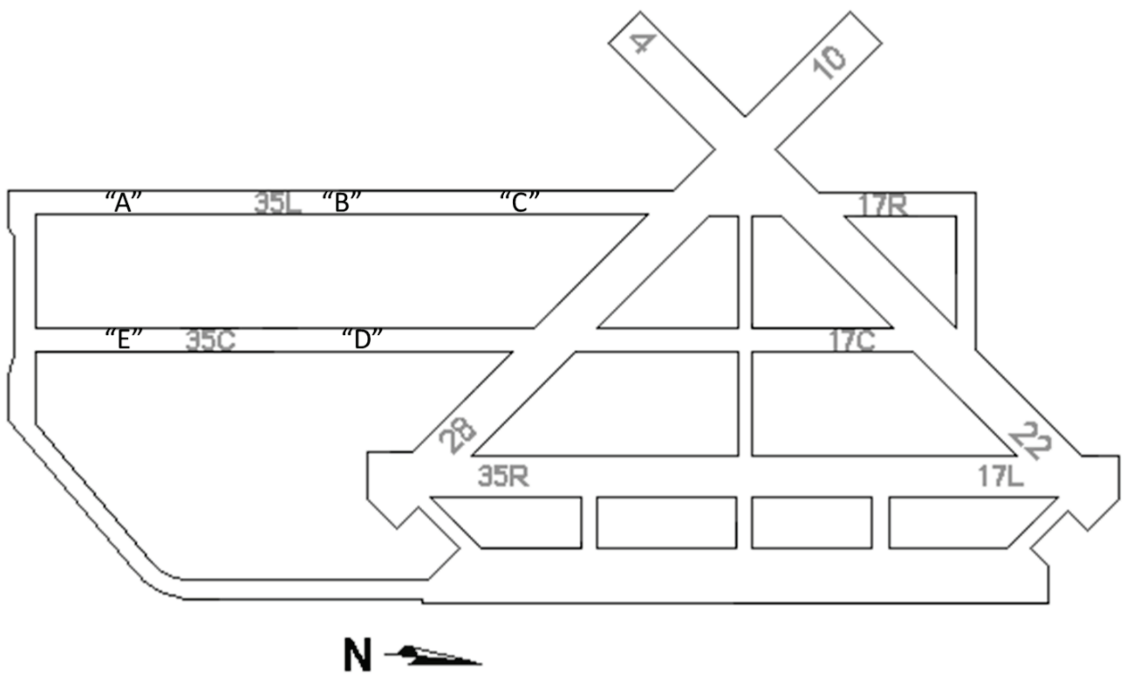

Figure 13. Treatment Positions Used During Closed-Course Study.

There were a total of nine treatments, so not all participants were able to view all of the treatments. The treatment orders were randomized to the extent possible. Due to the limited number of LCDs available for this study, the researchers were only able to set up one driveway at a time with LCDs as the main lane device. As a result there could only be one LCD driveway tested on a given night as opposed to up to four driveways where the 42-inch tall cones or the drums were the main lane device. The treatments with LCDs on the main lane were located at position E and were randomized as the first or fourth treatment seen by each participant on the first lap, depending upon the lap starting position. Other treatments were randomized in positions A through D. The researchers ran a total of 54 subjects through the courses, collecting data for 18 daytime participants and 36 nighttime participants.

DATA COLLECTION

At the TTI office, each participant completed visual screenings for acuity, contrast sensitivity, and color blindness to ensure minimum acceptable levels. After completing consent paperwork, each participant drove a global positioning system (GPS)-instrumented TTI fleet vehicle for two laps through the simulated work zone course. During the first lap, all of the driveways were located on the right side of the roadway. During the second lap, all of the driveways were located on the left side of the roadway. Each participant was told in advance which side of the roadway the driveway was located and also that they would need to turn into the driveway. Then they were asked to drive 40 mph and identify when they could see the driveway opening. The researcher riding along with the participant would mark the GPS file when the participant gave a verbal indication that they saw the driveway. Once the participant turned into the driveway opening, they were asked to stop the vehicle and answer questions about the driveway. Questions included:

- Why did you think that was the driveway opening?
- Was there anything that was confusing to you?
- What helped you most in locating the driveway opening?

Once the researcher recorded the participant responses on the data collection form, the participant was then instructed to proceed to the next driveway and the routine was repeated for the remaining driveways.

After the laps were completed, the participant returned to the TTI office for some follow-up questions. During this part of the study, the participants were shown five 8 inch by 10 inch photos (one photo for each right side driveway they encountered during the testing). The driveway photos, shown in the Appendix, were captured from a location 100 ft upstream of the driveways. The photos used for the follow-up questions were not necessarily representative of the participants' view of the driveway at the moment of detection (typically several hundred feet upstream). The participant was asked to assign a rank the driveways by placing the photos in order from best to worst. A score of 1 was given to the best treatment, while a score of 5 was given to the worst treatment. Then the participant was asked why they thought each one was best, second best, third best, etc. Once the participant responses were recorded, the participants were compensated for their efforts and dismissed.

RESULTS

Ranking Data

The researchers tabulated the results from the ranking data for all participants, stratifying the data by night and day. Researchers used JMP Pro Software (version 10.0.0) to conduct the statistical analysis. A comparison of means using the *t* distribution with a pooled estimate of variance at the 95 percent confidence interval was performed. Table 6 shows the nighttime ranking results, while Table 7 shows the daytime ranking results.

Table 6. Nighttime Ranking Results.

Treatment Number	Description (main lane device + driveway device)	Average Rank[1]	n^2	Group		
C8	18-inch tall LCDs + 18-inch tall LCDs	2.14	7	A	B	
C3	42-inch tall cones + 18-inch tall LCDs	2.17	28	A		
C9	18-inch tall LCDs + 36-inch tall type 1 barricades	2.37	8	A	B	
C7	18-inch tall LCDs + 28-inch tall cones	2.37	8	A	B	
C6	18-inch tall LCDs + 42-inch tall cones	2.75	8	A	B	C
C4	42-inch tall cones + 36-inch tall type 1 barricades	3.10	11		B	C
C2	42-inch tall cones + 28-inch tall cones	3.11	27		B	C
C1	42-inch tall cones + 42-inch tall cones	3.57	23			C
C5	Drums + Drums	3.60	30			C

[1] 1=best, 5=worst; [2] *n*=sample size

Table 7. Daytime Ranking Results.

