Driver Yielding with LED-Embedded Pedestrian- and School-Crossing Signs

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FOREWORD

The research documented in this report was conducted as part of the Federal Highway Administration's (FHWA's) Evaluation of Low-Cost Safety Improvements Pooled Fund Study (ELCSI-PFS). FHWA established this PFS in 2005 to conduct research on the effectiveness of safety improvements identified by the *National Cooperative Highway Research Program Report 500 Guides*, as part of the implementation of the American Association of State Highway and Transportation Officials' Strategic Highway Safety Plan. ELCSI-PFS studies provide a crash modification factor and benefit-cost analysis for each targeted safety strategy identified as a priority by member States of the PFS.

In the last decade, the number of pedestrian fatalities increased at a greater rate as compared to overall traffic fatalities. A traffic control treatment being used at pedestrian-crossing locations is the pedestrian- or school-crossing warning sign with light-emitting diodes (LEDs) embedded in the borders (called LED-Em in this report). The objective of this project was to determine the effectiveness of the LED-Em treatment. Included in the report are details of the methods used, and statistical findings of numerous test scenarios that support the researchers' determinations. The results of the research indicate that the LED-Em treatment can be effective at increasing driver yielding on lower traffic volume roads, lower posted speed limit roads, and narrower roads. This report may be of interest to roadway safety professionals, local road operators, and pedestrian & school safety advocates.

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Director, Office of Safety and Operations
Research and Development

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A traffic control treatment being used at pedestrian-crossing locations is the pedestrian- or school-crossing warning sign with light-emitting diodes (LEDs) embedded in the borders (called LED-Em in this report). The LED-Em treatment, which includes a pedestrian pushbutton, is pedestrian activated, so the LEDs flashes only when a pedestrian is present. For this research study, researchers considered more than 7,800 drivers involved in more than 3,675 staged pedestrian crossings at 62 sites. The average driver-yielding rates at those sites were analyzed using analysis of covariance models. Logistic regression was also used to evaluate individual driver decisions on whether to yield or not to yield to a pedestrian. These analyses considered both roadway characteristics and traffic control device characteristics. The statistical analyses showed that posted speed limit, vehicle volume at the time of the crossing, crossing distance (roadway width), and the presence of supplemental traffic control devices influenced a driver’s decision to yield to a pedestrian attempting to cross a street when the LED-Em treatment was active. Higher posted speed limits, higher vehicle volumes, and longer crossing distances are associated with low driver yielding.</td></tr>
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SI* (MODERN METRIC) CONVERSION FACTORS				
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
		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
		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 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa
APPROXIMATE CONVERSIONS FROM SI UNITS				
Symbol	**When You Know**	**Multiply By**	**To Find**	**Symbol**
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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LIST OF ABBREVIATIONS

AIC	Akaike information criterion
ANCOVA	analysis of covariance
BIC	Bayes information criterion
FHWA	Federal Highway Administration
GEE	generalized estimating equations
LED-Em	light-emitting diode-embedded
LEDs	light-emitting diodes
MUTCD	Manual on Uniform Traffic Control Devices
PHB	pedestrian hybrid beacon
RRFB	rectangular rapid-flashing beacon
TRB	Transportation Research Board
TxDOT	Texas Department of Transportation

CHAPTER 1. INTRODUCTION

INTRODUCTION

Traffic agencies are seeking solutions to the rise in pedestrian fatalities. A traffic control treatment that is gaining use is the pedestrian- or school-crossing warning sign with light-emitting diodes (LEDs) embedded in the borders (called LED-Em in this report). Figure 1 shows an example of an installation. Figure 2 and figure 3 show closeups of the LED-Em sign.

Figure 1. Photo. Example of LED-Em treatment at a four-lane divided site.

Figure 2. Photo. Closeup of active LED-Em treatment where the LEDs are illuminated as short bars.

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Figure 3. Photo. Closeup of active LED-Em treatment where the LEDs are illuminated as points.

Pressing a pedestrian pushbutton activates the LED-Em treatment, so the LEDs flash only when a pedestrian is present. This treatment is typically less costly than other pedestrian-crossing treatments, such as pedestrian hybrid beacons (PHBs), and is similar in cost to rectangular rapid flashing beacons (RRFBs).

LEDs are embedded in traffic signs to enhance the conspicuity of the signs. Section 2A.07 of the *Manual on Uniform Traffic Control Devices* (MUTCD) lists the provisions for retroreflectivity and illumination for use of LEDs in traffic signs; however, advice about when to use such a treatment is not provided within the MUTCD.(1) With the increased interest in the LED-Em treatment, guidance on when or where to install the device is desired.

With the growing interest in using this treatment, understanding its effectiveness and ways its effectiveness changes based on the roadway environment is important. Are there situations, such as wide roads or streets with high posted speed limits, that make the treatment less effective? Several methods are available for evaluating the effectiveness of a pedestrian-crossing treatment, including analyzing the number of crashes and safety surrogates (e.g., number of conflicts) associated with treatment locations. Given the relative newness of this treatment, a safety surrogate, rather than crashes, was used due to the lack of sufficient number of study sites and length of time the signs have been installed. This study used the safety surrogate of driver yielding, which can be expressed as the percentage of drivers who yielded to a pedestrian attempting to cross the street.

STUDY OBJECTIVE

The focus of this study was to evaluate the operational performance of the LED-Em treatment with respect to roadway and traffic control device characteristics. This Federal Highway Administration (FHWA) project attempted to address sample size limitation by collecting data at a greater number of sites as well as collecting data in multiple States. The objective of this research was to identify site and traffic control device characteristics associated with high and low driver-yielding values to provide insights as to where and when this treatment is effective.

STUDY APPROACH

The project began by reviewing previous research and identifying the variables of high interest for study. Next, the researchers identified locations where LED-Ems were installed and then selected study locations based on the number of installations in a region. Researchers recorded the road and traffic control device characteristics for each site. Researchers employed a staged pedestrian-crossing approach in this study to obtain a sample of pedestrian-crossing observations. The data were evaluated using multiple statistical analysis techniques. The results were considered when developing recommendations on when to consider the LED-Em for a site.

CHAPTER 2. LITERATURE

LITERATURE REVIEW OVERVIEW

This chapter presents a summary of the identified literature on the LED-Em.

FINDINGS

Driver yielding counts the number of drivers who did and did not yield to a crossing pedestrian, resulting in a driver-yielding percentage.

Most of the previous studies for the LED-Em signs included only a few sites. A Des Moines, IA, case study examined driver and nonstaged pedestrian behavior at two sites.(2) The activation of the lights was associated with an increase in the driver-yield rate from 24 and 33 percent to 72 and 63 percent at the two sites, respectively. A Vermont case study examined the effectiveness of the treatment on a two-lane road with a posted speed limit of 35 mph.(3) The results showed the highest increase in yield rate during the 1-yr period after installation and a slight decrease in yield rate from yr 1 to yr 4 after installation. The overall yield rate 4 yr after installation remained 12 percent high than the yield rate measured before installation. A case study in Maple Grove, MN, included 54 pedestrian crossings for the preinstallation period and 41 pedestrian crossings for the post-installation period.(4) The results showed no improvement in driver-yield rates and reported that less than 20 percent of pedestrians activated the treatment during crossings.

A 2019 Texas Department of Transportation (TxDOT) study is the largest study to date of the LED-Em treatment.(5,6) The study included data at 13 locations and found an average driver-yield rate of 40 percent. High hourly volumes, posted speed limits 45 mph and greater, lack of sidewalks, and 12-ft lanes (no deviation from the baseline 12-ft lane width) were found to adversely affect yield probability. The research team concluded that based on the findings, LED-Em would be a suitable pedestrian treatment at sites with sidewalks, lower operating speeds, lower traffic volumes, and narrower lanes.

