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

Final Report

by

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16. Abstract

The rectangular rapid-flashing beacon (RRFB) is a relatively recent pedestrian crossing treatment that has shown great potential in improving driver yielding to pedestrians compared to more traditional treatments that also use yellow beacons. Though observed results from RRFB treatments have been generally promising, results from several studies showed widely varying yielding rates (19 to 98 percent), indicating that there are variables other than RRFBs that have an effect on driver yielding. In this project, researchers combined data from previous Texas Department of Transportation and Federal Highway Administration projects to create a larger dataset that would be better suited to identify characteristics related to driver yielding. Funding from Texas A&M Transportation Institute Center for Transportation Safety (TTI CTS) permitted both the collection of additional field data that were added to the dataset and the analysis of that dataset to identify variables associated with driver yielding. Results from statistical analysis of staged pedestrian crossings at the 128 site-periods indicated that intersection configuration, presence of median refuge, crossing distance, approach of the crossing, and direction of vehicle travel (i.e., one-way or two-way) were statistically significant. A subset of the data was analyzed when one-minute volume counts were available near the time of the pedestrian crossing. Variables that had at least one level shown as significant included the one-minute count of vehicles per lane, intersection configuration, posted speed limit, presence of advance yield or stop signs, presence of transit stop within 200 ft, presence of a school within 0.5 mi, legend on the sign face, location of beacons (e.g., overhead or roadside), near or far side of the approach, and crossing distance.

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CHAPTER 1. INTRODUCTION

BACKGROUND

The rectangular rapid-flashing beacon (RRFB) is a pedestrian treatment that has received national attention in recent years because it has noteworthy characteristics that produce improved vehicle stopping and yielding behavior to pedestrians as compared to other pedestrian treatments that also use yellow beacons. Characteristics that result in the higher yielding are believed to include having brighter indications, employing unique beacon arrangement and flash patterns, and being active only when a pedestrian is present. Figure 1 shows an example of an RRFB installation.

Source: Kay Fitzpatrick

Figure 1. Example of RRFBs

The Federal Highway Administration (FHWA) provided interim approval (IA-11) for the optional use of RRFBs at uncontrolled pedestrian and school crosswalks on July 16, 2008 (*1*), but research still continues on the features of RRFBs that produce the best results for driver yielding to crossing pedestrians. The Signals Technical Committee (STC) of the National Committee on Uniform Traffic Control Devices (NCUTCD) assists in developing language for Chapter 4 of the *Manual on Uniform Traffic Control Devices* (MUTCD) (*2*). The STC is particularly interested in research and/or assistance in developing or refining material on the RRFB treatment, which is being considered for the next edition of the MUTCD. This interest led to FHWA-sponsored research projects to study characteristics such as beacon shape, placement, and flash pattern for optimal performance (*3*, *4*).

Results from several studies showed widely varying yielding rates, indicating that there are variables other than the presence of RRFBs that have an effect on driver yielding. Table 1

summarizes the driver yielding values for studies conducted between 2010 and 2014, while Table 2 summarizes the results from a California study that compared yielding results for RRFBs and circular rapid-flashing beacons (CRFBs). Table 3 presents the results for recent FHWA studies. While research has identified several variables as being associated with driver yielding, the variables are not consistent between studies and do not explain the large range of yielding rates observed. As listed in Table 1 through Table 3, previous research has identified driver yielding rates ranging from a low of 19 percent to a high of 98 percent.

Table 1. Overview of driver yielding to RRFBs from studies conducted between 2010 and 2014 that included data for before RRFB installation

Study	**Sites**	**Driver Yielding[a]**	**Unique Characteristics of Study**
2010 FHWA (*5*)	22 (most in St. Petersburg, Florida)	Before: average of 4% (staged)[b] After: 72 to 96% (staged)	Original study that included data for multiple years.
2009 FHWA (*6*)	2 (Miami, Florida)	Before: 4% day, 2 to 4% night (staged) After: 55 to 60% day, 66 to 70% night (staged)	Day and night.
2009 Florida (*7*)	1 (St. Petersburg)	Before: 2% overall After: 35% overall, 54% activated[c]	Trail crossing.
2011 Texas (*8*)	1 (Garland, Texas)	Before: < 1% (staged) After: 80% (staged)	School, overhead.
2011 Oregon (*9*)	3 (Bend, Oregon)	Before: 6 to 25% (staged) After: 74 to 83% (staged)	2 of the 3 sites had 45 mph posted speed limit.
2013 Calgary (*10*)	6 (Calgary, Alberta, Canada)	Before: 83% (staged) After: 98% (staged)	Type of before treatment not provided.
2014 Michigan (*11*)	1 (South Lyon Township, Michigan)	Before: 20% (staged) After: 69% (staged)	Comparison with gateway in-street signs (80%) and combination of gateway and RRFB (85%).
2014 Texas (*12, 13*)	22 (most in Garland, Texas)	Before: < 1% to 28% (staged) After: 37 to 89% (staged)	Significant variables: city, posted speed limit, crossing distance, one/two way.