Treatment Number	Description (main lane device + driveway device)	Average Rank[1]	n^2	Group				
C8	18-inch tall LCDs + 18-inch tall LCDs	1.00	5	A				
C3	42-inch tall cones + 18-inch tall LCDs	1.42	14	A				
C6	18-inch tall LCDs + 42-inch tall cones	1.50	4	A	B			
C9	18-inch tall LCDs + 36-inch tall type 1 barricades	1.75	4	A	B			
C7	18-inch tall LCDs + 28-inch tall cones	2.50	4		B	C		
C4	42-inch tall cones + 36-inch tall type 1 barricades	3.40	10			C	D	
C5	Drums + Drums	3.47	17			C	D	
C1	42-inch tall cones + 42-inch tall cones	3.92	13				D	E
C2	42-inch tall cones + 28-inch tall cones	3.93	15				D	E

[1] 1=best, 5=worst; [2] *n*=sample size

In addition to average rank for each treatment, the tables show the number of data points, *n*, used for each treatment. As explained earlier, the treatments that included LCDs as the main lane device have fewer views than the other treatments. Each treatment was compared to the others. Based on the findings, the researchers categorized the results into groups, shown in the tables. Treatments within the same group are not significantly different when a 95 percent confidence interval is used.

Overall, both night and day ranking results were very similar. While there was some variation between the night and day rankings, the ranking positions of the treatments had little movement between night and day (i.e., ± 2 positions). The daytime ranking had a larger range of values than did the nighttime ranking. Treatment C8 scored high for both day and night and was ranked as the best treatment every time it was seen during the day. In addition, for both day and night conditions, the researchers found that the average rank of treatments with LCDs was higher than those without LCDs.

Detection Distance Data

The researchers tabulated the results from the detection distance data for all participants and found that learning effects had an impact on the data. There was a clear trend indicating that treatments seen first had a much lower overall detection distance than those seen later in the study. As a result, the researchers focused on the data for those treatments seen in the latter half of each driver's participation. Specifically, data from the second lap through the devices (after they had seen each treatment once on the right side and the treatments were now on the left side) was used to mitigate impacts of the learning effect. Again, the data were stratified by night and day and statistics were computed using the JMP Pro software. Table 8 shows the nighttime detection distance results.

Table 8. Nighttime Detection Distance Results.

Treatment Number	Description (main lane device + driveway device)	Average Detection Distance (ft)	s^1	n^2	Group		
C1	42-inch tall cones + 42-inch tall cones	650	293	23	A		
C4	42-inch tall cones + 36-inch tall type 1 barricades	606	219	20	A	B	
C6	18-inch tall LCDs + 42-inch tall cones	601	189	8	A	B	
C3	42-inch tall cones + 18-inch tall LCDs	590	247	27	A	B	
C9	18-inch tall LCDs + 36-inch tall type 1 barricades	547	162	8	A	B	C
C2	42-inch tall cones + 28-inch tall cones	544	181	27	A	B	
C5	Drums + Drums	528	174	30		B	
C7	18-inch tall LCDs + 28-inch tall cones	500	121	8	A	B	C
C8	18-inch tall LCDs + 18-inch tall LCDs	484	280	7	A	B	C

[1] *s* =standard deviation of average; [2] *n*=sample size

The nighttime average detection distances ranged from 650 ft to 484 ft. Compared to the conservative stopping sight distance design value of 305 ft for 40 mph published by the American Association of State Highway and Transportation Officials (*14*), all of the average detection distance values allow sufficient time for driver response. The standard deviation, *s*, was expected to be approximately 100 ft. However, this study produced much higher values. The statistical software computed groups for the results. Treatments within the same group are not significantly different when a 95 percent confidence interval is used. While most detection distances for the treatments are not statistically different, the researchers were able to make more practical inferences from the results.

At night, when all other visual cues are masked, drivers rely heavily on retroreflective materials to see objects on or near the roadway. To identify differences among an array of objects, such as detecting a driveway among many channelizing devices, the difference in appearance of the retroreflective materials provides key information. Based on this concept, the researchers expected the treatments with significant differences in retroreflectivity on the main lane versus the driveway to perform better at night than those with similar retroreflectivity in both areas. The data indicated that this was the case, except for Treatment C1, which had the longest average detection distance. The researchers believe that the narrow profile of the 42-inch tall cones left large gaps between devices at 40-ft spacing on the main lane, allowing participants to see between the devices to the 42-inch tall cones forming the driveways. In addition, because these devices are so tall (and taller than all other devices used in this study), the researchers felt that it was possible for participants to see something on the side of the road from long distances and indicate their detection of the driveway to the researcher when, in fact, they may not know exactly which gap is appropriate for their turn until much later. The standard drum treatment (Treatment C5) had one of the shorter average detection distances. The researchers believe that the large drums on the main lane occluded the driveway drums, making their recognition difficult. Treatments C2 and C8 were the worst performers at night. Both of these treatments consist of low-profile devices (LCDs and 28-inch tall cones) that had little or no change in retroreflectivity between the main lane and the driveway, making the driveways more difficult to detect.

The daytime average detection distances, shown in Table 9, had a larger range of values than did the nighttime average detection distances. This may likely be a result of the decreased contrast between the bright devices and the bright pavement in contrast to the dark background experienced at night. In addition, during the day, participants may have been distracted by other features in the landscape that were masked at night.

Table 9. Daytime Detection Distance Results.

Treatment Number	Description (main lane device + driveway device)	Average Detection Distance (ft)	s^1	n^2	Group			
C9	18-inch tall LCDs + 36-inch tall type 1 barricades	820	483	4	A			
C3	42-inch tall cones + 18-inch tall LCDs	710	237	13	A	B		
C6	18-inch tall LCDs + 42-inch tall cones	607	32	4	A	B	C	D
C4	42-inch tall cones + 36-inch tall type 1 barricades	603	113	10	A	B	C	D
C7	18-inch tall LCDs + 28-inch tall cones	591	106	4	A	B	C	D
C1	42-inch tall cones + 42-inch tall cones	543	297	13		B	C	D
C5	Drums + Drums	477	198	17				D
C2	42-inch tall cones + 28-inch tall cones	393	242	15				D
C8	18-inch tall LCDs + 18-inch tall LCDs	389	178	5				D

[1] *s*=standard deviation of average; [2] *n*=sample size

The statistical groups do show some differences in the treatments, but the researchers again sought explain the detection distance differences. During the daytime, treatments that used main lane devices with a different size or shape than those on the driveway tended to have higher detection distances than those treatments that had the same or similar devices in both locations. For example, group A Treatments C9, C3, and C6 have considerable differences in height between the devices, while Treatment C4 had the most drastic difference in shape (narrow 42-inch tall cones vs. the wide barricades). Devices used in Treatment C7 were similar in height, but the gap between the 250-ft long continuous strings of the large orange and white LCDs on the main lane can be easily detected in the daytime when the driveway device is not also LCDs. The researchers feel that these differences assist drivers with detection, thus these treatments appeared to perform better than the others. Treatments C1, C5, C2, and C8 consist of devices that are the same or similar on both the main lane and the driveway. Remember, the retroreflective materials have little or no impact during daytime conditions, so even the small difference in height between the 42-inch tall cones and the 28-inch tall cones can be more difficult to detect, since they both appear to be orange cones in the daytime.

