Longitudinal Channelizing Devices along Business Entrances in Work Zones

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The Texas A&M University System
College Station, Texas 77843-3135

APPROXIMATE CONVERSIONS TO SI UNITS

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
AREA				
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
VOLUME				
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
TEMPERATURE (exact degrees)				
^oF	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	^oC
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
ILLUMINATION				
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
FORCE and PRESSURE or STRESS				
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

DISCLAIMER

This research was performed in cooperation with the Florida Department of Transportation. The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation. 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. (Texas-95917).

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This report documents the efforts and results of research to evaluate the effectiveness of alternatives to the use of channelizing drums for driveway delineation in work zones. The Florida Department of Transportation (FDOT) had originally sought to investigate the use of blue-striped channelizing devices but ultimately decided to examine the effectiveness of low-profile longitudinal channelizing devices (LCDs). LCDs are already an accepted device in the Manual on Uniform Traffic Control Devices and so would not require changes to the manual in order to be used on projects. The LCDs were compared against standard drum delineation in both a closed-course study and a field study in Florida work zones. The researchers used erratic maneuvers, speed profiles, and driveway user surveys as measures of effectiveness. The results indicated that there were no significant differences in the erratic maneuvers and speeds of turning vehicles that were attributable to the treatments. However, the survey results showed that drivers prefer LCDs over drums for helping them identify driveway openings. Meanwhile, other studies outside of Florida have shown that using LCDs instead of channelizing drums at a driveway improves driver ability to locate that driveway. Considered in total, researchers recommend that FDOT consider modifying its driveway delineation standard to allow LCD use. The standards should include requirements that they be delineated and that they be properly ballasted.</td></tr>
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EXECUTIVE SUMMARY

The objectives of this study were to evaluate the effectiveness of work zone business driveway delineation alternatives. To accomplish this, the researchers first conducted a literature review to identify driveway delineation alternatives used or considered by other transportation agencies. Low-profile longitudinal channelizing devices (LCDs) were found to have good potential to address various concerns with current work zone business driveway delineation practices. The researchers conducted a closed-course study at the Texas A&M University Riverside Campus testing facility in order to identify the best LCD configurations for further evaluation during the field studies. Based upon those results, the researchers performed field studies in Florida work zones to evaluate LCDs and compare them to the standard drum treatment used in Florida. During the field studies, the researchers collected video data of turning movements to conduct an erratic maneuvers study. They also recorded speed profiles, which were used to compare speeds and speed changes along the driveway approaches. In addition, a survey of driveway users was administered in order to garner opinions about the driveway treatments.

Overall, the researchers found no negative operational impacts of delineating business driveways with low-profile LCDs in work zones. The erratic maneuvers study showed no hard braking or swerving at any of the driveway treatments. However, two work zone intrusions occurred while the drum treatment was deployed. The speed profile study results indicated no differences in the speed reductions at either driveway treatment. However, a survey of users (including business owners, managers, employees, and customers who used the driveways) revealed that drivers had a preference for the LCDs over the drums.

The researchers found no adverse traffic operational impacts as a result of using low-profile LCDs to delineate driveways in work zones; they also found a driver preference for the use of low-profile LCDs over drums to better convey driveway locations. While the researchers' conclusions are based on a limited amount of data, the findings of this study are consistent with other recent research (Research Project 0-6781) sponsored by the Texas Department of Transportation. Based on these study results, researchers believe that low-profile (21 inches or less in height) LCDs can be an effective improvement to drums for driveway delineation in confined urban work zones where the speed limit is 45 mph or less.

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CHAPTER 1: INTRODUCTION

BACKGROUND

The 2015 Florida Department of Transportation (FDOT) Design Standard Index 600 (*1*) requires the placement of business entrance signs and channelizing devices at business entrances in work zones on non-access-controlled roadways, as shown in Figure 1-1. In most cases, highway contractors use orange and white plastic drums for the channelizing devices. These plastic drums are typically the same type and color as other temporary traffic control devices along the work zone, making it difficult for the traveling public to identify where to turn into the business driveways located within the work zone. In addition, Standard Index 600 calls for a reduced spacing of the channelizing devices at driveway entrances. However, field experiences indicate that the increased frequency of drums does not appear to significantly improve driveway detection for the traveling public and may actually add to the visual clutter of the work zone. The reduced spacing may also cause sight distance restrictions for traffic exiting the driveway.

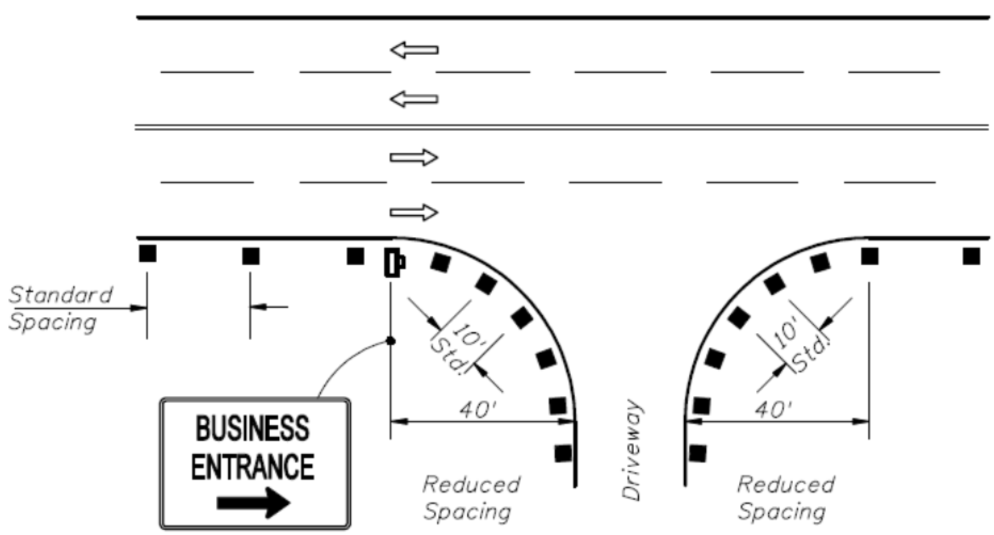

Figure 1-1. FDOT Temporary Traffic Control Standard for Business Driveways (*1*)

Figure 1-1 represents a typical application of the temporary traffic control standard. If the throat width of the driveway is 20 ft, the contractor would need 100 ft of longitudinal distance along the roadway to deploy the configuration shown. On many urban projects, particularly those corridors that have not been part of an access management program, driveways are too closely spaced to follow this typical application at every driveway. In addition, the placement of the business entrance signs may not be consistent along the corridor in the work zone. These factors tend to give the work zone a cluttered appearance, as shown in Figure 1-2, and may contribute to unnecessary driver confusion.