[a] Range provided shows the average driver yielding for the sites included in the study as reported by the authors. Results are shown for yielding rates before the RRFB was installed (existing treatment not always known) and after the RRFB was installed. See reference for details regarding study methodology and whether the findings are significant.
[b] Staged pedestrian protocol was used to collect the data, which included always activating the device.
[c] Findings reported for when the device was activated (i.e., pedestrian pushed the pushbutton).

Table 2. Overview of driver yielding to RRFBs from California study

Study	Sites	Driver Yielding[a]				Unique Characteristics of Study
		Shape	**Light**	**Activated[b, c]**	**Not Activated**	
2013 California (*14*)	2 (Santa Monica)	RRFB	Day	80–85 %	58–73 %	2 sites where the RRFB and CRFB were alternately used. Data available for dusk and for a third observation period where back plates were changed.
		CRFB	Day	63–92 %	57–83 %	
		RRFB	Night	80–95 %	35–60 %	
		CRFB	Night	65–90 %	35–80 %	

[a] Range provided shows the average driver yielding for the sites included in the study as reported by the authors. See reference for details regarding study methodology and whether the findings are significant.
[b] Staged pedestrian protocol was used to collect the data, which included always activating the device.
[c] Findings reported for when the device was activated (i.e., pedestrian pushed the pushbutton).

Table 3. Overview of driver yielding to RRFBs from studies conducted in 2015 and 2016

Study	Sites	Driver Yielding[a]	Unique Characteristics of Study
2015 FHWA Circular versus Rectangular (*3*, *15*)	12 (Texas, Arizona, Wisconsin)	Daytime average of 59% (RRFB) and 67% (CRFB)—not statistically different (staged)[b] Nighttime average of 72% (RRFB) and 69% (CRFB)—not statistically different (staged) 22 to 98%, daytime per site average for RRFBs (staged)	Compared beacon shape (circular and rectangular). Study identified brightness of beacon as being influential on yielding behavior at night.
2015 FHWA (*16*)	12 (Texas, Arizona, Wisconsin)	When a beacon—whether rectangular or circular—is activated, a driver is 3.68 times more likely to yield to pedestrians than when it is not activated	Used same 12 sites as circular versus rectangular study. Included both staged and general population pedestrians.
2016 FHWA Flash Pattern (*4*, *17*)	8 (most in Garland, Texas)	61 to 89% (staged, daytime, 2-5 pattern)	Study examined three flash patterns and found no significant difference between tested patterns.
2016 FHWA Above-Below (*4*, *18*)	13 (Colorado, Arizona, Illinois, Texas)	Daytime average of 64% (above) and 61% (below)—not statistically different (staged) Nighttime average of 68% (above) and 65% (below)—not statistically different (staged) Daytime per site average for RRFBs located below sign: 19 to 98% (staged)	Study compared above-sign to below-sign beacon locations and found no significant difference between beacon placements (above or below sign).

[a] Range provided shows the average driver yielding for the sites included in the study as reported by the authors. See reference for details regarding study methodology and whether the findings are significant.
[b] Staged pedestrian protocol was used to collect the data, which included always activating the device.

A larger dataset may provide the opportunity to identify the characteristics present at a pedestrian marked crosswalk that are associated with high driver yielding or low driver yielding. Funding from the Texas A&M Transportation Institute Center for Transportation Safety (TTI CTS) permitted the collection of additional field data that could be added to existing data collected as part of recent Texas Department of Transportation (TxDOT) and FHWA projects.