A 2020 TxDOT study also investigated the performance of several pedestrian traffic control treatments during both daytime and nighttime conditions.(7,8) Two statistical evaluations were used on the staged pedestrian data: analysis of covariance (ANCOVA) models that considered per-site mean yield rates, and logistic regression that considered the individual driver response to the crossing pedestrian. The research found the LED-Em to be more effective during the day than at night. Using the results from the logistic regression evaluation, researchers observed higher driver yielding at LED-Em sites in the low speed limit group (30 or 35 mph), with two lanes (rather than four lanes), with narrow lanes of 10.5- or 11-ft widths (rather than 11.5- or 12-ft widths), and with low hourly volumes. The results from the ANCOVA model for LED-Em also showed a statistically significant difference for yield lines (high yielding when present). Another key outcome from the 2020 TxDOT study was a comparison of driver-yielding differences between day and night, along with a comparison among three pedestrian treatments (RRFBs, PHBs, and LED-Em).

Figure 4 shows the comparison of daytime and nighttime driver yielding for the PHB, RRFB, and LED-Em. Overall, the average daytime driver yielding was 31 percent for the LED-Ems, 77 percent for the RRFB, and 97 percent for the PHBs.

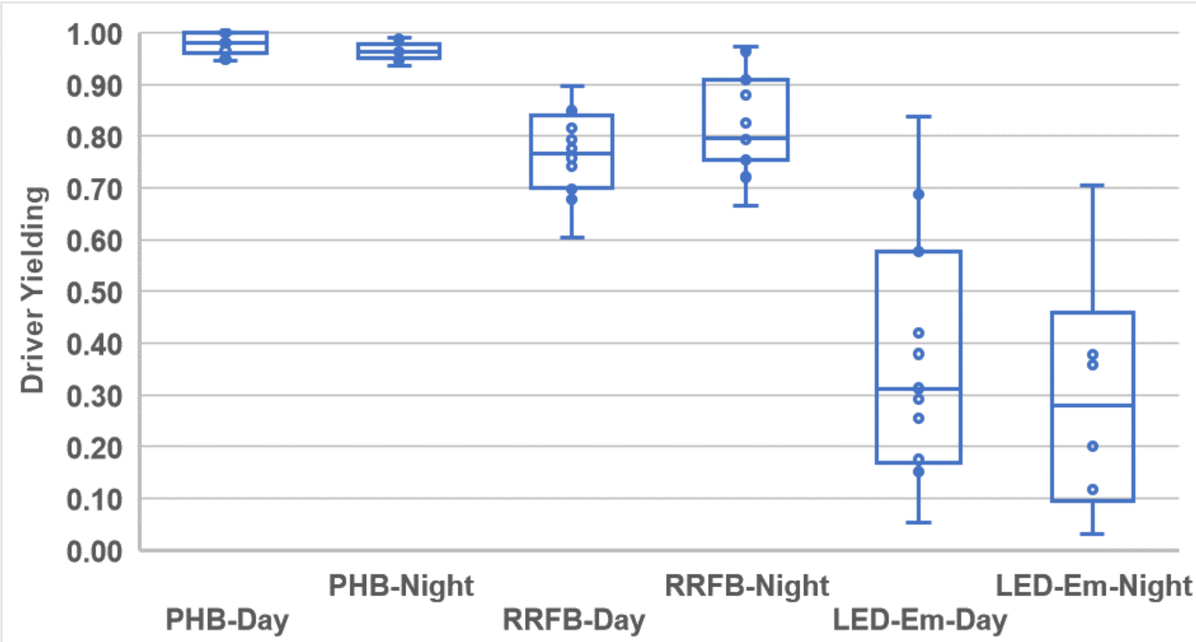

Figure 4. Graph. Range of per-site driver yielding by treatment type and light level (daytime and nighttime periods).[7]

LITERATURE REVIEW SUMMARY

With most of the previous research on the LED-Ems being conducted at only a few sites and in only one State, a larger study that includes multiple sites in different regions could provide a better understanding of the range of site conditions influencing driver behavior. Based on previous findings, the following variables should be included: posted speed limit, number of lanes (or crossing distance), and hourly vehicle volume.

CHAPTER 3. DATA COLLECTION AND REDUCTION

SITE IDENTIFICATION

The criteria established for a study site to be included in this FHWA study are as follows:

- Sign is a pedestrian (W11-2), school (S1-1), or trail (W11-15) crossing warning sign with LED-Em.
- Sign is at a marked crosswalk.
- Sign is activated by a pedestrian pushbutton.
- Crossing could have other pedestrian-related treatments, such as in-pavement lights, and these supplemental features will be considered in the evaluation.
- Crossing can have advance-warning treatments.

The research team used the following approaches to identify potential study sites:

- Polled a research team member's regional offices to identify locations known to their employees.
- Conducted a presentation at the Transportation Research Board (TRB) Pedestrian Committee in January 2020.
- Held discussions with vendors at the American Traffic Safety Services Association meeting in late January 2020.
- Prepared the following email request: "FHWA is starting a new project to investigate the safety performance for the MUTCD W11-2 Pedestrian Crossing Warning and S1-1 school-crossing signs with embedded LEDs. The research team is looking for locations where these signs have been installed and would greatly appreciate information on those sites. Please provide the intersection or street address (or latitude/longitude) for the installation to the research team."
- Sent an email request to the following groups: the chair of the National Committee on Uniform Traffic Control Devices Pedestrian Task Force for distribution to members, chairs of the TRB Pedestrian Committee for distribution to members, American Association of State Highway and Transportation Officials State bicycle and pedestrian coordinators (54 members), Walk Friendly Communities (64 members), FHWA for distribution to the traffic control device pooled fund members, and National Association of City Transportation Officials (NACTO) staff to distribute to NACTO members.
- Distributed the request via social media outlets and email listservs.

This outreach helped identify several potential study sites. The research team examined each site with the Google® Earth™ Street View function, reviewing the pedestrian-crossing signs for evidence that they had embedded LEDs (e.g., the sign had a solar panel, or the embedded LEDs were present) and a pedestrian pushbutton. Based on what could be viewed in the Google Earth Street View, the research team used the following criteria to categorize the sites into groups that reflected whether a site could be considered for this study:

- Groups that could be considered for this study:
  - LED-Em: These sites appear to meet the criteria of this study. They have pedestrian- or school-crossing signs with embedded LEDs that are activated by a pedestrian pushbutton.
  - LED (add treat): These sites appear to meet the criteria for this study but with additional pedestrian treatments present. They have pedestrian- or school-crossing signs with embedded LEDs that are activated by a pedestrian pushbutton. In addition, they have a supplemental pedestrian treatment feature, typically in-pavement lights or advance warnings. Inclusion of these sites in the study requires adding a variable to control for the supplemental pedestrian treatments present at the crossing.
- Sites that were grouped into "LED (NotFound)": These sites reportedly had an installation of pedestrian- or school-crossing signs with embedded LEDs, but when the research team examined them with Google Earth Street View, a pedestrian pushbutton was not seen, possibly indicating the signs were installed after the latest Google Earth Street View image. The research team planned to contact the city of the provided location for additional information if an insufficient number of sites were identified that fit the study's requirements.
- Groups that would not be considered for this study:
  - LED (24/7): These signs with embedded LEDs are at an intersection but flash 24 h/d 7 d/wk.
  - LED (signal): These signs with embedded LEDs are at an intersection controlled with a signal.
  - LED (stop): These signs with embedded LEDs are at an intersection with all-way-stop control.
  - LED (approach): These signs with embedded LEDs are on an approach to an intersection. They are assumed to flash 24/7 or were confirmed as flashing 24/7.

The outreach efforts identified 153 sites. Of the sites identified, 78 sites satisfied the key criteria for the study (pedestrian- or school-crossing signs with embedded LEDs that are activated by a pedestrian pushbutton). An additional 19 sites satisfy the key criteria but with supplemental pedestrian-related treatments. These 97 sites are located in 11 States.

SITE SELECTION

The goal of the study was to collect data at a minimum of 35 sites located in at least two States. For the 11 States identified with a treatment, most had only one installation. Only Texas and California had more than 10 installations and, therefore, were selected for inclusion in this study.

In California, most of the identified sites could logically be grouped into three areas: Oakland, Sacramento, and San Diego. For these sites, locations with high posted speed limits or great number of lanes had priority for data collection. For Texas, almost every site identified would be eligible for inclusion. Some of the Texas-based sites' data were collected from previous TxDOT studies to expand the sample size. Data were also collected in Texas for the FHWA study at a group of recent installations in Colleyville, TX, which is in the Dallas/Fort Worth, TX, metropolitan area, and in Houston, TX.