Figure 1-2. Business Entrance Signs on an FDOT Construction Project

Unfortunately, the driveway detection challenge is not mitigated simply by reducing the spacing of channelizing devices around the driveway. For example, Figure 1-3 shows an example of standard channelizing drums deployed in a Texas work zone. Although it is difficult to discern, there is a business entrance located between the third and fourth drum on the right. This figure demonstrates that motorists may find it difficult to locate driveways in urban arterial work zones, even at longer drum spacings.

Figure 1-3. Example of an Urban Roadway Work Zone in Texas

To help address the driveway detection challenge, FDOT personnel began to explore other options for delineating driveways in work zones. On June 15, 2011, FDOT submitted a Request for Experimentation to the Federal Highway Administration (FHWA) (*2*). The request specifically indicated the desire to experiment with blue-striped channelizing drums, such as the one shown in Figure 1-4. FDOT proposed to use the blue devices only in the curve radii of the business driveways. The color blue was selected to match the blue business entrance signs currently used in Florida.

Figure 1-4. Initial FDOT Proposed Device for Evaluation

FDOT contracted with the Texas A&M Transportation Institute (TTI) to evaluate the effectiveness of using blue-striped channelizing drums to improve business driveway delineation in work zones. However, for reasons described later in this report, FDOT modified the study to focus only on channelizing devices that were compliant with the *Manual on Uniform Traffic Control Devices* (MUTCD) (*3*).

RESEARCH APPROACH

The research contract included the following tasks:

- Task 1—Conduct Literature Review. The researchers examined related research to identify candidate driveway delineation techniques.
- Task 2—Refine the Experimental Plan. The researchers used a closed-course study to select the treatment(s) used in the field studies.
- Task 3—Conduct Field Studies. The researchers evaluated the treatments in real Florida work zones.
- Task 4—Prepare Project Reports. The researchers prepared the final report summarizing the findings of the research.

CONTENTS OF THIS REPORT

This report details the TTI effort to evaluate alternative delineation methods at business driveways in work zones. Chapter 2 provides an introduction and review of past research and other state policies regarding the use of alternative channelizing devices at business driveways in work zones. Chapter 3 describes the methodology used for the selection of driveway delineation treatments to be used in the Florida field studies. Chapter 4 describes the field studies conducted in Florida work zones. Finally, Chapter 5 provides the researchers' conclusions and recommendations regarding the use of delineation alternatives at business driveways in Florida work zones.

CHAPTER 2: LITERATURE REVIEW

The research team conducted a literature review to identify other studies where driveway delineation alternatives were evaluated. The researchers found that several research projects have investigated the challenges and potential improvements to driver detection of driveway openings in work zones. A brief review of the findings from these and other applicable research projects is provided in this chapter.

RELATED RESEARCH

Texas Work Zone Signing Study

Challenges associated with delineating the location of driveways in work zones have existed for many years. For example, in the late 1980s, research performed by Hawkins et al. (*4*) for the Texas Department of Transportation (TxDOT) addressed motorists' understanding of work zone signing that was used during the reconstruction of FM 1960, a major urban arterial in Houston, Texas. This project involved over 360 business driveways. 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?" Some of the business owners adjacent to FM 1960 had placed their own 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. About half of the survey respondents (53.5 percent) favored the use of these signs.

That 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 noted that the presence of channelizing devices at driveways may have created 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.

Texas Work Zone Longitudinal Channelizing Device (LCD) Study

More recently, TTI researchers completed a study of longitudinal channelizing devices for TxDOT (*5*). This research project sought to determine if the use of LCDs could improve work zone channelization in various applications. The research included a luminance evaluation of 32-inch-tall LCDs. Luminance is the amount of light reflected from a surface or emitted by a light source and is roughly equated to brightness. LCDs are manufactured and sold without any retroreflective material. Since retroreflectivity is required for nighttime use on state roadways, the researchers added sheeting to the LCDs that would imitate the materials found on drums (shown in Figure 2-1).

(a) Drum

(b) LCD

Figure 2-1. Devices Tested in TxDOT Research Project 0-6103 Luminance Evaluation (*5*)

While the drum was found to have approximately the same luminance when viewed from any angle, the luminance of the LCDs was found to decrease significantly when the LCDs were not perpendicular to the driver’s line of sight (i.e., when used in a longitudinal application, such as along the edge of the travel way). The researchers further experimented with other types of retroreflectivity for the LCDs in longitudinal applications, including delineators such as those used for permanent concrete barrier wall. The results indicated that the luminance values of the delineators at a 6-ft spacing (placed one on the top and one on the side of each 6-ft-long LCD) were only half of the luminance values of the drum arrays. However, this delineation of the LCDs was still easily visible to the human eye at night. In addition, the researchers noted that the LCDs were definitely different in appearance than the drums and that the delineators effectively accentuated this difference at night.

The Texas research project also included a closed-course human factors study of drums and 32-inch LCDs for driveway applications in a daytime setting. Specifically, subjects drove an instrumented vehicle on a simulated roadway with some driveways delineated with drums at various spacings and other driveways delineated with continuous 32-inch LCDs. Subjects were asked to identify the point at which they could see the driveway opening. Driveways with closely spaced drums had the shortest average detection distance (145 ft). The average detection distance was slightly longer (183 ft) for the LCD driveways, while the average detection distance for the driveways with the greater drum spacing was the longest (260 ft). When asked about the advantages and disadvantages of each type of treatment, subjects commented that they could more easily see between the drums that were spaced farther apart. Subjects also noted that they were more familiar with the drums. In some cases, subjects thought the drums all looked alike, making it more difficult to locate the driveway, particularly if drums became misaligned. Regarding the LCDs, subjects commented that the contrast in these devices around the driveways helped with driveway detection, and the solid line formed by continuous LCDs indicated something was changing or happening as one approached it. They also noted that it can be difficult to see on the other side of the 32-inch LCDs.

Based on these comments, the researchers in that study had concerns that taller LCDs may present undesirable sight distance conditions. Using a sight triangle analysis and assuming a flat and level grade, the researchers evaluated the impacts to side-street drivers of using LCDs placed longitudinally along the edge of the travel way. 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. The headlamp height of oncoming passenger cars is assumed to be 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 (or taller) LCDs and recommended that shorter LCDs (21 inches or less) be used in this application. Field testing of shorter LCDs in driveway applications was not conducted as part of this particular study.

The TxDOT research is important to the current FDOT research project because it:

- identified potential LCD delineation methods and evaluated them in a photometric setting;
- established that LCDs have a different appearance than drums to approaching motorists, particularly at night;
- verified by motorist opinion that the use of different devices around a driveway assists in detection of a change in the work zone channelization/delineation and that this provides a perceived benefit in terms of being able to locate a driveway;
- determined that LCD height should be limited to 21 inches in driveway applications to ensure adequate vertical sight distance for side-street drivers; and
- established the need for field testing of shorter LCDs in these applications.