Because driver yielding data were available from several recent studies, the research team combined those datasets and collected additional data as part of this TTI CTS project to expand the range of variables available. The existing sources of the driver yielding data are:

- **TxDOT.** TxDOT study (*12, 13*) that collected data at 22 sites, with most being in Garland, Texas.
- **Above-Below (A/B).** FHWA study (*4, 18*) that examined the placement of the rectangular beacons above or below the crossing warning sign at 13 sites in Arizona, Colorado, Illinois, and Texas.
- **Circular versus Rectangular (CvR).** FHWA study (*3, 15*) that examined the shape of the rapid-flashing beacons at 12 sites located in Arizona, Texas, and Wisconsin.
- **Flash Pattern (FP).** FHWA study (*4, 17*) that examined three flash patterns at eight sites, with most being in Garland, Texas.
- **TTI CTS**. Data gathered at 25 sites as part of this study during the summer of 2015.

STUDY OBJECTIVE

The objectives of this project were to identify variables that are associated with driver yielding at rectangular rapid-flashing beacons and to identify why some sites have very low yielding while others have very high yielding.

CHAPTER 2. LITERATURE REVIEW

Previous FHWA studies (*3*, *4*) contain comprehensive literature reviews of several pedestrian treatments being used at unsignalized pedestrian crossings. Readers are encouraged to review those reports if a review of pedestrian treatment literature is sought. This chapter provides background on the RRFB treatment and a review of recent literature that is relevant to the efforts within this project.

PREVIOUS RESEARCH ON THE RECTANGULAR RAPID-FLASHING BEACON

Rectangular rapid-flashing beacons flash in an eye-catching sequence to draw drivers' attention to the sign and the need to yield to a waiting pedestrian. They may be located on the side of the road below pedestrian crosswalk or school crossing signs or on a mast overhead with a sign. RRFB devices can be activated by a pedestrian either actively (pushing a button) or passively (detected by sensors). Several studies have examined the effectiveness of the device or elements contained within the device. All of the studies that used a before-to-after design (before indicating either no flashing beacon or continuously flashing beacon treatment, and after indicating RRFB installed) found an improvement in driver yielding after the RRFBs were installed. Table 1 summarizes the characteristics of these studies, which include the following: an FHWA study in the early 2000s that included 22 sites (*5*); a 2009 FHWA study that considered two sites in Miami, Florida (*6*); a 2009 study (*7*) that reported on an uncontrolled trail crossing of a four-lane urban street in St. Petersburg, Florida; a 2011 study (*8*) that considered an uncontrolled crossing in Garland, Texas; a 2011 Oregon DOT study (*9*) that examined three crosswalks in Bend, Oregon; a 2013 pilot project in Calgary, Canada, that included one site (*10*); and a 2014 Michigan study that examined a bike trail crossing (*11*).

Other studies focused on examining how different features of the rapid-flashing beacons affect driver yielding. A study of two sites in Santa Monica, California (*14*), compared the effect of an RRFB and CRFB assembly on yielding behavior at two crossings (see Table 2). The RRFB was installed at one site and the CRFB at the other, and after an evaluation period, they were switched and evaluated again. The study evaluated driver yielding rates both when the beacons were actuated and when they were not actuated. In all cases, driver yielding rates were higher when the beacons were activated.

FHWA sponsored two projects to assist in the investigation of questions concerning the RRFB. Details on those studies are available in FHWA reports (*3*, *15*, *17*, *18*, *19*). Summaries of the research efforts for the data being incorporated into this analysis from the FHWA projects and from a TxDOT project are provided in the following sections.

CIRCULAR OR RECTANGULAR BEACON SHAPE

To investigate whether beacons should be rectangular or circular, an open-road study was conducted at 12 pedestrian crossing sites in four cities (Austin, Texas; College Station, Texas; Flagstaff, Arizona; and Milwaukee, Wisconsin) between November 2012 and April 2014 (*3*, *15*). Both cities had two to five locations where they were willing to switch between the RRFB and

CRFB at each site. This enabled the research team to evaluate both devices at the same site and, therefore, have similar pedestrian and driver populations when comparing devices.

Researchers used a staged pedestrian protocol to collect driver yielding data to ensure that oncoming drivers received a consistent presentation of approaching pedestrians. Each staged pedestrian wore similar clothing (gray t-shirt, blue jeans, and gray tennis shoes) and followed specific instructions for crossing the roadway. The staged pedestrian was accompanied by a second researcher, who observed and recorded the yielding data from a concealed position. Typically, a minimum of 60 staged pedestrian crossings were obtained at each site during daytime conditions.

Driver yielding to staged pedestrians at sites with either the RRFB or CRFB ranged from a low of 22 percent to a high of 98 percent. Daytime average driver yielding to staged pedestrians was 59 percent for the RRFB and 63 percent for the CRFB, indicating only minor, if any, differences between the CRFB and the RRFB. Results from a detailed statistical analysis also indicated that there were no significant differences between the two beacon shapes.