DATA COLLECTION PERIODS

Researchers collected data during four periods.

- Fall 2020—9 Texas sites.
- Late spring and early summer 2021—31 California sites.
- Fall 2021—6 California sites and 3 Texas sites.
- Spring 2019 and winter 2020—13 Texas sites and previous TxDOT projects.[5,8]

The data collection periods were influenced by the weather, temperature (with the goal of avoiding the hotter parts of the year for the region), COVID-19 restrictions, and timing of when the sites had been installed or identified.

The COVID-19 pandemic affected the timing of data collection for this FHWA project. The nine Texas site studies were completed in the fall of 2020 when conditions in the State were near normal as businesses reopened and viral cases fell. The research team planned to collect data at sites in California in the fall of 2020 as well; however, they were postponed due to COVID-19-related travel and business restrictions that resulted in traffic volume and patterns that those familiar with local activity felt were different from the norm. Therefore, California data collection was completed in the late spring and early summer of 2021 as the pandemic conditions improved, businesses reopened, and travel restrictions lessened. Changes in pedestrian volumes did not affect the data collection because of the use of a staged pedestrian-crossing approach to measure driver yielding. Any reduction in the vehicle traffic volume was also accounted for in the 1-min traffic counts collected for each crossing from the video footage collected at the site. The details of the data collection approach are discussed in the next subsection.

DATA COLLECTION PROTOCOL

Researchers employed a staged pedestrian-crossing approach in this study to obtain a sufficient sample of pedestrian-crossing observations. Researchers based the protocol for data collection on the experiences gleaned from several previous research projects, including research on the PHB and the RRFB.[9,10] The protocol used a team of two, with one staff member playing the role of the staged pedestrian while the other staff member recorded the driver-yielding behavior. Before collecting data in the field, inexperienced data collection teams received a copy of the written protocol along with the data collection sheets. After their review, an experienced team trained the new teams on the staged pedestrian protocol.

The staged pedestrian was trained to approach the crossing in a similar manner for each location to minimize the effects of pedestrian behavior on drivers and to maintain consistency among study locations in how the pedestrian approaches a crossing. The staged pedestrian wore a gray t-shirt or sweatshirt, blue jeans, and predominantly dark shoes. A baseball cap and sunglasses were permitted. The staged pedestrians activated the LED-Em pedestrian-crossing sign while vehicular traffic was approaching. Once the vehicles stopped, the pedestrian cross the street. The staged pedestrian waited until all queued vehicles from the previous crossing had cleared before beginning another staged crossing so that drivers did not observe two consecutive actuations.

Researchers used a video camera to record data collection effort. The recordings served as a backup for the yielding data collected and was used to obtain the 1-min volume vehicle counts before each pedestrian crossing.

SITE CHARACTERISTICS

Researchers used aerial photographs to identify the roadway geometric characteristics, which were confirmed in the field as needed. Table 1 lists the descriptions of the variables considered in the statistical analysis. Additional variables were collected for each site, such as one-way or two-way operations; however, those variables were either uniform for all sites or were determined in the preliminary analyses not to be influential with respect to driver yielding.

Table 1. Variable descriptions.

Variable Name	Description
Driver Yielding	Average driver yielding for the site (percent)
HourVol	Estimated hourly volume: Estimated from counting vehicles for approximately 1 min prior to the pedestrian crossing the street, total of both directions (vehicles/hour)
M:Bike	Main: Is a bike lane present? (0 = none, 1 = one side, 2 = both sides)
M:Curb2Curb+Med	Main: Calculated distance between curbs including median, bike lanes, and parking lanes, if present (feet)
M:CurbExten	Main: Is a curb extension present? (yes or no)
M:MT	Main: Median type (TWLTL, raised (offset, short), none)
M:Parking	Main: Is on-street parking present? (0 = none, 1 = one side, 2 = both sides)
M:SW	Main: Is a sidewalk present? (0 = none, 1 = one side, 2 = both sides)
MTCD:AddTreat	Main TCD: Are supplemental features present at the crossing, for example in-pavement lights or multiple sets of LED-Em signs? (yes/no)
MTCD:CW_Mark	Main TCD: Crosswalk marking type (e.g., continental, ladder, transverse, other)
MTCD:FaceLED	Main TCD: Combination of sign face and LED style in sign
MTCD:Flash	Main TCD: Flash duration (seconds)
MTCD:InPaveLights	Main TCD: Are in-pavement warning lights present? (yes or no)
MTCD:LED-InSign	Main TCD: LED style in the sign face (bar or dot)
MTCD:PSL	Main TCD: Posted speed limit (mph)
MTCD:SignFace	Main TCD: Type of sign (e.g., pedestrian or school crossing)
MTCD:SignLoc	Main TCD: Location of signs (right only, both right and median, both right and left)
MTCD:SZ	Main TCD: Is crossing within a school zone? (yes or no)
MTCD:YieldBar	Main TCD: Is advance-yield bar present? (yes or no)
S:Dev	Site: Development type (commercial, residential, or mixed)
S:Legs	Site: Number of legs/approaches
S:ID	Site: Number for site

TWLTL = two-way left-turn lane. TCD = traffic control device.

Table 2 and Table 3 provide the summary statistics for the numerical variables or the number of sites for the categorical variables. Table 4 provides additional details on the number of sites by roadway characteristics. For traffic control devices, table 5 provides details about the signs at the sites, and Table 6 provides the number of sites with pavement markings. Table 7 shows the summary statistics for crossing distance, hour volume, and length of time the treatment flashed after activated by the pedestrian. At most of the sites, the LED-Em flashed for between 20 and 30 s. In California, one of the sites only flashed for 10 s, while a site in Texas flashed for 80 s, the longest recorded in this study. Placement of LEDs on signs vary. In some cases, the LEDs looked like dots, and in other cases they are in a row that resembled an LED bar. Another sign variation is where the LEDs are placed on the sign, for example either in the sign's black border or in the yellow portion of the sign.

Table 2. Summary statistics for numerical variables used in the analysis.

Variable Name	Minimum	Maximum	Mean	Std. Deviation
DataDY:#Crossings	10	121	59.27	21.24
DataDY:Driver Yielding	0.05	0.95	0.58	0.24
HourVol	14	1745	465.15	378.52
M:Curb2Curb+Med	20	128	54.19	22.70
MTCD:PSL	25	50	34.03	6.13
S:Flash	10	80	27.11	10.65

Table 3. Summary statistics for categorical variables used in the analysis.

Variable Name	Value (Number of Sites)
M:Bike?	0 (40), 2 (22)
M:CrDis2Group	<40 ft (22), >40 ft (40)
M:CurbExten	Yes (6), No (56)
M:MT	None (22), Raised (29), TWLTL (11)
M:PK?	0 (51), 1 (2), 2 (9)
Main:PSL	PSL_25 (8), PSL_30 (18), PSL_35 (23), PSL_40 and above (13)
MTCD:AddTreat	Yes (20), No (42)
MTCD:AdvSignTreat	Yes (26), No (36)
MTCD:SignFace	S1-1 (19), W11-15 (1), W11-2 (42)
MTCD:SignLoc	Right and left (11), Right and median (13), Right only (38)
MTCD:SZ?	Yes (21), No (41)
MTCD:YieldBar	Yes (30), No (32)
Period	Prepandemic (49), pandemic (13)
S:Dev	Commercial (11), Mix (21), Residential (30)
S:Legs	2 (20), 3 (23), 4 (19)
S:ST	CA (37), TX (25)

Note: The number in parentheses corresponds to the frequency of that variable.

Table 4. Number of sites by roadway characteristic, State, and data collection period.

Variable Name[1]	Variable Level[2]	CA: Pandemic	TX: Pandemic	TX: Prepandemic	All
M:Bike	0	18	12	10	40
	1	0	0	0	0
	2	19	0	3	22
M:CurbExten	No	31	12	13	56
	Yes	6	0	0	6
M:MT	None	12	5	5	22
	Raised	17	4	4	25
	Raised, offset	1	0	0	1
	Raised, short	2	1	0	3
	TWLTL	5	2	4	11
M:Parking	0	26	12	13	51
	1	2	0	0	2
	2	9	0	0	9
M:SW	0	0	0	4	4
	1	2	4	1	7
	2	35	8	8	51
S:Dev	Commercial	7	0	4	11
	Mix	17	2	2	21
	Residential	13	10	7	30
S:Legs	2	13	3	4	20
	3	11	8	4	23
	4	13	1	5	19
Total	All sites	37	12	13	62

[1]Descriptions of variables are available in Table 1.
[2]Column includes variable level.