Oregon Blue Tubular Markers and Blue Business Access Sign Study

The Oregon Department of Transportation (ODOT) performed an evaluation of blue temporary business access signs with blue tubular markers at business access points in work zones (*6*). One of the driveways studied is shown in Figure 2-2. It should be noted that the blue tubular marker is not currently listed in Chapter 6F of the MUTCD (*3*) as a compliant channelizing device.

The study primarily used telephone surveys of motorists and business owners to determine the usefulness of the signs and markers. Sixty-two percent of the 381 area motorists surveyed noticed the blue signs and markers at the test driveways, while 78 percent of that group felt that these devices helped them locate the driveways into the businesses. Of course, the novelty effect of the unique color of the markers may have contributed to this opinion. In any event, owners at 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. However, no operational data were collected. The research report summary indicates that no negative impacts were found, and the authors recommended continued use of the blue signs and tubular markers. ODOT implemented the use of the blue signs and markers, including language and the photo shown in Figure 2-3 in its *Traffic Control Plans* (TCP) *Design Manual* (*7*).

Figure 2-2. Blue Delineation of a Business Driveway in Oregon

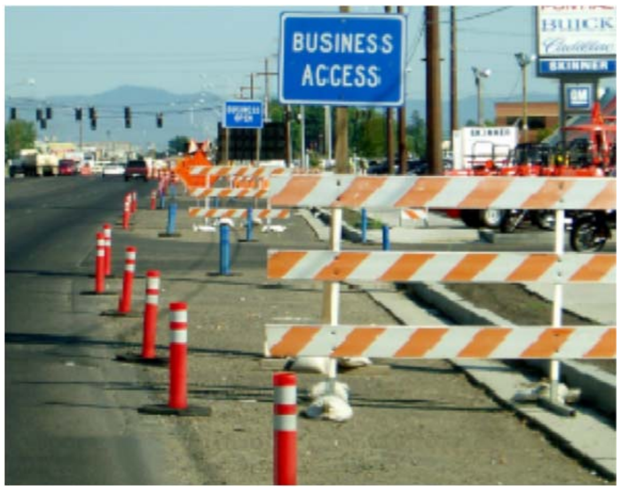

Figure 2-3. Enhanced Delineation for Business Entrances in Oregon TCP Design Manual

Pennsylvania Green and Yellow Drums Study

The Pennsylvania Department of Transportation (PennDOT) sponsored an evaluation of green and yellow drums at business access points in work zones (*8*). One of the driveways studied is shown Figure 2-4. It should be noted that the green and yellow drum is not currently an MUTCD-compliant channelizing device.

The study included video recordings of traffic operations that were intended to be used to glean speed data and document erratic maneuvers. The researchers were not able to determine speeds from the video data that were collected, and identified no erratic maneuvers while either treatment was deployed. The researchers also stopped traffic to ask for driver opinions of the treatments. The survey results indicated that approximately 85 percent of the respondents noticed the green and yellow drums, and approximately 94 percent indicated that the different colors on the drums were helpful. The researchers recommended that PennDOT implement the use of green and yellow drums. FHWA ruled that the final research report did not include sufficient information to adopt this device, but would allow further experimentation if requested (*9*,*10*,*11*).

(a) Standard Drums

(b) Green and Yellow Drums

Figure 2-4. Driveway Delineation Research in Pennsylvania

SUMMARY

There is no question that other state transportation agencies are concerned with driver identification of 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, alternative devices, 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.

CHAPTER 3: SELECTION OF TREATMENTS FOR FIELD STUDY

INTRODUCTION

FDOT originally proposed to evaluate the effectiveness of blue-striped channelizing drums for improving driveway delineation in work zones. A Request for Experimentation was submitted to FHWA. FHWA granted the request on October 4, 2011, in FHWA letter 6(09)-9 (*12*), noting that this device would not be in compliance with current language in the MUTCD (*3*). Because of this, FHWA requested that FDOT also experiment with a different type of MUTCD-compliant device to provide a visual indication of driveway entrance locations. Ultimately, FDOT opted to abandon the blue drum concept and revised the TTI research contract to include an evaluation of other work zone driveway delineation alternatives that would be MUTCD compliant.

FDOT CLOSED-COURSE STUDY

The objective of the Florida closed-course study was to identify whether different driveway delineation methods would have an effect on average detection distances and driver opinions regarding the ease of identification. While the MUTCD Chapter 6F language includes a variety of channelizing devices that are considered compliant, FDOT elected to include only LCDs in the evaluation. Upon conclusion of the closed-course study, the most promising delineation techniques would be evaluated in real Florida work zones.

Treatments

The researchers sought to determine the best configuration of LCDs to use in the closed-course study. Prior research on the use of LCDs showed that these devices may be useful in this application; however, the LCD height should not exceed 21 inches since LCDs taller than this could create sight obstructions at driveways (*5*). For this FDOT study, the researchers were able to identify only one LCD product with a height that did not exceed 21 inches and included it in the closed-course study.

The treatments tested are shown in Figure 3-1. The throat widths of the driveways were 20 ft regardless of treatment to represent a worst-case condition for driveway detection. The standard drum treatment, shown in Figure 3-1a, consisted of drums at 40-ft spacing along a tangent, with drums at 10-ft spacing in the radii of the driveway entrance. Two LCD treatments were included in the study. LCDs are not manufactured with any retroreflective material adhered to them, but the MUTCD requires that they have retroreflective material during nighttime use. The researchers developed two options for the LCD: tubular markers, such as those required for low-profile concrete barrier in Florida, and delineators, such as those commonly used for permanent barrier wall in Florida. The treatment using LCDs with tubular markers, shown in Figure 3-1b, had a total of 10 LCDs. One tubular marker was placed in each LCD, creating a 6-ft spacing between markers. The treatment using LCDs with delineators and a longer upstream tangent, shown in Figure 3-1c, had the same LCD geometry as the tubular marker treatment with six additional LCDs added to the upstream tangent. One top-mounted delineator was placed on each LCD, giving them a 6-ft spacing. No warning lights were on the drums or the LCDs. Also, no blue business entrance signs were at the closed-course driveways. By evaluating the driveway setups in their simplest form (i.e., channelizing devices only), any differences could be attributed to the devices and not the learned behavior associated with the blue signs or other confounding factors.