In conclusion, the shape of the yellow rapid-flashing beacon does not have a significant impact on whether a driver decides to yield to pedestrians. Because no difference was found and because there was a lack of other research supporting the use of one shape over the other, and due to the number of pedestrian treatment assemblies already installed with a rectangular shape and the desire for consistency in appearance, FHWA decided to not allow the option of using a circular shape. The existing interpretations require a rectangular shape.

BEACON PLACEMENT (ABOVE/BELOW)

Building on the results of a closed-course study (*4*, *19*), researchers conducted an open-road study (*4*, *18*) using a staged pedestrian protocol. Researchers collected driver yielding data at 13 sites in four locations: Aurora, Illinois; Douglas County, Colorado; Marshall, Texas; and Phoenix, Arizona. Data collection occurred between October 2014 and May 2015, with two data collection periods at each site: one with beacons below the sign and one with beacons above the sign. Statistical analysis of the data showed no statistically significant differences in yielding between the two beacon locations; average daytime yielding for staged pedestrians was 64 percent above the sign and 61 percent below the sign. Given that the location of the beacons does not have an impact on driver yielding, and because a positive effect on detection time and glare provided by the RRFB position above the sign was demonstrated in the closed-course study, FHWA has prepared an official interpretation (*20*) that will allow agencies to install the beacons above the sign.

RAPID-FLASHING PATTERNS

An open-road study format (*4*, *17*) was also used to examine different flash patterns for RRFBs. The study included eight sites located in College Station and Garland, Texas. Seven of the eight sites had four lanes with a posted speed limit of 40 or 45 mph. The remaining site had two lanes and a posted speed limit of 30 mph.

A temporary light bar and controller were developed to give the research team control over several of the beacon characteristics, including flash pattern and intensity. The light bar was designed so that it was not obvious that the temporary beacons were any different from the permanent RRFB light bar to which they were mounted. The following three flash patterns were selected for testing in the field using the temporary light bars:

- A proposed pattern using a combination of long and short flashes (called Blocks).
- A proposed pattern using a combination of wig-wag and simultaneous flashes (called WW+S).
- The pattern that was specified in FHWA's original interim approval (called 2-5).

The research team used the staged pedestrian protocol to evaluate driver yielding for the different patterns. Data were collected for a minimum of 40 crossings for each pattern at each site during February and March 2014. The intensity of the flashing beacons was the same for all three flash patterns and for all eight sites. Researchers used logistic regression to model the yielding and not-yielding data for each individual crossing. The results indicate that there is no significant difference between the 2-5 pattern and the WW+S pattern or between the 2-5 pattern and the Blocks pattern. To provide context for the yielding results, the overall average driver yielding for each pattern at the eight sites was also calculated. The overall average driver yielding was 80 percent for the WW+S and Blocks patterns and 78 percent for the 2-5 pattern. Thus, the WW+S and Block patterns developed as part of this research study were equally as effective as the 2-5 pattern. Key characteristics of the WW+S pattern, namely its greater percentage of dark time and lower amount of total on time, led FHWA to favor the WW+S flash pattern and include it as an option for existing or new RRFBs in a 2014 interpretation (*21*).

TXDOT STUDY

In the TxDOT project (*12, 13*), driver yielding to staged pedestrian crossings at 22 RRFB sites were collected, and the average driver yielding rate was 86 percent. The Texas RRFB yielding results were slightly higher than results from other studies, perhaps because all of the RRFB sites included in the analysis had school crossing signs and were located near a school. The number of devices within a city may have had an impact on driver yielding. Cities with a greater number of RRFBs had higher driver yielding rates compared to cities where the device was used at only a few crossings. Comparing the number of days since installation revealed statistically significant higher driver yielding rates for those devices that had been installed longer. The data revealed a trend of lower driver yielding rates for wider crossing distances, which strongly suggests that there is a crossing distance width where a device other than the RRFB should be considered. As part of this study, researchers conducted a before-and-after field comparison at four RRFB sites to identify the changes in driver yielding and selected pedestrian behaviors resulting from installing these treatments at previously untreated crosswalks. The installations resulted in noticeable improvement in the number of yielding vehicles.