Table 5. Number of sites by sign characteristic, State, and data collection period.

Variable Name[1]	Variable Level[2]	CA: Pandemic	TX: Pandemic	TX: Prepandemic	All
MTCD:Face LED	PedXing_bars in black (8 or 16)	7	0	0	7
	PedXing_bars in yellow (8)	7	0	0	7
	PedXing_dots (12)	0	0	2	2
	PedXing_dots (16)	5	0	0	5
	PedXing_dots (8)	8	7	7	22
	Sch_bars in black (8)	6	0	0	6
	Sch_bars in yellow (8)	3	0	0	3
	Sch_dots (5)	1	5	4	10
MTCD:LED-InSign	LED bars in black (16)	1	0	0	1
	LED bars in black (8)	11	0	0	11
	LED bars in yellow (8)	11	0	0	11
	LED dots (12)	0	0	2	2
	LED dots (16)	5	0	0	5
	LED dots (5)	1	5	4	10
	LED dots (8)	8	7	7	22
MTCD:PSL	25	8	0	0	8
	30	3	9	6	18
	35	19	0	4	23
	40	3	3	0	6
	45	4	0	1	5
	50	0	0	2	2
MTCD:SignFace	S1-1 (school crossing)	8	5	4	17
	SW24-2 (school crossing with arrow)	2	0	0	2
	W11-15 (bicycle/pedestrian crossing)	1	0	0	1
	W11-2 (pedestrian crossing)	26	7	9	42
MTCD:Sign Loc	Right only	8	3		11
	Right and left	11		2	13
	Right and median	18	9	11	38
MTCD:SZ	No	28	7	6	41
	Yes	9	5	7	21
Total	All sites	37	12	13	62

[1]Variable description are available in Table 1.
[2]Column includes variable level: PedXing = pedestrian-crossing warning sign; Sch = school-crossing warning sign.

Table 6. Number of sites by pavement traffic control device characteristic, State, and data collection period.

Variable Name[1]	Variable Level	CA: Pandemic	TX: Pandemic	TX: Prepandemic	All
MTCD:AddTreat	No	19	10	13	42
	Yes	18	2	0	20
MTCD:CW_Mark	Continental	13	0	1	14
	Continental, split	3	0	0	3
	Ladder	16	6	11	33
	Ladder, diagonal	1	0	0	1
	Ladder, split	1	0	0	1
	Transverse	3	6	1	10
MTCD:InPaveLights	No	24	10	13	47
	Yes	13	2	0	15
MTCD:YieldBar	No	13	9	10	32
	Yes	24	3	3	30
Total	All sites	37	12	13	62

[1]Descriptions of variables are available in table 1.

Table 7. Summary statistics by select variables, State, and data collection period.

Variable Name[1]	Variable Level[2]	CA: Pandemic	TX: Pandemic	TX: Prepandemic	All
MTCD:Flash (seconds)	Min	10	20	29	10
	Max	40	30	80	80
	Ave	23	28	38	27
M:Curb2Curb+Med (feet)	Min	20	20	22	20
	Max	126	78	87	126
	Ave	58	47	50	54
HourVol (vehicles/hour)	Min	14	38	168	14
	Max	1,745	987	1,640	1,745
	Ave	453	420	541	465

[1]Descriptions of variables are available in table 1.
[2]Column includes: min = minimum; max = maximum; ave = average.

The goal was to collect data at sites with high posted speed limits and wider crossings. For this group of sites, the posted speed limit ranged from 25 to 50 mph. (See table 5 for the distribution of number of sites by posted speed limit.) The crossing distance was measured curb to curb and included the width of the median and bike lanes or parking lanes when present. The crossing distance generally ranged from 20 ft to 87 ft, except for one site with a crossing distance of 126 ft wide.

LED-EM FLASH TIME, CURRENT PRACTICE

As shown in the data (table 7), the length of time the LEDs flash varies by location, which is to be expected, since the crossing lengths vary. The 2009 edition of the MUTCD does not provide information regarding the length of flash time.[(1)] The calculated pedestrian clearance time from

MUTCD, chapter 4, "Pedestrian Control Features," Section 4E.06 can be used to determine the minimum length of time for the LED-Em flash. As stated in the MUTCD, "the pedestrian clearance time should be sufficient to allow a pedestrian crossing in the crosswalk who left the curb or shoulder…to travel at a walking speed of 3.5 feet per second of at least the far side of the traveled way or to a median of sufficient width for a pedestrian to wait."[(1)] The MUTCD allows characteristics of the pedestrian population and signal technology factors to increase the walking speed to 4 ft/s or low it to 2.8 ft/s.

VIDEO DATA REDUCTION

Researchers used the video to count the number of vehicles driving across the crosswalk in both directions for 1-min before each staged pedestrian crossing. The 1-min increment provides an estimate of the volume of traffic present just before the specific pedestrian crossing. When there are many vehicles, drivers may be hesitant to stop for the pedestrian because of a concern with their vehicles being hit from behind. In a few cases, researchers used a time slightly longer than 1 min to avoid starting the count with a vehicle in the crosswalk. In a few cases, researchers used a shorter period to accommodate the start time of the video file. They also converted the 1-min traffic counts into hourly volumes by using the exact number of seconds reflected in the vehicle count.

This study included about 250 h of video recordings, resulting in data for 7,805 drivers and 3,675 pedestrian crossings at 62 sites.

DRIVER YIELDING RATE CALCULATION

Each driver responding to a staged pedestrian crossing was coded as being either 1 (for yielding) or 0 (for not yielding). Figure 5 shows the calculation used to determine the average driver-yielding rate (*DYR*).

$$DYR = \frac{\sum Number\ of\ Drivers\ Yielding}{\sum Total\ Number\ of\ Drivers}$$

Figure 5. Equation. Driver-yielding rate.

A large range of per-site driver yielding is present for the 62 sites. As illustrated in figure 6, the range of per-site driver yielding was 5 to 95 percent with the range being smaller for California sites (38 to 95 percent) than Texas sites (5 to 90 percent). Both States had sites with very high driver yielding (90 percent or more). The average driver yielding for California sites was 66 percent, while it was 58 percent for data collected at Texas sites during the pandemic and 38 percent for data collected at Texas sites prior to the pandemic. While the prepandemic average driver yielding is much low compared to the pandemic average driver yielding, the difference is not due to the pandemic. Rather, it is due to the type of sites represented in both groups. The Texas prepandemic sites included many sites that had high speed limits (3 sites had 45 or 50 mph posted speed limits) and a rural appearance.