(a) Drums

(b) LCDs with Tubular Markers

(c) LCDs with Delineators and Longer Upstream Tangent

Figure 3-1. Treatments Evaluated in FDOT Closed-Course Study

Data Collection

There were 28 nighttime participants in this study. Each participant was required to satisfactorily complete a visual screening to ensure minimum acceptable vision for driving. The screening included tests for visual acuity, contrast sensitivity, and colorblindness. The participants completed consent forms and were given instructions for the study. The participants drove an instrumented 2009 Ford Explorer around the course, which was staged with various work zone driveway treatments and other traffic control devices used as distractors. Each participant saw two driveways: the drum treatment driveway and one of the two LCD treatment driveways. The order in which the treatments were seen was randomized. Participants were asked to indicate when they could see a driveway opening in the simulated work zones. Their response was marked in the data file, which continuously recorded time, speed, and global positioning system (GPS) location. If the participants missed the driveway, that information was recorded as well. Once the participants turned into the driveway, they stopped the vehicle and were asked a series of questions about the driveway opening:

- Why did you think that was the driveway opening?
- Was there anything that was confusing to you?
- What helped you the most in locating the driveway opening?
- One a scale of 1 to 3, how helpful were the devices in the driveway in letting you know that there was a driveway opening? (A score of 1 indicated that the treatment was very helpful, a score of 2 indicated that it was helpful, and a score of 3 indicated that it was not helpful.)

Their answers were recorded on the questionnaire form, and the participants were instructed to drive to the next part of the study. After the driving portion of the study was completed, the subjects were each shown photos of the two driveway treatments that they saw and asked which one was better. They were also asked to state why they thought that treatment was better.

Data Analysis

The vehicle used in the study was equipped with a GPS recording system. Using the marks made in the file, the researchers were able to determine the GPS coordinates corresponding to the location at which participants indicated they could see the driveway opening. With known GPS locations for each driveway, simple math could produce the distance between the GPS points. This distance was determined to be the detection distance for that treatment for the participant. The detection distances were tabulated by treatment. Table 3-1 shows the average detection distances for those participants who made the correct turn, sample size, and standard deviations for each treatment.

Table 3-1. Statistics for Treatments Evaluated in the Closed-Course Study

Treatment	Average Detection Distance (ft)	Sample Size	Standard Deviation (ft)
Standard drums	153	23[1]	71
LCDs with tubular markers	104	11[2]	42
LCDs with delineators and longer upstream tangent	168	13[3]	83

[1] Five participants missed the drum driveway.
[2] Two participants missed the LCDs with tubular markers driveway.
[3] Two participants missed the LCDs with delineators and longer upstream tangent driveway.

Using a statistical test of two means and a 95 percent confidence interval, the researchers found that the LCDs with tubular markers had a shorter detection distance than the drums. While the LCDs with delineators and longer upstream tangent appeared to have a slightly longer detection distance than the drums, this difference was found to be not significant.

Table 3-2 shows the average rating that subjects gave each treatment. In this study, a lower average rating number indicates a more helpful treatment. While the LCDs with tubular markers had the same rating as the drums, the LCDs with delineators and longer upstream tangent had a better average helpfulness rating than the drums.

Table 3-2. Average Rating Scores for Treatments Evaluated in the Closed-Course Study

Treatment	Average Rating*
Standard drums	2.0
LCDs with tubular markers	2.0
LCDs with delineators and longer upstream tangent	1.5

* 1 = very helpful, 2 = helpful, and 3 = not helpful.

The data were then divided into two groups. The first group consists of data for those subjects who saw the drums and the LCDs with tubular markers, while the second group consists of data for those subjects who saw the drums and the LCDs with delineators and longer upstream tangent. When asked which type of driveway delineation was better, the drums scored about the same as the LCDs with tubular markers in the paired comparison. However, the LCDs with delineators and longer upstream tangent were preferred 3:1 over the drums. When asked why they preferred the LCDs with delineators and longer upstream tangent over the drums, nine of the fifteen participants mentioned that the reflectors (i.e., delineators) on the LCD were helpful, while four others mentioned that the driveway gap was clear among the otherwise continuous devices.

Researchers hypothesized that the difference in location of the delineators from where the retroreflective tape existed on the tubular markers may have been one of the reasons for the improved detection and driver preference. When viewed from a distance at night, the location of the retroreflective stripes on the tubular markers would align fairly closely with those on the channelizing drums. In contrast, the lower mounting location of the delineators actually resulted in a gap in the top row of retroreflective stripes on the drums upstream and downstream of the driveway, making it easier to locate the driveway visually. It is also possible that the longer length of LCDs on the upstream tangent may have assisted in this process by making the gap in the top stripe when viewed at a distance upstream. However, it was not feasible to collect enough closed-course data to try and discern which aspect of this treatment (delineators at LCD height or the additional LCDs on the upstream tangent) was most responsible for the improved detectability of a driveway. Researchers recognized that site conditions would likely dictate the length of tangent section that LCDs could be used on around each driveway. Therefore, the field studies focused on a minimal-tangent distance configuration of this treatment.

TXDOT CLOSED-COURSE STUDY

The findings in the FDOT closed-course study were similar to those from a concurrent study performed for TxDOT. While the Texas study used other configurations, including other types of channelizing devices, the low-profile LCDs with top-mounted delineators around the driveway radii were again viewed as preferable to using drums that looked the same throughout the work zones. The results of that study can be found in TTI Report 0-6781-1 (*13*).

CONCLUSIONS

Working with TTI researchers, FDOT made a decision to investigate the use of low-profile LCDs for improved driveway delineation. These devices were chosen for several reasons:

- Their height is 18 inches, which should not create sight distance problems around driveways.
- Their connectivity can potentially provide improved positive guidance for drivers.
- They were preferred by participants in both the Florida and Texas closed-course studies.
- They are already listed in the MUTCD in Section 6F.71.

CHAPTER 4: FIELD STUDY OF LONGITUDINAL CHANNELIZING DEVICES

INTRODUCTION

This chapter describes the field studies performed to determine the effects of using LCDs at business driveways in work zones. Using information obtained from the field studies, the researchers planned to compare the LCDs with delineators and longer upstream tangent to drums. The optimum length of the upstream tangent was not known.

METHODOLOGY

The researchers used three measures of effectiveness for the field study:

- erratic maneuvers based on video observations,
- speed profiles, and
- driveway user opinions.

For this study, two different work zones were used for data collection: Cocoa Boulevard and Overseas Highway. Both work zones were located along Florida State Route 5 (also known as U.S. Highway 1) in different areas of the state.

Cocoa Boulevard Work Zone

The first work zone was along Cocoa Boulevard (SR 5/US 1) in Cocoa, Florida. The FDOT project number was T5431, and it was located in Brevard County. The construction area is shown on the map in Figure 4-1. At this work zone, the roadway was being widened from four to six lanes, along with some drainage improvements. The posted speed limit was 45 mph. Area land uses included many small businesses and a few restaurants. Most of the businesses were closed at night. No street lighting was present. The researchers documented the work zone setup with photographs, video, and GPS identification of key locations. The researchers collected data at this work zone on two different occasions, corresponding to two different construction phases.