Data Analysis

Most of the data groupings for each type of data appear to be fairly consistent. The exception is the notable switch between Treatments C8 and C1 when comparing the two types of data. Treatment C8 is clearly at the top in the ranking data and is clearly at the bottom for detection distance. Treatment C1 is at the bottom in terms of rank, but has a very high nighttime average detection distance. For reasons already mentioned, Treatment C1 did not have a very high average daytime detection distance. The researchers feel that this may be likely due to the difference in the setting in which the participants were asked to rank each driveway treatment versus the setting in which they were asked to detect the driveway. Remember, after participants ran the course they were shown pictures of each driveway set-up taken from a distance of 100 ft upstream of the driveway. Detection distances are generally much larger than 100 ft and the appearance of the driveways is different at these distances. Treatment C8 may be the preferred set-up for short distances, but when drivers need to see the driveway from a distance an alternative may be preferred.

Treatment Selection for Field Evaluation

It is important to keep in mind that each of these treatment options, excluding Treatment C5 (which was included as the standard for comparison purposes) was expected to do well. The results indicate that none of the treatments performed substantially worse that the all drum scenario represented by Treatment C5. Selecting any of these device combinations would be seen as an improvement over or comparable to current practice. But the project scope and budget does not allow for field testing of all alternative treatments. Therefore, only the best one or two treatments chould be evaluated during the field studies.

Initially it was felt that providing a treatment which included a device change in the driveway throat area would help drivers locate the driveway sooner. Three treatments tested did not have a device change (Treatments C1, C5, and C8), and the results appear to support the researchers' hypothesis. Treatment C5, which was included as the baseline treatment, performed poorly in all measures, and Treatments C1 and C8 traded low spots between the measures. Thus, the researchers recommend eliminating these three treatments from further consideration.

Treatments C2 and C7 both include the use of 28-inch tall cones on the driveway. The average performance measures for these treatments were typically in the bottom half of the results tables for both night and day conditions. Based on their relatively poor performance, coupled with the fact that they are currently not allowed by TxDOT in nighttime work zones, the researchers could not justify pursuing these treatments. Thus, they were eliminated from further consideration.

There were a number of negative participant comments regarding Treatments C9 and C4, both of which consist of type 1 barricades on the driveway. These were criticized for presenting a conflicting message. Drivers mentioned that barricades are typically used to prohibit movements and that they were confused by their use for a driveway treatment. Researchers felt that due to the high number of complaints, it would be best not to pursue field evaluation of these two treatments in order to avoid confusion.

The remaining, high-performing devices included Treatments C3 and C6. Both of these treatments had good visibility characteristics in both night and day conditions. Treatment C3 combined 42-inch tall cones on the main lane with 18-inch tall LCDs in the driveway. Treatment C6 used 18-inch tall LCDs along the main lane with 42-inch tall cones in the driveway. For both treatments, the difference in retroreflectivity at night is helpful to motorists. During daytime, the size and shape differences provide good visual cues for motorists.

The researchers noted that the comments made by participants in research project 0-6103 resonated with the comments obtained by participants in this closed-course study. In particular, comments included the following:

- A preference for a change in device type.
- A perception that the continuity of LCDs reduces confusion.
- An indication that the drum opening was hard to see because the drums blended together.

Based on these findings, the following treatments were selected for the field evaluation in real Texas work zones:

- 42-inch tall cones on the main lane with 18-inch tall LCDs in the driveway.
- 18-inch tall LCDs along the main lane with 42-inch tall cones in the driveway.
- 36-inch tall standard drums along the main lane and in the driveway.

CHAPTER 4:
FIELD EVALUATION

INTRODUCTION

This chapter describes the human factors field evaluation of the driveway delineation treatments. The purpose of the field evaluation was to compare the alternative treatments to the standard treatment. This required the researchers to establish specific measures of effectiveness that would be used to quantify the differences in the treatments. The study protocols were approved by the Texas A&M University System Office for Research Compliance and Biosafety as Protocols IRB2013-0610M and IRB2013-0790D.

TREATMENTS

The three treatments recommended for evaluation during the field evaluation are shown in Figure 14 through Figure 16. The F in the treatment number denotes a treatment used in the field study. The field evaluation consisted of a driver eye-tracking study, video observations of traffic operations at the driveway treatments, and interviews with owners, managers, and employees of businesses located near the driveway treatments.

Figure 14. Treatment F1.

Figure 15. Treatment F2.

Figure 16. Treatment F3.

Treatment F1 consisted of 18-inch tall LCDs on the main lane with 42-inch tall cones on the driveway radii. Treatment F2 consisted of 42-inch tall cones on the main lane and 18-inch tall LCDs on the driveway radii. Treatment F3 consisted of 36-inch tall drums on both the main lane and the driveway radii. Treatment F3 is considered the standard driveway delineation technique that is widely used in TxDOT work zones.

DRIVER EYE-TRACKING STUDY

The purpose of the driver eye-tracking study was to determine how drivers respond to the different treatments with regard to their visual attention. This study was performed at two different locations. During the weeks of March 18, 2014, and April 7, 2014, the researchers used the work zone located on US 75 in McKinney, Texas. At this work zone, the northbound frontage road had a mixture of low profile barrier and drums in different segments. In the segment located from Rockhill Road to University Drive (US 380), the right lane was closed and several business driveways were located within the closure, including numerous restaurants and retail stores. The driveway throats were approximately 20–30 ft wide and the length of the driveway (also the width of the construction area) was approximately 40-65 ft. Figure 17 shows an example of the typical work zone traffic control found in the McKinney work zone.

Figure 17. Typical Work Zone Setup at McKinney Driveways.

During the week of March 25, 2014, the researchers used the work zone located on IH 610 near the US 290 interchange in Houston, Texas. At this work zone, the westbound frontage road between Ella Boulevard and T. C. Jester, as well as sections of T. C. Jester, had drums delineating the right lane closures. The driveway throats were approximately 30–40 ft wide and the length of the driveways (also the width of the lane closure) were considerably smaller than the McKinney driveways. Figure 18 shows an example of the typical work zone traffic control found in the Houston work zone.