PRACTITIONERS' PERSPECTIVES OF DRIVER YIELDING BEHAVIOR

A 2013 online survey gathered practitioners' perceptions of driver yielding behavior in cities throughout North America (*22*). Responses were received from 387 practitioners in 171 cities. The authors reviewed and created categories for the answers to the following open-ended questions: Why do you think that drivers in your community exhibit this yielding behavior? Do

you think any local, state, or federal policies have influenced yielding behavior, either directly or indirectly? Table 4 summarizes the number of respondents by factor group.

Table 4. Influences on a driver's decision to yield to a pedestrian—number of respondents per category, identified from an online survey (compiled from *22*)

Number of Respondents	Category
142	Driver behavior norms
123	Urban design and roadway design
105	Enforcement of laws
101	Education about laws
55	Land use and pedestrian volume
42	Vehicle speed
27	Pedestrian behavior norms
21	Social fabric and socio-demographic characteristics
Fewer than 20	Vehicle volume
Fewer than 20	Driver alertness/distraction
Fewer than 20	Pedestrian visibility

The majority of the participants felt that behavior norms influence how individual drivers and pedestrians behave at specific crosswalk locations. Behavior norms are the typical behaviors exhibited by drivers and pedestrians throughout the community. Examples of behavioral norms provided by respondents included assertive and passive pedestrians who may be communicating an expectation of yielding or not yielding, respectively. One of the participants stated, "Minnesota 'nice' has something to do with it, I believe. I have worked and lived in Boston and New York and the rate of stopping for pedestrians seems much higher in Minnesota."

The category with the second highest frequency of responses was urban design and roadway design. Examples of features associated with the design mentioned by the respondents included traffic control devices (e.g., crosswalk markings), curb-to-curb width, number of lanes, curb extensions, traffic calming features, vehicle speed, building setback, and presence and size of street trees.

About a third of the respondents believed that enforcement and education levels could influence the rate of driver yielding. Fewer respondents indicated that land use, pedestrian volume, and vehicle speed influence driver yielding decisions.

The authors (*22*) developed a map to show the perceived driver yielding rates in North American cities for two-lane roads with 25 to 30 mph speeds as provided by the online respondents. The data represent the median value selected by professionals with pedestrian safety experience in each city. The locations with the higher assumed yielding were located on the coasts, both west (e.g., Seattle and San Jose) and east (e.g., Philadelphia). None of the cities in the central part of North America had a perceived yielding rate where drivers wilyield to a pedestrian better than "about half the time."

CHAPTER 3. STUDY METHODOLOGY

SELECTION OF VARIABLES

Potential Variables

As noted in the previous chapter, several variables can influence a driver's decision to yield to a crossing pedestrian. An obvious example is whether the region is more oriented toward pedestrians, either in that it has a large and active public transportation system, is a tourist destination, is in a downtown or residential area, or is in a community where members feel connected. Drivers' attitudes toward the function of the roadway in terms of whether it is primarily for cars or primarily for pedestrians could also be influential. These types of attitudes or social norms are difficult to quantify.

Other influential variables that are more easily quantified could be vehicle volume, pedestrian volume, crossing distance (or number of lanes), and operating speed on the roadway. Where the pedestrian crosswalk is located with respect to a school or major pedestrian generator (e.g., park or hospital) may also affect a driver's decision. Driver yielding may be more influenced by the vehicle and pedestrian volume near the time of the actual crossing; however, daily counts could also reflect how a driver may perceive the pedestrian crossing site.

Previous Open-Road Findings

Previous open-road studies found select variables as being significant predictors of driver yielding at an RRFB; however, the studies did not always find the same variables significant. The number of sites within a study can limit the range of values for a given variable, which would affect whether that variable would be found significant. Following is a summary of the variables that were found to be significant in recent RRFB studies:

- **TxDOT.** In the TxDOT study (*12, 13*), significant variables were city, posted speed limit, crossing distance, and one-way/two-way traffic. Unexpectedly, higher compliance was found with higher speed limits. A closer review of the 35- and 40-mph sites revealed that yielding was only 1 percentage point higher for the 40-mph sites as compared to the 35-mph sites. Thus, while there may have been a statistically significant increase in driver yielding by speed limit, the authors considered the difference to be not of practical significance.
- **A/B.** In the FHWA A/B study (*4, 18*), significant variables were natural light conditions (day or night), posted speed limit, state, and intersection configuration. The model indicated that the driver yielding at the midblock offset configuration is statistically different from the driver yielding at three-leg intersections. A caution with this finding was offered since there was only one site with a midblock offset configuration in the dataset. Most of the sites for this study had either 30- or 35-mph posted speed limits. Three of the Colorado sites had a unique series of signs in advance of the crossing (see example in Figure 2). The series started with a Pedestrian Crossing (W11-2) warning sign with an AHEAD (W16-9P) plaque. Next was a SPEED LIMIT 25 (R2-1) regulatory sign with a WHEN FLASHING (S4-4P)