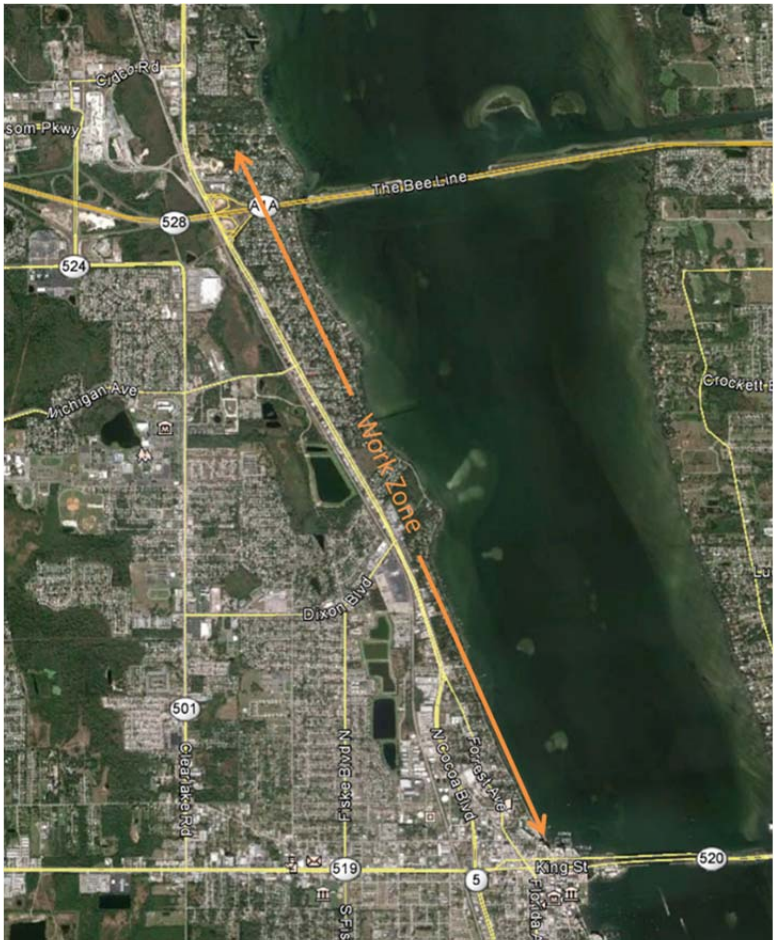

Figure 4-1. Location of Cocoa Boulevard Reconstruction Project in Cocoa, Florida

The first data collection trip occurred in November 2013. At that time, a section of the northbound lanes was delineated with drums on the right side of the outside lane. The researchers focused on two businesses that were expected to generate a reasonable amount of turning traffic:

- Wells Fargo Bank at 834 N. Cocoa Blvd. and
- Gatto's Tires and Auto Service at 510 N. Cocoa Blvd.

The researchers collected video data of turning movements at each driveway during daytime hours only. No surveys were collected during this trip. The purpose of the video data was to document traffic conditions and turning movements for the erratic maneuvers study. The video data were recorded from a camera mounted on an aerial lift platform located approximately 200 ft upstream of the driveway. During this data collection, the researchers used an enhanced tangent section upstream of the driveways while the LCD treatment was in place. The tangent section was approximately 132 ft long. Figure 4-2 shows the two treatments deployed at the Wells Fargo Bank driveway. The setup at Gatto's Tire and Auto Service was similar to the one shown in Figure 4-2.

(a) Drums

(b) LCDs with Longer Upstream Tangent

Figure 4-2. Treatments Used at Wells Fargo Driveway on Cocoa Boulevard

After the data were collected, the researchers returned to the office to review the video data. Unfortunately, the driveways had very low turning volumes. The number of turning movements recorded on the videos is shown in Table 4-1.

Table 4-1. Video Data Collection Summary at Cocoa Boulevard Work Zone—First Data Collection Trip

Treatment	Driveway	
	Wells Fargo	Gatto's
Drums	386 minutes 100 turns	281 minutes 26 turns
LCDs with longer upstream tangent	392 minutes 160 turns	160 minutes 25 turns

No driveway user survey data were collected during this trip because the researchers could not obtain consent to conduct the surveys at the Wells Fargo Bank or Gatto's Tire and Auto Service. The researchers reviewed the video data and found no erratic maneuvers by drivers making turns into the driveways. However, video alone may not provide sufficient data for developing conclusions regarding the effectiveness of LCDs at driveways. The researchers noted that the two driveways selected for use did not have any other driveways located immediately upstream (where the longer upstream tangent was located) or immediately downstream. Therefore, this scenario may not represent the worst case for drivers attempting to locate a specific driveway in a work zone, such as the driveways shown in Figure 1-2. Thus, the researchers sought to find closely spaced driveways to use in this study.

One month later, traffic on the Cocoa Boulevard project was shifted such that a section of the southbound side of the roadway was delineated with drums on the right side of the outside lane. The researchers returned to this work zone in December 2013 to collect additional data, focusing on two businesses:

- Chaparral Mexican Grill at 1341 N. Cocoa Blvd. and
- Burger King at 911 N. Cocoa Blvd.

Both of these businesses were expected to generate a reasonable amount of turning traffic under both daytime and nighttime conditions. In addition, both businesses had adjacent business driveways located nearby. Unfortunately, the Chaparral restaurant did not generate much traffic, and the drums were frequently moved around at this location. Thus, the researchers were not able to obtain any data at this driveway. The researchers focused on collecting video, speed profiles, and survey data at the Burger King entrance.

At this driveway, the researchers modified the LCD treatment in an effort to keep the treatments looking the same at all study driveways for the remainder of the project. Since the length of upstream tangent space available at future study locations was not known, the researchers relied on findings from the TxDOT driveway delineation study. Recalling that the device type located on the radii of the driveway was noticed five times as often as the device type located on the tangent section, the researchers minimized the treatment by removing the upstream tangent and limiting the use of LCDs to the driveway radii. In addition, the line of LCDs from the driveway radii to the edge of the right of way was also eliminated, significantly reducing the number of LCDs required to deploy the treatment. This LCD configuration would also allow room for the contractor to traverse the work zone driveways without removing the LCDs. This new LCD treatment could be deployed using eight LCDs (four on each side of the driveway), as shown in Figure 4-3.

Figure 4-3. LCD Treatment Used for the Remainder of the Study

Figure 4-4 shows the two treatments deployed at the Burger King driveway. The drum treatment shown Figure 4-4a shows a CITGO driveway located immediately upstream of the Burger King driveway. Unfortunately, the contractor closed the driveway overnight to reclaim asphalt, so the same upstream driveway is not shown in Figure 4-4b when the LCD treatment was deployed. The LCD treatment consisted of four LCDs on each radius of the driveway and did not include the longer upstream tangent section. During periods of darkness, the LCDs had white delineators on top (one per LCD) and were placed perpendicular to the length of the LCDs.

(a) Drums

(b) LCDs

Figure 4-4. Treatments Used at Burger King Driveway on Cocoa Boulevard

The researchers used aerial lift platforms to record the video data from a position located approximately 300 ft upstream of the driveway. A summary of the video data collected is shown in Table 4-2.