Figure 18. Typical Work Zone Setup at Houston Driveways.

Table 10 shows a summary of the driveways used. Note that the McKinney driveways and Houston driveways differed both in terms of use of blue business driveway signs, and in the overall visual appearance of the driveways themselves. Specifically, the McKinney driveways crossed sections of dirt (the construction area) and so looked different than the area immediately upstream of them, whereas the Houston driveways were across a closed travel lane and so looked exactly like the area immediately upstream of them (i.e., pavement).

Table 10. Driveways Used in Human Factors Study.

ID	Description	Sign	Width (ft)	Length (ft)	Surface	Dates Used
MCK1	Whataburger Restaurant	Yes	23	63	Unpaved	March 18–20
MCK2	CVS Pharmacy	Yes	23	61	Unpaved	March 18–20
MCK3	Cici's Pizza Restaurant	Yes	26	56	Unpaved	March 18–20
MCK4	Golden Corral Restaurant	Yes	23	56	Unpaved	April 7–9
MCK5	U.S. Post Office	Yes	29	55	Unpaved	April 7–9
MCK6	Enterprise Rental Car	Yes	28	38	Unpaved	April 7–9
HOU1	Office Building	No	38	12	Paved	March 25–27
HOU2	Denny's Restaurant	No	41	12	Paved	March 25–27
HOU3	Juanita's Restaurant	No	33	34	Paved	March 25–27

The human factors study was conducted under both daytime and nighttime lighting conditions. Each participant saw three driveway treatments. The researchers changed the order in which the participants saw the treatments so that not all participants saw the same treatment first. This was accomplished by moving the treatments each morning. All of the participants who drove on a particular day or night drove the same route. The treatments were moved again the following morning and another group of participants drove the same route on that day and night. There were a total of six unique setups in McKinney, and three unique setups in Houston.

Data Collection

Participants were recruited using flyers posted at area businesses and call lists from previous studies where the participants requested to be contacted again for future studies. At the McKinney work zone, participants met with the researchers at a hotel conference room. In Houston, the TTI Houston Office conference room was used. 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 in-vehicle video cameras. Figure 19 shows the faceLAB™ dash-mounted eye-tracking infrared (IR) 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. Although not shown in the figure, a forward scene camera was also mounted behind the vehicles' 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 instructions for the participant, while the other operated the data collection equipment.

Figure 19. FaceLAB™ IR Transmitters and Cameras.

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 notification and completion of the turn were of interest to the researchers. These data were used to determine how frequently and for how long each participant's eyes were drawn to various points of interest. Figure 20 shows a screen shot of one participant's eye-tracking data when they glanced at a blue business sign.

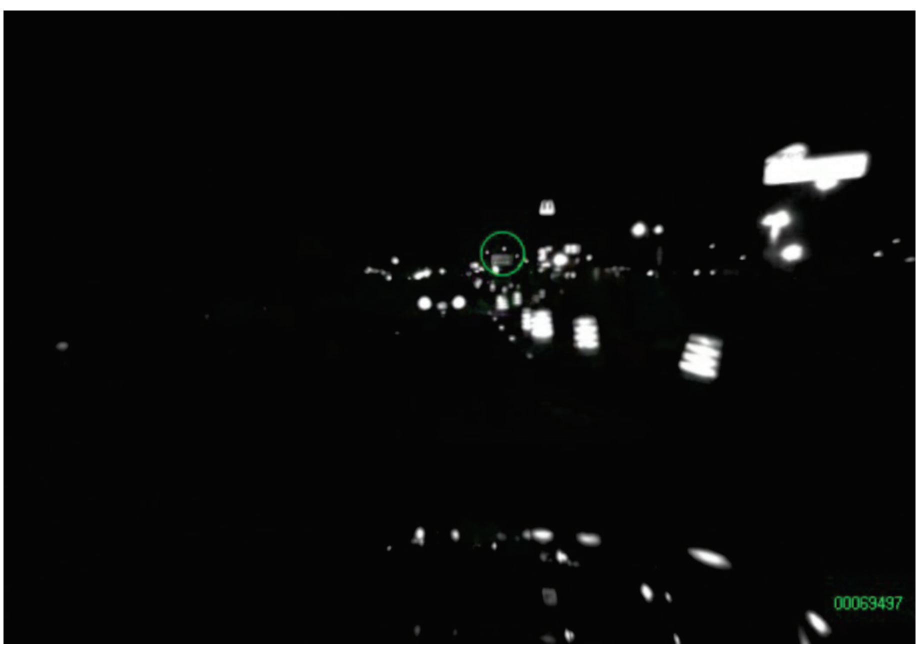

Figure 20. Example of Participant's Glance at a Blue Business Driveway Sign.

Data Reduction and Analysis

Upon completion of the data collection, the researchers reduced and analyzed the data. The goal was to identify if eye-tracking behavior was different for each of the three treatments. 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 were 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 data for 55 participants viewing Treatment F1, 62 participants viewing Treatment F2, and 63 participants viewing Treatment F3. Table 11 shows the composition of the final data set.

Table 11. Number of Participants Viewing Treatments during Eye-Tracking Study.

Lighting Conditions	Treatment		
	F1	F2	F3
Daytime	15	21	21
Nighttime	40	41	42
Total	55	62	63

Measures of Effectiveness

The researchers sought to answer many questions using the data. The first question was, "Is the participant's visual attention drawn more frequently to the correct driveway region when the different treatments were 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 proper driveway area when the different treatments are 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 delineation treatment providing higher relative frequencies of glances to the driveway opening and/or longer glance times at the driveway would be considered better.

The researchers also collected participant-identified detection distances of driveway using GPS in the test vehicles. The intent was to determine if any driveway treatments consistently had longer detection distances than other treatments. The researchers also wanted to know if participants would miss the turn into the driveways more frequently when certain treatments were deployed. After each approach and turn into the driveway, researchers asked each participant what they remembered about each driveway where they turned. In addition, the participants were later asked to rank the driveway setups based on photo images. This gave the researchers some insight into motorists' attention to and opinion of the treatments.

In summary, the researchers identified the following measures of effectiveness to evaluate the data collected:

- Participant glance distributions.
- Average glance durations.
- Detection distances.
- Missed driveways.
- Participant perception of driveway treatments.
- Participant opinions of treatments.

Effect of Treatment on Participant Glance Distributions in the Visual Field

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

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

As shown in Figure 20, categorization of glances at blue business driveway signs and at treatments was rather straightforward. Treatment glances were also readily identifiable. 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 or non-treatment edge line delineation, glances at the roadway within edge lines, as well as glances to judge 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.