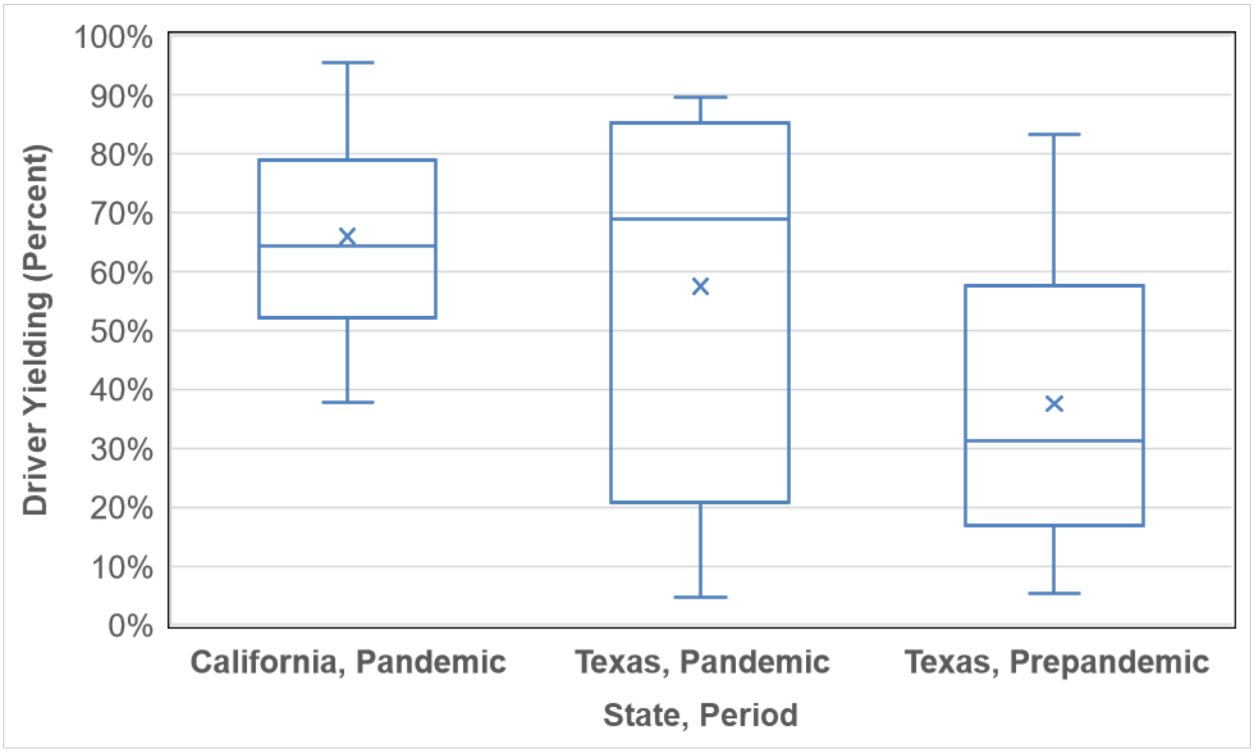

Figure 6. Graph. Distribution of per-site driver yielding by State and time period.

CHAPTER 4. ANALYSIS

This chapter presents the results of the evaluation of the per-site data and the per-driver data.

APPROACH TO ANALYSES

Per-Site Analysis

The objective of the per-site analysis was to explore the relationship between site-level driver yielding (i.e., average driver yielding rates) and traffic control device and site characteristic variables. Analyses were performed using a normal linear model, specifically the ANCOVA model, applied to driver-yielding rates averaged by each site. An ANCOVA model was employed because many of the predictor variables, which are either continuous or categorical, are site-based or traffic control device based (e.g., sign face), rather than individual crossing event based, and because the average driver-yielding rates satisfy the underlying assumptions for ANCOVA models. The average driver-yielding rates approximately follow a normal distribution because they are the averages computed based on much more than 30 crossings. The independence and equal variance assumptions for ANCOVA were also checked by examining the residual plot and the Durbin–Watson test, although those are not included in this report.

Table 1 shows the list of variables used in the per-site analysis, including driver yielding rates, site characteristics, and traffic volume variables, along with summary statistics. Note that not all potential predictors in table 1 may have a significant relationship with driver yielding rates.

Although it is possible to keep all variables in the full model if the coefficients are physically meaningful, researchers also performed variable selection on candidate predictors shown in table 1 to develop more parsimonious models (having important predictors only). Several ANCOVA models were explored based on adjusted R^2. The automatic stepwise (forward, backward, or mixed) model selection procedure available in the statistical package JMP® (SAS® product) was also utilized to perform variable selection with diverse selection criteria. Specifically, the following three stopping rules were used in implementing a stepwise model selection procedure in JMP: *p*-value threshold, minimum Akaike information criterion (AIC), and minimum Bayesian information criterion (BIC). Both AIC and BIC are penalized-likelihood criteria for model selection that balance the choice of model by adding a penalty for the number of predictors used to the residual sum of squares.(11) Although a low AIC or BIC means a better model, a simpler model can be selected by the principle of parsimony whenever there is not much difference in AIC or BIC values among competing models. One needs to keep in mind, however, that the best choice of a model may also depend on how useful the model is in the given context, not just on statistical model selection criteria. The models chosen by an automatic stepwise model selection procedure did not include the HourVol variable. While HourVol had a statistically significant relationship with Driver Yielding rates when included in the model by itself, it became statistically insignificant with the addition of MTCD:PSL to the model.

Per-Driver Analysis

Like the per-site analysis, the objective of the per-driver analysis was to explore the relationship between driver yielding (expressed as the probability of yielding for each driver), traffic control device, and site characteristic variables, including traffic volume, and to assess their effects on the probability of driver yielding. The nature of the per-driver analysis permits detailed consideration of the traffic volume present when the staged pedestrian is attempting to cross the street. The dataset contains the individual driver response to the crossing pedestrian, 1 if yielding or 0 if not yielding along with the site and traffic control device characteristic variables and the two-way hourly volume estimate based on a 1-min count for each crossing.

Because the outcome variable is dichotomous with 1 for Yield, 0 for Not Yield, researchers employed the logistic regression analysis for the per-driver analysis. The log-odds of the probability of driver yielding given the value of predictor variables (**X**), $P(Y = Yield\ \mathbf{x})$ are expressed in figure 7.

$$g(\mathbf{x}) = \ln\left[\frac{P(Y = Yield|\mathbf{x})}{1 - P(Y = Yield|\mathbf{x})}\right] = \beta_0 \div \beta_1 x_1 \cdots \div \beta_k x_k$$

Figure 7. Equation. Log-odds of probability of driver yielding.

Where:
$g(\mathbf{x})$ is the logit (log-odds)
x = value of the predictor variables $X_1,\cdot,X_k$, e.g., HourVol, S_Flash, (e.g., MTCD_PSL, MTCD_YieldBar, MTCD_AddTreat, etc.).
β_0 = baseline level of the logit.
β_k = change in the logit that occurs with a unit change in X_k.

Note that the logit, g(x), is linear in its parameters. The intercept β_0 represents the baseline level of the logit, and β_k represents the change in the logit that occurs with a unit change in X_k. Figure 8 shows the conditional probability that the driver yields at site i in jth pedestrian crossing.

$$P(Y_{ij} = Yield|x) = \frac{e^{g(x)}}{1 + e^{g(x)}} = \frac{e^{\beta_0 + \beta_1 x_{i,1j} \cdots + \beta_k x_{i,kj}}}{1 + e^{\beta_0 + \beta_1 x_{i,1j} \cdots + \beta_k x_{i,kj}}}$$

Figure 8. Equation. Conditional probability of driver yielding.

To account for possible correlation in the outcome variable obtained for multiple crossings from the same site, the generalized estimating equations (GEE) was employed as an estimation method.

RESULTS

ANCOVA was used with 3 datasets: sites available early in the project (53 sites, called “initial sites”), all sites where data had been collected by the research team within the past 3 yr (62 sites, called “all sites”), and those sites where data were collected during the pandemic (49 sites, called “pandemic sites”). The findings from the analysis of the initial sites were also reported elsewhere.[12]

Per-Site Analysis, Initial Sites

The initial analyses used 53 sites whose data were available for preliminary analyses. Table 8. ANCOVA model with key variables and per-site mean yield rates. provides the results for the model that used a minimum number of variables and that had only statistically significant variables. Posted speed limit and hourly volume are significant and indicate lower driver yielding for higher posted speed limits and hourly volumes. For this model, the research team included a variable to describe if supplemental treatments were present at the site, such as in-pavement warning lights or extra signs for the LED-Em treatment, which would help draw additional attention to the crossing. The variable, MTCD:AddTreat, was significant, indicating that for this set of sites, the additional treatments helped increased the conspicuity of the crossing, resulting in more drivers yielding to the crossing pedestrians. The coefficient for posted speed limits indicates a 6.7-percent decrease in driver yielding for each 5-mph increment increase and a 7.6-percent decrease in driver yielding for an increase of 250 vehicles/hour.

Table 8. ANCOVA model with key variables and per-site mean yield rates.