Table 4-2. Video Data Collection Summary at Cocoa Boulevard Work Zone—Second Data Collection Trip

Treatment	Daytime	Nighttime
Drums	179 minutes 48 turns	117 minutes 17 turns
LCDs	216 minutes 83 turns	77 minutes 13 turns

Speed data were recorded using laser speed measurement instruments (i.e., LIDAR) to collect speed profiles of vehicles approaching the driveways. The instruments were connected to laptops to electronically download speed and distance measurements every half second for as long as the device was locked on to a vehicle. This method allowed the researchers to create speed profiles for vehicles as they approached the driveways. If the vehicle did not turn, it was not included in the dataset. The position of the researcher was recorded at each site so that all profiles could be adjusted to reflect the vehicles' actual distances from the beginning of the upstream driveway radius. An example of a speed profile is shown in Figure 4-5.

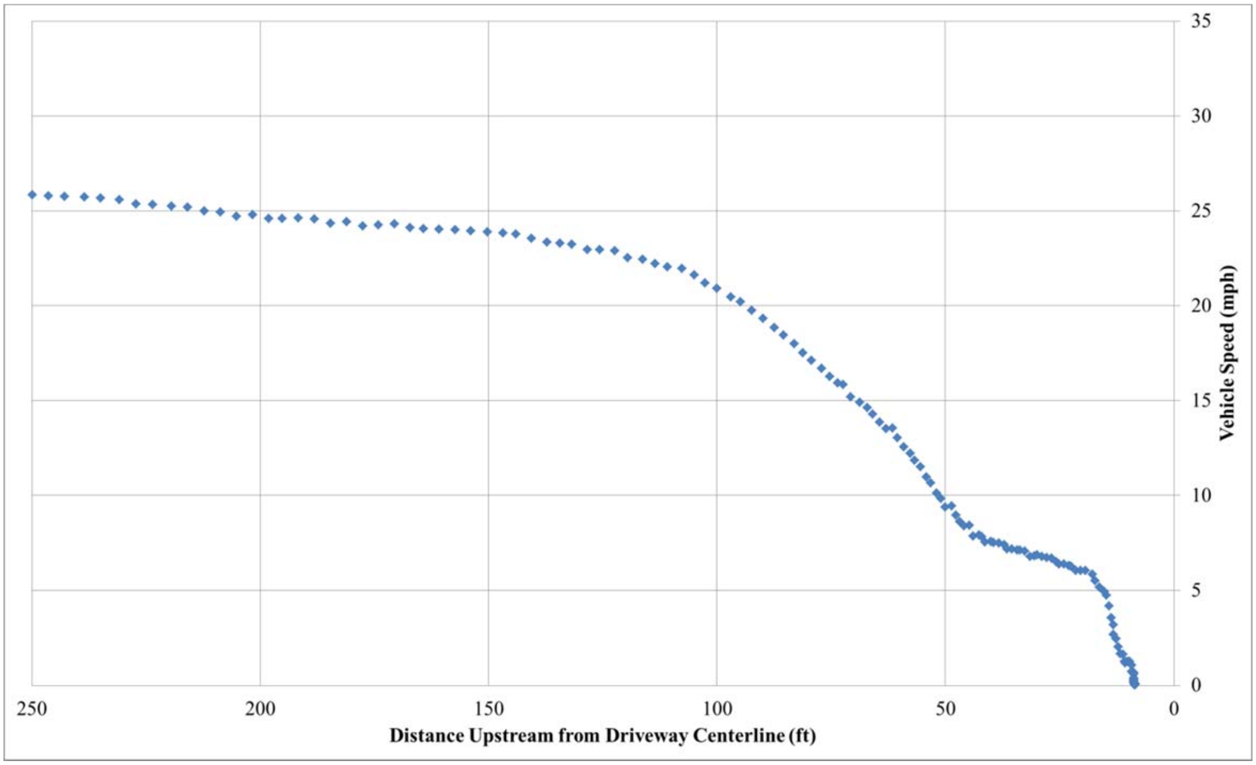

Figure 4-5. Speed Profile Example

The researchers collected speed profiles under both daytime and nighttime conditions while each of the two treatments was deployed at the Burger King driveway. Table 4-3 shows the number of speed profiles for turning vehicles that were collected at the Burger King driveway. During the final day of data collection, the researchers arrived to find that the contractor had closed the

Burger King entrance in order to reclaim materials. Thus, the dataset for the speed profiles was rather small.

Table 4-3. Number of Speed Profiles Collected at Cocoa Boulevard Work Zone

Treatment	Daytime	Nighttime
Drums	22	4
LCDs	23	9

The researchers also obtained 37 surveys from restaurant patrons and employees at Burger King. Table 4-4 shows the conditions under which the survey data were collected (i.e., which treatment was deployed and what the lighting condition was).

Table 4-4. Number of User Surveys Collected at Cocoa Boulevard Work Zone

Treatment	Daytime	Nighttime
Drums	0	4
LCDs	26	7

The survey questions were designed to get user opinions of the driveway delineation treatments in the Cocoa Boulevard work zone. After responding to standard demographic and background questions, respondents were asked the following questions:

- How easy or difficult was it for you to identify the driveway to this parking area ahead of time? (Answers were recorded as "Easy," "Difficult," or "No Opinion.")
- How easy was it for you to slow down and turn into the driveway? (Answers were recorded as "Easy," "Difficult," or "No Opinion.")
- Did you notice anything different about the work zone at the driveway entrance? (This question was asked only if LCDs were in use at the driveway.) If so, what?

The respondents were then shown the two photos in Figure 4-4. After looking at the images, the respondents were asked the following questions:

- Which of these do you think would work better?
- Why?

And finally, the respondents were asked about improving the driveway delineation with the following question:

- Is there anything else you believe could improve the work zone channelization around business driveways?

All of the survey responses were recorded on individual survey forms. The responses were later tabulated in a spreadsheet for analysis.

Islamorada Work Zone

The second work zone was Overseas Highway (SR 5/US 1) in Islamorada, Florida. The FDOT project number was E6H34, and it was located in Monroe County. The construction area is shown on the map in Figure 4-6. At this work zone, the roadway was being resurfaced, along with some drainage improvements. The posted speed limit was 45 mph. Area land uses included several small tourism-related businesses and a few restaurants.

Figure 4-6. Location of Overseas Highway Reconstruction Project in Islamorada, Florida

In this work zone, researchers, focused on three driveways that were expected to generate a reasonable amount of turning traffic under daytime conditions:

- Burger King at 82201 Overseas Hwy.,
- KZK Productions' temporary parking area at 82779 Overseas Hwy., and
- United States Post Office at 82801 Overseas Hwy.

While the Burger King restaurant was also open during nighttime conditions, traffic volumes were low during that time. KZK Productions was using a temporary parking area for their crews and actors who were engaged in filming a show for an on-demand Internet streaming media provider. This parking area was in use for only two days during the data collection period but was located adjacent to the Post Office driveway. The Post Office was only open during daylight hours. The researchers obtained daytime video data and speed profiles for each treatment at all three driveways. The researchers could not obtain permission to conduct surveys at any of these businesses.