The researchers then determined the distribution of glances over the four categories for each participant for each driveway approach and treatment tested. Researchers first assessed whether the distribution of glances was independent of treatment order, and thus the data could be consolidated. Because only the McKinney sites had blue business driveway signs, the McKinney and Houston data had to be analyzed separately. In addition, daytime and nighttime data were analyzed separately. Thus, researchers conducted a series of Pearson's chi-squared test of independence (also known as the test of homogeneity) upon each of the four main subsets of glance distribution data (McKinney daytime, Houston daytime, McKinney nighttime, and Houston nighttime). Using an alpha value of .05, this test was successful across all of the subsets of the data.

The researchers also conducted a test to see if the McKinney daytime and Houston daytime data could be merged (which would suggest that the blue driveway signs had no impact upon daytime visual scanning for driveways). However, the blue business driveway sign glances did cause the chi-square test to fail. The results of the subsequent consolidated glance distribution data are shown in Table 12 through Table 15.

Table 12. Number and Distribution of Eye-Glance Types – McKinney Daytime Data.

Glance Type	Treatment		
	F1	**F2**	**F3**
Blue Business Driveway Signs	5 *(2%)*	6 *(3%)*	9 *(5%)*
Treatment	63 *(23%)*	29 *(12%)*	8 *(4%)*
Lane-keeping	85 *(31%)*	80 *(34%)*	67 *(35%)*
Non-lane-keeping	121 *(44%)*	121 *(51%)*	107 *(56%)*
Totals	274 *(100%)*	236 *(100%)*	191 *(100%)*

Table 13. Number and Distribution of Eye-Glance Types – Houston Daytime Data.

Glance Type	Treatment		
	F1	F2	F3
Treatment	23 *(18%)*	26 *(18%)*	15 *(8%)*
Lane-keeping	54 *(44%)*	64 *(43%)*	87 *(48%)*
Non-lane-keeping	47 *(38%)*	57 *(39%)*	80 *(44%)*
Totals	124 *(100%)*	147 *(100%)*	182 *(100%)*

Table 14. Number and Distribution of Eye-Glance Types – McKinney Nighttime Data.

Glance Type	Treatment		
	F1	F2	F3
Blue Business Driveway Signs	23 *(4%)*	17 *(3%)*	21 *(3%)*
Treatment	63 *(10%)*	93 *(15%)*	61 *(8%)*
Lane-keeping	249 *(40%)*	237 *(38%)*	327 *(40%)*
Non-lane-keeping	295 *(46%)*	270 *(44%)*	396 *(49%)*
Totals	630 *(100%)*	617 *(100%)*	805 (*100%)*

Table 15. Number and Distribution of Eye-Glance Types – Houston Nighttime Data.

Glance Type	Treatment		
	F1	F2	F3
Treatment	26 *(18%)*	17 *(11%)*	15 *(8%)*
Lane-keeping	54 *(37%)*	65 *(42%)*	69 *(38%)*
Non-lane-keeping	67 *(45%)*	73 *(47%)*	98 *(54%)*
Totals	147 *(100%)*	155 *(100%)*	182 *(100%)*

An initial review of the data shows that the percentage of glances toward the treatment was lower for Treatment F3 than for the other treatments. In addition, the non-lane-keeping glances appeared to be consistently higher for Treatment F3 than the other treatments. The lane-keeping glances appeared to be consistent across treatments, while the blue business sign glances (McKinney only) also seemed consistent across treatments. The researchers performed statistical tests to validate these assumptions. A test of proportions was used to determine which glance distributions were different. The results showed that within each of the four data groups the differences were not statistically significant for the blue business sign glances (McKinney only), the lane-keeping glances, nor for the non-lane-keeping glances. However, the differences were significant for the treatment glances. Those results are summarized in Table 16.

Table 16. Test of Proportion Results for Treatment Glance Distributions.

Data Set	Treatment			Glance Relationships
	F1	F2	F3	
MCK-Day	23%	12%	4%	Trt F1 > Trt F2 > Trt F3
HOU-Day	18%	18%	8%	(Trt F1 = Trt F2) > Trt F3
MCK-Night	10%	15%	8%	Trt F2 > (Trt F1 = Trt F3)
HOU-Night	18%	11%	8%	Trt F1 > Trt F3; Trt F1 = Trt F2

Interestingly, the treatment glances at Treatment F3 were significantly lower than both of the other treatments during the daytime. While Treatment F1 had the same distribution of treatment glances as Treatment F2 in Houston during the daytime, it had significantly more glances in McKinney during the daytime. At night, the treatment glances at Treatment F3 were lower than the other treatments as well. This suggests that drivers may have some difficulty identifying Treatment F3 at night. The reason(s) for the differences were not identified, but the researchers hypothesize that certain driveway characteristics, such as length and width, as well as lighting conditions may play a significant role.

Analysis of Duration of Glances by Participants

The researchers tabulated the total glance time for each treatment type. The researchers used Statistical Analysis System (SAS) 9.4 to conduct a nested fixed effects analysis of variance (ANOVA) with the treatment orders nested within treatments to determine if the total glance times 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 calculation. The procedure SAS used was the General Linear Model procedure. The alpha value was set to 0.05 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.

The McKinney daytime model showed that the treatments did not produce a statistically significant difference in treatment glance times. However, the McKinney nighttime model showed that the treatments did produce a statistically significant difference in treatment glance times. The researchers used Tukey's studentized range test to calculate how each treatment affected the results of the McKinney nighttime data. The results showed that Treatment F2 has the largest value in difference between means when compared to Treatments F1 and F3. There was no difference between Treatments F1 and F3. Figure 21 shows a summary of the average total treatment glance time data.

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 0.0526). The Tukey's test showed that Treatment F2 again had the largest difference between means when compared to Treatments F1 and F3. Once again, there was no difference between Treatments F1 and F3.

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.