Parameter Estimates	Estimate	Std Error	*t* Ratio	Prob > |*t*|
Intercept	1.2057807	0.129366	9.32	<0.0001*
MTCD:PSL	−0.013417	0.003772	−3.56	0.0008*
HourVol	−0.00029	8.012e-5	−3.62	0.0007*
MTCD:AddTreat[No]	−0.071914	0.025492	−2.82	0.0069*

Std error = standard error; *t* ratio = test statistic used for the *t*-test; prob > |*t*| = *p*-value for the *t*-test; * = statistically significant at alpha=0.05.
Note: summary of fit: R^2 = 0.466614, R^2 adjusted = 0.433958. Root mean square error = 0.158903, mean of response = 0.583585, observations (or sum weights) = 53

Per-Site Analysis, All Sites

The per-site analysis then considered all sites with the LED-Em treatment whether the data collection occurred prepandemic or during the pandemic. Researchers explored several ANCOVA models and the model that, overall, performed better in terms of model selection criteria (smaller AIC or BIC) along with variables with a *p*-value greater than 0.2 removed. The fixed-effect test for the model (table 9) provides the estimated model coefficient and model fitting results. Researchers did not include State variable in the model as it was not a significant variable. However, the period variable was significant and may explain some of the variability that the State variable would have explained since all the prepandemic sites were in one State (Texas).

Table 9. ANCOVA model for per-site mean yield rates with key variables fitted based on all available sites (n = 62).

Parameter Estimates	Estimate	Std Error	t Ratio	Prob > |t|
Intercept	1.1185094	0.120545	9.28	<0.0001*
Period[Pandemic]	0.1052489	0.026105	4.03	0.0002*
HourVol	−8.376e-5	5.639e-5	−1.49	0.1433
MTCD:PSL	−0.016147	0.003416	−4.73	<0.0001*
MTCD:YieldBar[No]	0.0505354	0.022224	2.27	0.0270*
MTCD:SignLoc[Right & Left]	−0.108768	0.035567	−3.06	0.0035*
MTCD:SignLoc[Right & Median]	0.0548842	0.037438	1.47	0.1484
MTCD:AddTreat[No]	−0.096238	0.023542	−4.09	0.0001*

Std error = standard error; t ratio = test statistic used for the t-test; prob > |t| = p-value for the t-test; * = statistically significant at alpha=0.05.
Note: summary of fit: R^2 = 0.734238, R^2 adjusted = 0.655075. Root mean square error = 0.140689, mean of response = 0.583871, observations (or sum weights) = 62.

In some cases, the coefficient for the variable may be counterintuitive. For example, yielding should be higher when a yield bar is present. For this set of sites, the presence of an advance yield bar was associated with slightly lower driver yielding, which, perhaps, is a reflection that yield bars were added at sites where pedestrian visibility is a concern.

The location of the warning sign generated a counterintuitive result and an expected result. The crossing warning signs could be located on the right only, on both the right and left sides of the street, or on the right side of the street and in the raised median. The MTCD:SignLoc variable indicates the location of the crossing warning signs that an approaching driver can see. Right only reflects the condition when the driver can see the face of the sign on the right side of the road only. Right and left reflects the condition when the driver can see the face of the sign on both the right side and on the far-left side of the road. Typically, this situation occurs when crossing warning signs are located on both sides of the signpost so that drivers coming from both approaches to the crossing can see the warning sign. The condition of having a right and a median sign reflects the thought that having a sign closer to the approaching driver on the left as compared to when the sign is located on the left-side of the road.

The coefficients for the variable MTCD:SignLoc had an expected positive response when the signs were right and median, but a counterintuitive response for when the signs are located right and left. The theory is that in having more than one sign face visible, drivers will be more aware of the crossing and more likely to yield. Having the warning sign on the right is believed by the Research Team members to have the lowest driver yielding; however, the coefficients indicate that lower driving yielding occurs when the signs are located on both the right-side and the left-side of the road. Having signs located both on the right side of the roadway and in the median, which places the sign closer to the approaching driver, resulted in the highest driver yielding.

Another factor impacting driver yielding may be the distance the warning signs are from the driver. While having an additional warning sign on the left side of the road for an approaching driver to see should be of value, the cross-section width could result in the sign being outside the typical field of view for the driver. The sites with pedestrian crossing warning signs on the right and left had wider cross sections compared to pedestrian crossings with right only warning signs. Future research is needed to fully explore the benefits of having multiple crossing warning signs visible as a function of the number of lanes at the crossing. The presence or absence of a raised median is another factor that also needs to be considered. Within this study's site sample, the median type was not significant; however, the sign location variable may explain some of the variation in driver yielding that could be attributed to the median presence.

The street's posted speed limit was significant, with lower driver-yielding rates as the posted speed limit increased. This coefficient had the strongest impact on driver yielding estimates. Assuming a site has the warning signs in the median and on the right along with supplemental treatments, and an hourly volume of 650 vehicles/h, the estimated driver yielding is 81 percent for a 20-mph road, 48 percent for a 40-mph road, and a low of 32 percent for a 50-mph road.

Per-Site Analysis, Sites Collected During the Pandemic

With concerns expressed by members of the review panel that driver behavior was different during the pandemic compared to prepandemic, a per-site analysis was conducted using the 49 sites where the data were collected during the pandemic. Again, researchers explored several ANCOVA models and included in this report the findings of the model that, overall, had the best measures (small AIC or BIC) and most interesting results.

Previous research[10,12] indicated that the crossing distance for the pedestrian, the posted speed of the street, and the traffic volume during the time of the crossing are important. The model shown in table 10 includes those variables along with other selected variables with a *p*-value of less than 0.2.

Table 10. ANCOVA model for per-site mean yield rates with key variables fitted based on sites collected during pandemic (n = 49).

Parameter Estimates	Estimate	Std Error	*t* Ratio	Prob > |*t*|
Intercept	1.3491735	0.172545	7.82	<0.0001*
M:Bike?[0]	−0.043511	0.025956	−1.68	0.1011
MTCD:PSL	−0.017571	0.00597	−2.94	0.0053*
MTCD:SignLoc[Right & Left]	−0.101612	0.037148	−2.74	0.0091*
MTCD:SignLoc[Right & Median]	0.0570401	0.044624	1.28	0.2082
MTCD:AddTreat[No]	−0.085798	0.02593	−3.31	0.0019*
M:Curb2Curb+Med	−0.001976	0.001391	−1.42	0.1630

Std error = standard error; *t* ratio = test statistic used for the *t*-test; prob > |*t*| = *p*-value for the *t*-test; * = statistically significant at alpha=0.05.
Note: summary of fit: R^2 = 0.560158, R^2 adjusted = 0.497324. Root mean square error = 0.149282, mean of response = 0.639184, observations (or sum weights) = 49.

The results demonstrate that for the LED-Em treatment, the variables—street's posted speed limit and crossing distance (M:Curb2Curb+Med)—are both significant, with lower driver-yielding rates as those variables increase. The coefficient for posted speed limit indicates about 8.8 percent decrease in driver yielding for each 5-mph increment increase. The presence of bike lanes and additional treatments were significant, with higher driver yielding occurring for those sites with a bike lane or with additional treatments such as in-pavement warning lights or additional warning signs. The location of the crossing warning signs was significant with slightly higher driver yielding rates when the sign was located both to the right and in the median. For this dataset, the hourly traffic volume and several other variables were not statistically significant.

Per-Driver Analysis

The per-driver analysis focused on those crossings where the traffic volume for the 1-min prior to the staged pedestrian crossing was available. It also only considered the sites where the data were collected during the pandemic. For data at the 49 sites collected during the pandemic, the video for 1 of the sites was accidentally erased, so data for 48 sites were available. Table 11 lists the number of drivers considered in the analysis along with the range of hourly traffic volume per State. Each of the 5,003 drivers made a choice to yield (2,834 drivers) or not to yield (2,169 drivers).

Table 11. Number of drivers considered in per-driver analysis along with hourly traffic volume.

State	Number of Sites	Number of Drivers	Min Vehicle Volume (vehicles/h)	Max Vehicle Volume (vehicles/h)	Average Vehicle Volume (vehicles/h)
CA	36	3,519	60	667	7,920
TX	12	1,484	60	622	2,100
Both	48	5,003	60	654	7,920

Several logistic regression models were explored, and the model that included only variables with at least one level significant at the 0.05 level is provided in this report. Table 12 provides the estimates of the model coefficients.