The researchers repeated the treatments that were used at the Cocoa Boulevard Burger King. Figure 4-7 shows the two treatments deployed at the Burger King driveway in Islamorada. Again, the LCDs were placed only in the radii of the driveways and were not used in the upstream tangent.

(a) Drums

(b) LCDs

Figure 4-7. Treatments Used at Burger King Driveway on Overseas Highway

Table 4-5 summarizes the amount of video data collected at each driveway in the Overseas Highway work zone. All of the data were collected during daytime hours.

Table 4-5. Video Data Collection Summary at Overseas Highway Work Zone

Treatment	Burger King	KZK Productions	Post Office
Drums	286 minutes 84 turns	229 minutes 65 turns	229 minutes 88 turns
LCDs	231 minutes 93 turns	245 minutes 195 turns	245 minutes 172 turns

Table 4-6 summarizes the number of speed profiles collected at each driveway during daytime conditions at this work zone. During the final day of data collection, high winds produced a lot of dust in the air along the work zone. While the contractor attempted to mitigate it by spraying water, enough dust remained in the air that it interfered with the LIDAR equipment readings. Thus, the number of speed profiles was significantly lower at the Burger King driveway while the LCDs were deployed and at the KZK Productions and Post Office driveways while drums were deployed.

Table 4-6. Number of Speed Profiles Collected at Overseas Highway Work Zone

Treatment	Burger King	KZK Productions	Post Office
Drums	38	13	23
LCDs	16	81	47

RESULTS

Erratic Maneuvers Study Results

For the purpose of this research, erratic maneuvers were defined as hard braking, swerving, or intruding into the closed lane. A review of the video data indicated that drivers of turning vehicles did not have any adverse reactions to the driveway treatments (such as hard braking or swerving), but two work zone intrusions were captured in the videos.

In some cases, drivers who were following the turning vehicles made last minute lane changes, but these appeared to be more likely due to their inattentiveness rather than any action on the part of the driver of the turning vehicle. These maneuvers were not included in the analysis.

At the KZK Productions driveway, there were a few cases where turning vehicles stopped in the right lane to allow traffic exiting the driveway to make a turn into the right lane. This was likely due to the fact that the throat width of the driveway was approximately 20 ft, and the turning vehicles were competing with each other for space. In these cases, the speed profile data were omitted from the dataset. This behavior was not observed at the other driveways, likely due to the wider driveway throats (28, 40, and 30 ft) and the fact that they operated as entry-only driveways.

In the cases of vehicle intrusion into the work zone, the researchers recorded two vehicles cutting between the drums to access a driveway. One such intrusion occurred at the Cocoa Burger King while drums were deployed at the driveway and is shown in Figure 4-8. The figure shows a white truck cutting between the drums at two closely spaced driveways. The other intrusion occurred at the Islamorada Post Office driveway while drums were deployed. In both cases, the turn was made into the second of two driveways that were closely spaced. It is not known if the driver was attempting to make a higher-speed turn (in lieu of remaining on the main lane and making a 90-degree right turn) or if the drums were confusing to the driver. The researchers noted that this type of maneuver would not have been possible with the LCDs because they were connected with no spaces between them.

Figure 4-8. Vehicle Intrusion into Cocoa Boulevard Work Zone

Speed Profile Study Results

Despite the posted speed limit of 45 mph at all study locations, a review of the speed profile data indicated that drivers may have approached the different driveways at different speeds. If approach speeds were different at the different driveway test locations, it would not be possible to aggregate the data, and so only site-by-site comparisons of driver responses to each delineation treatment would be required. To test whether the approach speeds of vehicles at the test driveways were different, researchers used regression analysis with indicator variables assigned to the various driveways and the treatments used to assess statistical significance of the speed differences. Regression analysis was used in lieu of a more traditional analysis of variance because of the different sample sizes that were available for each driveway/delineation treatment combination tested. The results indicated that approach speeds differed by driveway, and therefore treatment comparisons had to be performed individually for each driveway in the study.

Once the decision to perform driveway-by-driveway comparisons of the treatments was made, researchers hypothesized that any differences in the treatments would most likely be evident in the last-minute speed reductions that would occur within 100 ft of the driveway. This is likely a critical area for rear-end collisions to occur. If either treatment showed higher average speed reductions in this area, it would be perceived as less desirable. Therefore, for each speed profile, the researchers tabulated the speed at points located 100 and 50 ft upstream of the driveways, along with the net change in speed between these points for each profile. These were then averaged for each treatment at each driveway. A *t*-test was performed to compare the average speed reductions. The results are shown in Table 4-7.

Table 4-7. Results of Speed Profile Analysis

Driveway	Treatment	Average Speed Reduction (mph/50 ft)	Number of Data Points	Standard Deviation (mph)	*t*-test Results
Burger King (Cocoa)	Drums	6.68	22	2.66	No difference
	LCD	7.72	23	2.13	
Burger King (Islamorada)	Drums	6.17	36	1.99	No difference
	LCD	6.94	16	2.02	
KZK Productions	Drums	8.92	13	2.10	No difference
	LCD	8.20	80	2.59	
Post Office	Drums	6.95	21	2.20	No difference
	LCD	6.40	45	2.90	

Based on the data available, the researchers concluded that there were no differences in the speed reductions of turning vehicles based on the type of delineation treatment that was deployed.

Driveway User Opinion Survey Results

All of the survey data were collected at the Burger King restaurant on Cocoa Boulevard. Driveway users included business owners, managers, employees, and customers who used the driveway. When asked how easy it was to identify the driveway, most (three out of four) of the respondents who had just made the turn through the drum treatment at night indicated that it was difficult to identify the driveway opening. For the survey respondents who had just turned into the business through the LCDs at night, four of the seven performing that turn reported that identifying the driveway was easy, and only one of the seven thought it was difficult. Of the 26 respondents who turned through the LCDs in the daytime, about half reported no opinion regarding the ease or difficulty of identifying the driveway. This is an indicator that other cues that were visible in the daytime were likely used to assist with identifying the driveway opening.

In terms of the ease with which drivers were able to make a turn into the driveway, four of the four drivers turning though the drums at night reported that it was easy. For those who turned through the LCDs at night, four of the seven reported that it was easy to make the turn, while 16 of the 26 turning through the LCDs in the daytime also said it was easy. Regardless of treatment, very few respondents reported any difficulty with making the turns.

When shown the photos of the LCD driveway and the drum driveway, 27 of the 37 survey respondents said they preferred the LCDs. When asked why they thought this, 22 of the 27 reported that the LCDs more clearly marked the driveway or made it easier to see. Five of the 37 respondents preferred the drums because they were more familiar or less confusing, while the remaining five respondents had no preference.