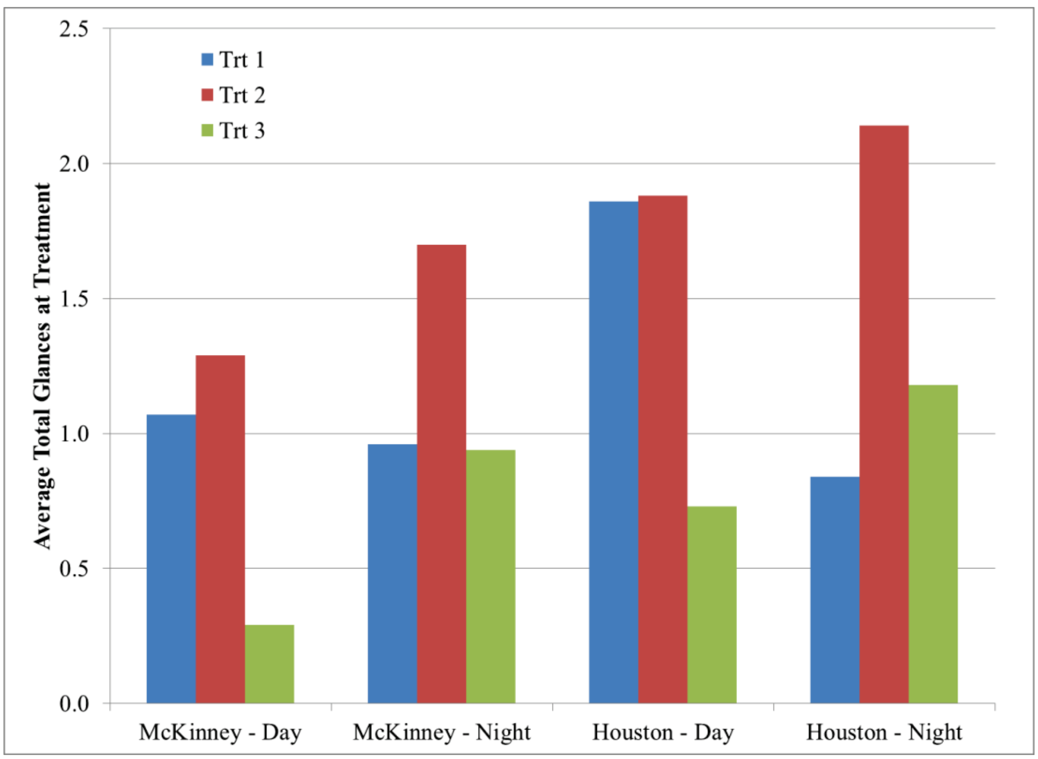

Figure 21. Average of Total Treatment Glance Times.

In further review of the treatment total glance times in Figure 21, the researchers felt that longer treatment glances were favorable, since more time looking at the treatment was indicative of the success of treatment in attracting attention to the actual driveway location and the driver's focus on the task of properly negotiating the driveway turn. Overall, the researchers found that glance durations were longer for Treatment F2 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.

Detection Distance

During the driver eye-tracking study, the researchers used GPS data to record the location at which each participant gave a verbal indication that they could identify each driveway opening. With the GPS locations of the driveways known, the researchers were able to calculate the indicated detection distances. There were a total of 81 participants, each of which saw three treatments. Each of these 243 participant-treatment combinations constitutes one data point. Some data were removed from the data set for various reasons. For example, if the participant failed to turn into the correct driveway, the detection distance was assumed to be invalid. Equipment failures caused the loss of other data. Once these data were eliminated, 193 data points were left. Table 17 shows the composition of the detection distance data.

Table 17. Detection Distance Data Set.

Lighting Conditions	Sample Size by Treatment		
	F1	F2	F3
Daytime	26	28	25
Nighttime	40	40	34
Total	66	68	59

As with the eye-tracking data, the researchers had to first determine if the data for each treatment could be merged across the different driveway locations. McKinney data were kept separate from the Houston data, again primarily due the presence of the blue business driveway signs. Daytime and nighttime data were also separated. Using SAS 9.4, the researchers created a two-way nested unbalanced ANOVA model (order again nested within treatment) for the detection distance data. This calculation was run on each data set (McKinney daytime, Houston daytime, McKinney nighttime, and Houston nighttime. The results showed that randomness within the data prevented any statistical significance related to the treatments or to treatment order. Closer examination of the individual participant data revealed that several participants had relatively long detection distances that likely exceeded the actual sight distance to the driveway. Table 18 and Table 19 show the average detection distances for each data set.

Table 18. Average Detection Distances and Standard Deviations – Daytime.

Driveway Locations	Average Detection Distances by Treatment (ft)			Standard Deviations by Treatment		
	F1	F2	F3	F1	F2	F3
McKinney	300	332	330	128	89	145
Houston	257	253	268	92	108	166

Table 19. Average Detection Distances and Standard Deviations – Nighttime.

Driveway Locations	Average Detection Distances by Treatment (ft)			Standard Deviations by Treatment		
	F1	F2	F3	F1	F2	F3
McKinney	301	350	266	126	131	143
Houston	223	297	162	90	178	58

Missed Driveway Analysis

The researchers wanted to look more closely at the times when participants missed the driveways they were asked to identify and make a turn into. There were a total of 81 participants in the driving study: 32 during the daytime and 49 during the nighttime. Table 20 shows the number of driveways missed by treatment, and the corresponding percentage of all attempts at that driveway treatment. However, a simple visual inspection shows that Treatment F3 at night had the highest percentage of missed turning movements. The researchers believe that the high percentage of missed turns suggests that the current practice of delineating driveways with drums is somewhat challenging to motorists. This is also consistent with the glance distribution data, which showed a lower number of glances at Treatment F3 than at the other treatments, and the glance duration data, which showed shorter glance durations for Treatment F3.

Table 20. Number of Driveway Turns Missed by Participants in the Driving Study.

Lighting Condition	Treatment		
	F1	F2	F3
Daytime	3 (9%)	2 (6%)	1 (3%)
Nighttime	5 (10%)	9 (18%)	13 (27%)

Participant Perception of Driveway Treatments

After each participant turned into each driveway opening, they were asked to stop the vehicle for a brief discussion. The researcher asked if they noticed anything different about the driveway and, if so, what did they notice. Once the researcher recorded the participant responses on the data collection form, the participant was then instructed to proceed to the next driveway and this routine was repeated for the remaining driveways. The question was primarily aimed at determining if Treatments F1 and F2 would be noticed more when used in lieu of Treatment F3 (the standard drum configuration). Data were analyzed only for the 116 participants who successfully made a turn into the correct driveway and noticed the 42-inch tall cones or LCDs in either Treatment F1 or F2. Treatment F3 was not included in the analysis because there was essentially nothing different to notice. If the 42-inch tall cones or the LCDs were noticed by the participant, the researchers noted whether those devices were located along the main lane or in the radii of the driveway. Figure 22 shows the results.