Table 12. Logistic regression model coefficients estimated by GEE.

Variable	Level	Estimate	Standard Error	95% Confidence Limits		Z	Pr > |Z|
Intercept	–	2.0411	0.7079	0.6536	3.4286	2.88	0.0039
S:Flash	–	0.0606	0.0156	0.0300	0.0911	3.89	0.0001
M:Curb2Curb+Med	–	−0.0160	0.0051	−0.0261	−0.0059	−3.11	0.0019
MTCD:PSL	–	−0.1005	0.0265	−0.1524	−0.0485	−3.79	0.0001
S:ST	CA	0.5903	0.2571	0.0863	1.0942	2.30	0.0217
S:ST	TX	0.0000	0.0000	0.0000	0.0000	.	.
M:Bike?	2	0.5761	0.2390	0.1078	1.0445	2.41	0.0159
M:Bike?	0	0.0000	0.0000	0.0000	0.0000	.	.
MTCD:SignLoc	Right only	0.4258	0.2710	−0.1053	0.9569	1.57	0.1161
MTCD:SignLoc	Right and median	0.7034	0.3063	0.1029	1.3038	2.30	0.0217
MTCD:SignLoc	Right and left	0.0000	0.0000	0.0000	0.0000	.	.
MTCD:AddTreat	Yes	0.4678	0.2244	0.0280	0.9075	2.08	0.0371
MTCD:AddTreat	No	0.0000	0.0000	0.0000	0.0000	.	.

– = No data; . = not applicable (the value is not relevant since this level is the base for the variable).

The estimated logit (the log-odds of the probability of driver yielding) is given by the following expression (figure 9):

$$\hat{g}(\boldsymbol{x}) = 2.0411 + 0.0606 \times S{:}Flash - 0.0160 \times M_{Curb2Curb_{Med}} - 0.1005 \times MTCD{:}PSL \\ + 0.5903 \times \boldsymbol{I}[S{:}ST = CA] + 0.5761 \times \boldsymbol{I}[M_{Bike} = 2] \\ + 0.4258 \times \boldsymbol{I}[MTCD{:}SignLoc = RightOnly] \\ + 0.7034 \times \boldsymbol{I}[MTCD{:}SignLoc = Rightandmedian] \\ + 0.4678 \times \boldsymbol{I}[MTCD{:}AddTreat = Yes]$$

Figure 9. Equation. Log-odds of probability of driver-yielding from analysis.

Like the linear regression, the estimated logistic regression coefficient in figure 9 represents the expected change in the logit per unit change (for a continuous predictor such as S:Flash) or going from the base level (the level not shown in figure 9) to the specified level (for a categorical variable such as S:ST).

Note that for S:Flash, a one-unit change (i.e., an increase of length of time the beacons are flashing by 1 s) may be too small to be considered important. A change of 10 s might be more useful. Increasing S:Flash by 10 s multiplies the odds of driver yielding by $e^{(0.0606 \div 10)}$ (=1.8331). That is, the estimated odds ratio for an increase of 10 s is 1.8331, which indicates that for every increase of 10 s in S:Flash, odds of driver yielding increase 1.8 times.

When the predictor variable is dichotomous (i.e., measured at two levels), the regression coefficient (β) represents the difference in the logit, and the interpretation can be given in terms of the odds ratio (OR), reflected as OR = exp(β), the ratio of the odds for the specified level (non-base level) to the odds for the base level). The odds ratio for MTCD:AddTreat can be estimated by exp(MTCD:AddTreat) = exp(0.4678) = 1.5965, which suggests that driver yielding is 1.6 times as likely to occur where additional treatments are present comparted to the sites with no additional treatments.

When the predictor variable is polychotomous (i.e., having more than two categories), the odds ratio is given for each non-base level, using one of the categories as the base level. For example, the variable MTCD:SignLoc is coded at three levels (right only, right and median, and right and left) as shown in table 12 that right and left is currently designated as a base level (reference group). The coefficients for right only (0.4258) and right and median (0.7034) of MTCD:SignLoc represents the log of the odds ratio for each of right only and right and left. The odds ratios for MTCD:SignLoc = right only (compared to MTCD:SignLoc = right and left) is given by exp(0.4258) = 1.5308, which indicates that driver yielding is 1.5 times as likely to occur for right only sites than right and left sites. Similarly, the odds ratio for MTCD:SignLoc = right and median (compared to MTCD:SignLoc = right and left) is given by exp(0.7034) = 2.0206, which indicates that driver yielding is 2.0 times as likely to occur for right and median sites than right and left sites.

CHAPTER 5. SUMMARY AND CONCLUSIONS

SUMMARY

For this research analysis, researchers considered over 7,800 drivers involved in more than 3,675 staged pedestrian crossings. Both ANCOVA and logistic regression were used in this study. The ANCOVA considered per-site mean yield rates, while the logistic regression was able to consider the decision made by an individual driver. The nature of ANCOVA modeling permits easy and intuitive interpretation of the results. Three efforts were conducted using ANCOVA: sites available early in the project (53 sites, called "initial sites"), all sites where data had been collected by the research team within the past 3 yr (62 sites, called "all available sites"), and sites where data were collected during the pandemic (49 sites, called "pandemic sites"). Table 13 summarizes the findings from these efforts.

Table 13. Overview of significant variables in models.

Variable	Pandemic Dataset	All Dataset	Initial Dataset	Pandemic with Video Dataset
Statistical analysis approach	ANCOVA	ANCOVA	ANCOVA	Logistic
MTCD:PSL	−	−	−	−
HourVol	NS	−	−	−
MTCD:AddTreat[No]	−	−	−	Base
MTCD:AddTreat[Yes]	Base	Base	Base	+
M:Bike?[2]	Base	NS	NS	+
M:Bike?[0]	−	Base	Base	Base
MTCD:YieldBar[No]	NS	+	NS	NS
MTCD:YieldBar[Yes]	Base	Base	Base	Base
S:Flash	NS	NS	NS	+
M:Curb2Curb+Med	−	NS	NS	−
MTCD:SignLoc[Right Only]	Base	Base	Base	+
MTCD:SignLoc[Right & Median]	+	+	NS	+
MTCD:SignLoc[Right & Left]	−	−	NS	Base
Period[Pandemic]	NA	+	NS	NS
S:ST[CA]	NS	NS	NS	+
S:ST[TX]	Base	Base	Base	Base

+ or − = variable (or at least one level of the variable) was significant with + indicating a positive relationship and – indicating a negative relationship; base = variable level represents the base condition in the model; NA = variable not applicable to the dataset; NS = variable was not significant in the model.
Datasets include: Pandemic dataset = 49 sites where data were collected between fall 2020 and fall 2021; all dataset = 62 sites where data were collected between spring 2019 and fall 2021; initial dataset = 53 sites where data were collected between spring 2019 and summer 2020; pandemic with video dataset = 7,805 drivers within 48 sites where data were collected between fall 2020 and fall 2021.

There was some variation in which variables were significant from the three datasets using ANCOVA along with the dataset for the logistic regression analysis; however, in all cases, the posted speed limit was significant. For the LED-Em treatment, use on high-speed roads is clearly associated with low driver yielding rates. Table 14 provides the average driver yielding rates by posted speed limit for the sites, which, in addition to the findings from the ANCOVA and logistic regression analyses, clearly shows the trend of low driver yielding on high-speed roads.

Table 14. Per-site average driver yielding by posted speed limit and time period.

Posted Speed Limit (mph)	Pandemic (*N*)	Pandemic, Driver Yielding (percent)	Prepandemic (*N*)	Prepandemic, Driver Yielding (percent)	All (*N*)	All, Driver Yielding (percent)
25	8	78	0	NS	8	78
30	12	75	6	56	18	68
35	19	61	4	26	23	55
40	6	39	0	NS	6	39
45	4	55	1	16	5	48
50	0	NS	2	16	2	16
Grand Total	**49**	**64**	**13**	**38**	**62**	**58**

N = number of sites; NS = driver yielding not provided because there were no sites.