When asked if there was anything else that could be done to improve driveway channelization in work zones, 27/37 said “No,” while the remaining respondents stated that they wanted the construction completed as soon as possible. While the driveway user surveys generally favored the LCD treatment, the preference questions were based on the driver's opinion of photographs and not necessarily on the driver's personal viewing or recall of the treatment.

COMPARISON OF FINDINGS TO RECENT TXDOT RESEARCH

As noted previously, TxDOT had TTI conducting work zone driveway delineation research (*13*) at the same time as this FDOT study. Both studies used closed-course studies to identify potential driveway delineation alternatives to the use of channelizing drums around the driveway radii. However, whereas the FDOT study focused on the collection of traffic operations data with some driveway user survey data, the TxDOT study incorporated a more comprehensive human factors evaluation component into the field studies of the most promising delineation alternatives. Specifically, researchers recruited subject motorists to drive an instrumented vehicle through a set of test work zones at night. The vehicles were outfitted with eye-tracking equipment to allow researchers to gather detailed data on the frequency, location, and duration of glances drivers made while approaching a driveway where they were instructed to turn.

Overall, the results of that TxDOT study support the findings of this study. Specifically, researchers found that drivers could more quickly and easily identify the work zone driveways when LCDs with top-mounted delineators were used in the driveway radii in lieu of the standard drum treatment. The percentage of participant glances at the LCD treatment was greater than with the drums, indicative of increased driver attentiveness to (and thus awareness of) the true driveway location. The average total glance duration at the LCD treatment was also longer, suggesting that drivers were able to better focus on the treatment and spent less time scanning the work zone looking for the driveway.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

This report details the evaluation of alternative delineation methods at business driveways in work zones. The research focused on driveway delineation treatments that would be acceptable under current MUTCD standards. Once a specific treatment of LCDs was identified, the researchers collected data in real Florida work zones. The researchers faced challenges in identifying suitable work zones where the research could be conducted, so a limited number of driveways were studied. Data used in the study included video documentation of traffic operations and erratic maneuvers, as well as speed profiles of turning vehicles, when the LCD and drum treatments were deployed. The data also included driveway user surveys to obtain opinions about the alternate treatment. This section summarizes the key conclusions from each of these analyses.

CONCLUSIONS

Erratic Maneuvers Study

The researchers did not find any adverse reactions to any of the driveway treatments evaluated. However, two vehicles committed work zone intrusions near the driveways while the drum treatments were in use, apparently due to confusion as to the actual location of the driveway. Researchers suspect that the intrusions would likely not have occurred had the LCD treatment been used.

Speed Profile Study

The researchers found no statistically significant differences in the speed reductions of turning vehicles when the different treatments were deployed.

Driveway User Opinion Survey

The LCD treatment was preferred by most survey participants.

RECOMMENDATIONS

While the amount of data available was limited, the researchers believe that low-profile (21 inches or less in height) LCDs can be more effective than channelizing drums when used in confined urban work zones where the speed limit is 45 mph or less. Similar research performed by TTI for TxDOT supports the concept that LCDs can provide some benefit in helping drivers quickly and easily locate driveways in work zones.

During this research, the researchers had to frequently move the LCDs around in the work zone. Therefore, they were not ballasted. The researchers recommend that FDOT review the manufacturer's specifications for ballasting and use the LCDs in a fashion that maintains their crashworthiness as a channelizing device. In addition, the LCDs were used without signs, so the stability of LCDs with signs is not known. The researchers did not find any record of the low-profile LCD being crash-tested with signs of any height when used in the channelizing application.

Based on the results of these evaluations and other research, the researchers recommend that FDOT adopt the use of LCDs to improve driveway delineation in work zones.

REFERENCES

1. Standard Index 600, *General Information on Traffic Control through Work Zones.* Florida Department of Transportation. Available at http://www.dot.state.fl.us/rddesign/DS/15/IDx/00600.pdf. Accessed February 1, 2015.

2. Letter to Mark Kehrli, Federal Highway Administration, from Mark C. Wilson, Florida Department of Transportation, dated June 15, 2011, and referenced as FHWA Request Number 6(09)-9.

3. *Manual on Uniform Traffic Control Devices*. Federal Highway Administration, U.S. Department of Transportation, Washington, D.C., May 2012. Available at http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm. Accessed February 1, 2015.

4. Hawkins, Jr., H.G., K.C. Kacir, and M.A. Ogden. *Traffic Control Guidelines for Urban Arterial Work Zones—Volume 2 Technical Report.* Research Report 1161-5, Volume 2, Texas Transportation Institute, College Station, Texas, February 1992.

5. Finley, M.D., L. Theiss, N.D. Trout, J.D. Miles, and A.A. Nelson. *Studies to Determine the Effectiveness of Longitudinal Channelizing Devices in Work Zones.* Research Report 0-6103-1, Texas Transportation Institute, College Station, Texas, January 2011. Available at http://tti.tamu.edu/documents/0-6103-1.pdf. Accessed February 3, 2015.

6. Griffith, A., and D. Horton. *Evaluation of Modified Work Zone Traffic Control Devices at Business Accesses*. Oregon Department of Transportation Research Unit, Salem, Oregon, January 2001. Available at http://ntl.bts.gov/lib/10000/10500/10530/traffic.pdf . Accessed February 3, 2015.

7. *Traffic Control Plans Design Manual*. Traffic Roadway Section, Oregon Department of Transportation, Salem, Oregon, 2011. Available at http://www.oregon.gov/ODOT/HWY/TRAFFIC-ROADWAY/pages/tcp_manual.aspx. Accessed February 3, 2015.

8. Garvey, P.M., M.T. Pietrucha, and S.J. Damin. *Evaluation of Striped Vertical Panels in Temporary Traffic Control Zones.* Research Report No. PA-2009-001-PSU-003, Pennsylvania Department of Transportation, Harrisburg, Pennsylvania, April 2009.

9. Federal Highway Administration Ruling No. 6-197. Available at http://mutcd.fhwa.dot.gov/reqdetails.asp?id=944. Accessed February 22, 2015.

10. Letter to Robert Arnold, Federal Highway Administration, from R. Scott Christie, P.E., Pennsylvania Department of Transportation, dated May 26, 2009.

11. Letter to R. Scott Christie, P.E., Pennsylvania Department of Transportation, from Hari Kalla, Federal Highway Administration, dated October 14, 2009.

12. Letter to Mark C. Wilson, Florida Department of Transportation, from Ken Wood, Federal Highway Administration, dated October 4, 2011.

13. Theiss, L., S. Swindell, G.F. Gillette II, and G.L. Ullman. *Improved Business Driveway Delineation in Urban Work Zones.* Research Report 0-6781-1, Texas A&M Transportation Institute, College Station, Texas. Available at http://tti.tamu.edu/documents/0-6781-1.pdf. Accessed April 27, 2015.