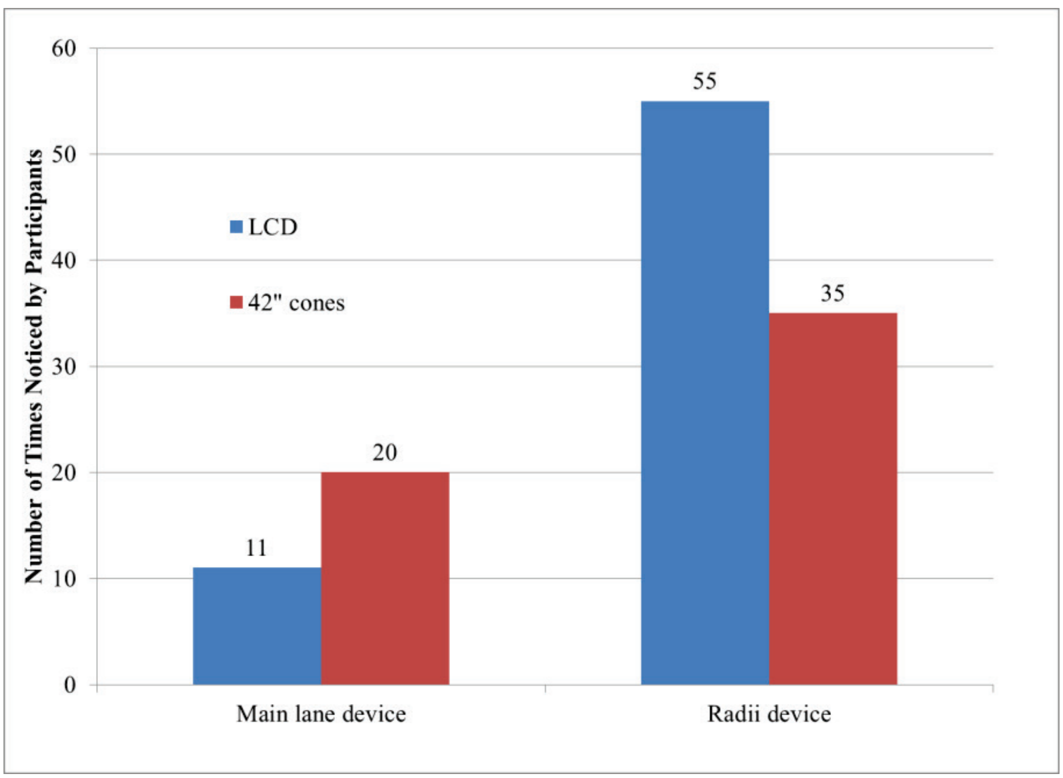

Figure 22. Number of Times Traffic Control Features Were Noticed by Participants.

Although the data set was too small for computing statistics, the researchers did notice some interesting trends. Recall that Treatment F1 had LCDs on the main lane and 42-inch tall cones on the driveway radii, and that Treatment F2 had 42-inch tall cones on the main lane and LCDs on the driveway radii. When the LCDs were placed on the radii (i.e., Treatment F2), they were noticed five times more often than when they were placed on the main lane. When the 42-inch tall cones were placed on the radii, as in Treatment F1, they were also noticed considerably more than when they were placed on the main lane. This may be indicative of the devices in the radii playing a larger role in driver perception and recognition than when they are placed along the main lane.

Participant Ranking of Treatments

After each participant completed the driving portion of the human factors study, they returned to the study conference room for some follow-up questions regarding their perception of detection distance and positive guidance at each driveway. Each participant was shown six 8 inch by 10 inch photos (two photos for each driveway included in the study). Daytime participants were shown daytime photos, while nighttime participants were shown nighttime photos.

The first three photos were taken from a distance approximately 250 ft upstream of each driveway. Each participant was asked to rank the driveways from best to worst in terms of how well the delineation helped the participant to detect the driveway farther away. Then each participant was asked to justify their ranking. The participant answers were recorded on the data collection forms.

Next, each participant was shown the remaining three photos of the same driveways taken from a distance approximately 100 ft upstream of the driveway. Each participant was asked to rank the driveways from best to worst in terms of how well the delineation helped the participant to make a smooth turn and not accidentally drive into the work area (both considered to be measures of positive guidance). Then each participant was asked to justify their ranking. The participant answers were recorded on the data collection forms.

The researchers reduced the data and analyzed them by assigning a score of 3 for each time a participant ranked a treatment as best. A score of 2 was assigned for each time a participant ranked a treatment as neither best nor worst, and a score of 1 was assigned for each time a participant ranked a treatment as worst. Thus, the highest possible score, if every participant had ranked a particular treatment as best, was 3. The lowest possible score, if every participant had ranked a treatment as worst, was 1. Table 21 shows the overall scores for each treatment.

Table 21. Ranking Results of Driveway Delineation Treatments.

Treatment		Detection Distance		Positive Guidance	
Number	Description	Daytime	Nighttime	Daytime	Nighttime
F1	42-inch cones on radii LCDs on main lane	1.69	2.09	1.82	2.00
F2	LCDs on radii 42-inch cones on main lane	2.71	2.62	2.58	2.67
F3	Drums on radii and main lane	1.64	1.27	1.43	1.29

For detection distance in the daytime, Treatment F2 had the highest average ranking (2.71). Treatment F1 and Treatment F3 were close, scoring 1.69 and 1.64, respectively. Many participants explained that the broadside view of the orange and white LCD when placed in the driveway radii was a major factor in increasing driveway detection distance. The detection distance results were similar at night for Treatment F2; however, Treatment F3 ranked lower than Treatment F1. While the LCDs in the radii of the Treatment F2 driveways did not provide retroreflective material at night when viewed from broadside, the bright contrasting colors were still visible to participants from the test vehicle's headlamp lighting. Many participants explained their low ranking of Treatment F3 by stating that the drums looked just like all the other drums in the work zone.

For positive guidance in the daytime, Treatment F2 again had the highest average ranking (2.58), followed by Treatment F1 (with a score of 1.82) and Treatment F3 was still the worst (with a score of 1.43). When LCDs were placed in the radii, as with Treatment F2, the closer view of the driveway gave the appearance of a continuous line on each side of the driveway, a characteristic identified by more than half of the participants who preferred this treatment. The positive guidance results were similar at night for Treatment F2, and Treatment F3 still ranked lower than Treatment F1.

Based on these ranking results, Treatment F2 had the highest average score and was preferred by participants over the other treatments for both detection distance and positive guidance in both daytime and nighttime conditions. However, Treatment F1 also ranked higher than Treatment F3, suggesting that either of the alternative treatments could provide some benefit over the standard drum treatment.

VIDEO OBSERVATIONS

While the driver eye-tracking study was underway, observations of turning movements were collected at two driveways using video cameras. The researchers used TTI's video trailer, which has the capacity to raise a video camera 30 feet into the air to record the study site from a bird's eye view. The researchers anticipated that the video data could be used to identify any adverse driving behaviors in the presence of different work zone channelization treatments.