The various statistical approaches along with the various datasets used in the evaluation of the LED-Ems' effectiveness identified variables as being significant in the models. When using an automated stepwise variable selection procedure with ANCOVA, the HourVol variable was not significant. While HourVol had a statistically significant relationship with driver-yielding rates when included in the model by itself, it became statistically insignificant when MTCD:PSL was added to the model. When variable selection was guided by the research team, the team included the HourVol variable in the model with a negative coefficient, indicating that as the traffic volume increases, driver yielding decreases. Another variable found to be significant in some of the models was crossing distance for the pedestrian. As the crossing distance (roadway width) increases, driver yielding decreases.

CONCLUSIONS

The results of the research indicate that the LED-Em treatment is effective in certain conditions, including:

- Lower traffic volume roads.
- Lower posted speed limits roads.
- Narrower roads.
- Presence of supplemental traffic control devices, such as in-street pedestrian crossing warning signs, in-roadway lights, or additional advance crossing warning signs.

Previous research showed higher percent driver yielding on roads with lower hourly traffic volumes.[12] In a low-volume environment, drivers may be more likely to see and react to LED-Em signs and the pedestrian waiting to cross. The findings from this research confirmed that conclusion. It showed that higher posted speed limits are associated with lower driver yielding with about an 8.8-percent decrease in driver yielding for each 5-mph increase. Regarding the impact of crossing distance on driver yielding, this research showed lower driver yielding on wider roads with about a 4-percent decrease in yielding for each additional 12 ft in crossing distance. One reason for this finding is that narrower roadway width may create an environment conducive to seeing pedestrians and yielding at crossings with LED-Em signs as a result. The use of supplemental traffic control devices increased driver yielding, likely because they provide increased conspicuity of the crossing.

The length of time the LED-Em flashed was significant in the logistic regression model; however, at most of the sites, the LED-Em flashed between 20 s and 30 s. While increasing the length of time the LED-Em flashing may be associated with higher driver yielding, the researchers caution that change may not offset the lower driver yielding associated with higher speed, higher traffic volumes, or wider crossing distances. Roadways with these characteristics (e.g., higher posted speed, higher traffic volume, or wider crossing distances) may require increased attention from driver, and LED-Em flashing signs are harder to recognize and react to as part of the driver's tasks.

The presence of bike lanes on the street was associated with higher driver yielding. Having a bike lane helps to communicate to the driver the likelihood that vulnerable users may be present. Future research could investigate the street characteristics associated with communicating to drivers a pedestrian-friendly or bicyclist-friendly environment.

Research also is needed to answer the following questions:

- What is the best way to define pedestrian-friendly or bicyclist-friendly environments, and how should the impact that the environment has on driver yielding be measured? Driver operating speed is a potential measure.
- How does the number of crossing warning signs within the driver's field of vision influence driver yielding?
- How beneficial is placing the crossing warning signs on both the right and left sides of the road as a function of the road's cross section?
- What cross sections should have an overhead crossing warning sign in addition to a right-side, ground-mounted sign?

When using the per-driver data only, this research found that the length of time the LED-Em flashes was associated with higher driver yielding. To better explore the impact of flash time on driver yielding, a future study could systematically vary the flash time during the study while gathering driver yielding data for select sites. For example, an initial effort could collect data with a 30-s flash time, while an effort several days or weeks later could collect data at the same site with a 40-s flash time. This approach will hold other roadway and surrounding characteristics constant, which would result in a better likelihood of the study determining the influence of flash time on driver yielding. The study should start with identifying different approaches to establishing the flash time length for different crossing distances, including whether a median is present with or without a pedestrian pushbutton. The study could consider both LED-Ems and RRFBs.

Finally, laws regarding crosswalks continue to evolve, and future research could examine their impacts on driver yielding. The study sites included in this research were in two States, California and Texas. California law, section 21950 requires the driver of a vehicle to yield the right-of-way to a pedestrian crossing the roadway within any marked crosswalk or within any unmarked crosswalk at an intersection.[(13)] In September 2021, revisions to Texas law (Title 7, Sec. 552.003) became effective.[(14)] It requires drivers to come to a full stop for pedestrians or cyclists who are properly in an intersection. Before the new law, drivers were required to yield to pedestrians, but not required to come to a full stop. Across the country, laws vary along with their requirements such as basing the required driver behavior on where the pedestrian is located within the roadway (e.g., within an adjacent lane or on the other half of the roadway). With the increased focus on pedestrian safety, uniform laws across the country, as well as uniform traffic control devices, will all play a role in improving safety.

REFERENCES

1. Federal Highway Administration. 2009. *Manual on Uniform Traffic Control Devices*. Washington, DC: Federal Highway Administration. http://mutcd.fhwa.dot.gov/pdfs/2009r1r2/pdf_index.htm, last accessed June 30, 2019.

2. Hawkins, N., and B. A. Bektas. 2012. *Evaluating the Effectiveness of the City of Des Moines LED and RRFB Pedestrian Crossing Treatments on Multi-Lane Roadways*. Report No. Intrans 10-387. Ames, IA: Iowa Department of Transportation.

3. Ellis, W., and J. P. Tremblay. 2014. *Evaluation of BlinkerSign® Crosswalk Lighting System*. Report No. 2014-13. Barre, VT: State of Vermont Agency of Transportation.

4. Hourdos, J. 2018. *Assessing the Impact of Pedestrian-Activated Crossing Systems.* Report No. CTS 2016031. Saint Paul, MN: Minnesota Department of Transportation.

5. Finley, M. D., K. Fitzpatrick, E. Rista, M. A. Brewer, R. Avelar, A. Pike, T. P. Barrette, and S. Datta. 2020. *Traffic Control Device Analysis, Testing, and Evaluation Program: FY2019 Activities*. Report No. FHWA/TX-19/0-6969-R2. Austin, TX: Texas Department of Transportation.

6. Rista E., and K. Fitzpatrick. 2020. "Comparison of LED-Embedded Pedestrian Crossing Signs to RRFBs and PHBs." *Transportation Research Record: Journal of the Transportation Research Board* 2674, no. 11: 856−866.

7. Finley, M. D., A. M. Pike, K. Fitzpatrick, E. S. Park, L. Theiss, M. P. Pratt, N. Chaudhary, S. Sunkari, N. Wood, and S. Datta. 2021. *Traffic Control Device Analysis, Testing, and Evaluation Program FY2020 Activities*. Report No. FHWA/TX-20/0-6969-R3. Austin, TX: Texas Department of Transportation.

8. Fitzpatrick, K., and E. S. Park. 2021. "Nighttime Effectiveness of the Pedestrian Hybrid Beacon, Rectangular Rapid Flashing Beacon, and LED-Embedded Crossing Sign." *Journal of Safety Research* 79: 273–286.

9. Fitzpatrick K., V. Iragavarapu, M. Brewer, D. Lord, J. Hudson, R. Avelar, and J. Robertson. 2013. *Characteristics of Texas Pedestrian Crashes and Evaluation of Driver Yielding at Pedestrian Treatments*. Report No. FHWA/TX-14/0-6702-1. Austin, TX: Texas Department of Transportation.

10. Fitzpatrick, K., M. Brewer, R. Avelar, and T. Lindheimer. 2016. *Will You Stop for Me? Roadway Design and Traffic Control Device Influences on Drivers Yielding to Pedestrians in a Crosswalk with a Rectangular Rapid-Flashing Beacon*. Report No. TTI-CTS-0010. College Station, TX: Texas A&M Transportation Institute.

11. Spiegelman, C. H., E. S. Park, and L. R. Rilett. *Transportation Statistics and Microsimulation*. Boca Raton, FL: CRC Press, 2010.

12. Fitzpatrick, K, E. S. Park, and N. Johnson. 2022. "A Multistate Analysis Investigating Roadway Characteristics that Affect Driver Yielding at LED-Embedded Pedestrian- and School-Crossing Signs." *Transportation Research Record* 2676 no. 8: 1–10. https://doi.org/10.1177/03611981221085513, last accessed March 2022.

13. California Legislative Information. 2022. Accessed from: https://leginfo.legislature.ca.gov/faces/codes_displaySection.xhtml?sectionNum=21950.&lawCode=VEH, last accessed February 2023.

14. Texas Transportation Code. 2019. Accessed from: https://statutes.capitol.texas.gov/Docs/TN/htm/TN.552.htm, last accessed February 2023.

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