The researchers collected over 88 hours of video data and did not identify any erratic maneuvers related to any of the treatments. This is not surprising, since erratic maneuver rates tend to be very small and much more data would be required to detect any differences in treatments.

BUSINESS INTERVIEWS

While the driver eye-tracking study and video observations were being performed in McKinney, the researchers also conducted field interviews at businesses where the treatments were deployed. No interviews were conducted in Houston.

The purpose of the interviews was to ask the business owners, managers, and employees about their opinions of the treatments. A total of 17 surveys were administered. Nine surveys were administered when Treatment F2 was deployed, and eight surveys were administered when Treatment F3 was deployed. All of the respondents had traveled through the work zone several times during the past week. While the researchers expected to obtain anecdotal data regarding the impact of the different treatments, the treatments had not been deployed long enough to be noticed by most of the people interviewed. Only two of the 17 respondents recalled seeing the LCDs. Thus, the researchers used 8 inch by 10 inch photographs of Treatments F2 and F3 to demonstrate their appearance to the respondents. When prompted with photos, three additional respondents recalled seeing the LCDs.

Using the photos, the respondents were asked which scenario would be better for delineating the driveway. Based on the photos, 15 of the 17 respondents indicated that Treatment F2 was better than Treatment F3. When asked why, 12 respondents indicated that they could see and/or navigate the driveway better with Treatment F2, while two respondents indicated that they could see and/or navigate the driveway better with Treatment F3. When asked about the blue business driveway signs, 16 of the 17 respondents thought that the blue signs were helpful in identifying the driveway where they needed to turn. Overall, the survey results are consistent with other research findings on this project.

CONCLUSIONS

Based on the information obtained to date, the researchers found that deploying either Treatment F1 or Treatment F2 could provide some benefits over the existing practice of using Treatment F3. Although drivers tend to consistently prefer Treatment F2, the eye-tracking data suggested that certain site conditions may be more conducive to use of Treatment F1.

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APPENDIX: CLOSED-COURSE EVALUATION TREATMENTS

Figure A-23. Treatment 1: 42-Inch Cones on Main Lane with 42-Inch Cones on Driveway.

Figure A-24. Treatment 2: 42-Inch Cones on Main Lane with 28-Inch Cones on Driveway.

Figure A-25. Treatment 3: 42-Inch Cones on Main Lane with 18-Inch LCDs on Driveway.

Figure A-26. Treatment 4: 42-Inch Cones on Main Lane with 36-Inch Type I Barricades on Driveway.

Figure A-27. Treatment 5: Drums on Main Lane with Drums on Driveway.

Figure A-28. Treatment 6: 18-Inch LCDs on Main Lane with 42-Inch Cones on Driveway.

Figure A-29. Treatment 7: 18-Inch LCDs on Main Lane with 28-Inch Cones on Driveway.

Figure A-30. Treatment 8: 18-Inch LCDs on Main Lane with 18-Inch LCDs on Driveway.

Figure A-31. Treatment 9: 18-Inch LCDs on Main Lane with 36-Inch Type I Barricades on Driveway.

Figure A-32. Treatment 1: 42-Inch Cones on Main Lane with 42-Inch Cones on Driveway.

Figure A-33. Treatment 2: 42-Inch Cones on Main Lane with 28-Inch Cones on Driveway.

Figure A-34. Treatment 3: 42-Inch Cones on Main Lane with 18-Inch LCDs on Driveway.

Figure A-35. Treatment 4: 42-Inch Cones on Main Lane with 36-Inch Type I Barricades on Driveway.

Figure A-36. Treatment 5: Drums on Main Lane with Drums on Driveway.

Figure A-37. Treatment 6: 18-Inch LCDs on Main Lane with 42-Inch Cones on Driveway.

Figure A-38. Treatment 7: 18-Inch LCDs on Main Lane with 28-Inch Cones on Driveway.

Figure A-39. Treatment 8: 18-Inch LCDs on Main Lane with 18-Inch LCDs on Driveway.

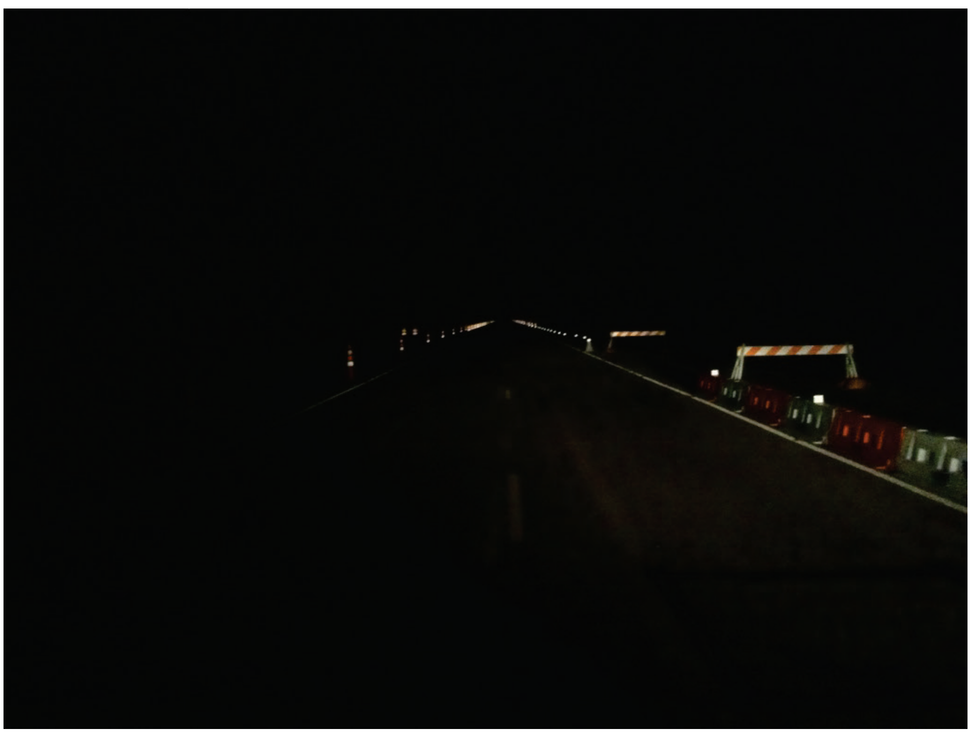

Figure A-40. Treatment 9: 18-Inch LCDs on Main Lane with 36-Inch Type I Barricades on Driveway.