plaque and a 12-inch circular beacon. The beacon flashes when the RRFBs at the crossing are activated (see example shown in Figure 2). At the crossing on the roadside is the RRFB with the Pedestrian Crossing (W11-2) warning sign and diagonal downward pointing arrow (W16-7P) plaque. Also at the crossing and in the median are the STATE LAW YIELD TO (pedestrian symbol) WITHIN CROSSWALK (R1-6) sign and RRFB. Within the data analysis, these sites were considered to have a posted speed limit of 22 mph to distinguish them from other sites with traditional speed limits.

Source: Kay Fitzpatrick

Figure 2. Example of speed limit sign assembly used at three sites in Colorado

- **CvR.** In the FHWA CvR study (*3, 15*), significant variables were natural light conditions (day or night) and city. When focusing on the data where beacon intensity (also known as brightness) was available, the significant variables were natural light conditions (day or night), intensity, and city. A separate analysis (*16*) also examined both staged and nonstaged pedestrians and found beacon activation along with city as being significant. While one-minute vehicle counts were considered, the model showed that percent yielding decreased as volume increased, but that relationship was not statistically significant.
- **FP.** In the FHWA FP study (*4, 17*), several variables were examined during the analysis of flash patterns; however, none of the roadway characteristic variables were found to be significant. Limited ranges were present for posted speed limit values (40 mph for six of the eight sites), crossing distance (most sites were four lanes), and location (most were in one city). To maximize the opportunity to find potential differences in driver yielding due to the flash pattern, the selection of study sites focused on minimizing the variability in variables that were suspected to affect driver yielding. The comparison between two types of equipment (i.e., the equipment that

the city installed and the equipment the research team installed) did reveal a significant difference for city and equipment. Therefore, the characteristics of the city and the characteristics of the beacons other than the flash pattern influenced driver yielding; for example, characteristics that were not measured, perhaps brightness, possibly influenced a driver's decision to yield or not yield.

Selection of Variables for this Study

Based upon the previous findings, the following variables were a priority: intersection configuration, number of lanes (and distance) being crossed, posted speed limit, and whether the traffic was one-way or two-way. Because of the challenges with identifying which variables may be influential and the associated costs with gathering the needed data for those variables, this study focused on variables that could be modified by a transportation agency, such as crossing distance, or that reflected the location within the region for the crosswalk, such as city or state. Several other variables were desired, for example, typical number of pedestrians that use the crosswalk. To gather that data, however, would have required collecting data for a longer period at each site, which would have resulted in fewer study sites. The research team encourages consideration of pedestrian volume in future studies.

Table 5 and Table 6 provide the list of variables considered for the analysis. These tables also provide comments on whether the variable was modified during the study to better consider the site characteristics in the evaluation. The variables associated with the region, with a nearby school, or specific to the approach considered in this study are listed in Table 5. Table 6 lists the major street-related variables collected and considered in this analysis.

Several other variables were considered and explored to try to better describe the characteristics of the site; however, they were not included in the analysis. These variables included the following:

- Crime rate (for city or region within city).
- Population density.
- Number of RRFBs in the region.
- Age of the device (i.e., time between when it was installed and when the crossing data were collected).

Crime rate and population density were not considered in the analysis because of the limited range in values. The research team could not reliably obtain the number of RRFBs in the region or the date each RRFB was installed for all the sites, so those variables were also not considered in the analysis. Future research efforts may want to consider these variables.

Table 5. Potential region, approach, or school variables for analysis

Variable Name	Variable	Description
State	State	State (two-letter code for Arizona, Colorado, Illinois, North Carolina, Texas, Washington, or Wisconsin).
City	City	City (two-letter code for Flagstaff, Arizona; Phoenix, Arizona; Douglas County, Colorado; Aurora, Illinois; Chapel Hill, North Carolina; Cary, North Carolina; Davidson, North Carolina; Fayetteville, North Carolina; Indian Trail, North Carolina; Morrisville, North Carolina; Austin, Texas; College Station, Texas; Frisco, Texas; Garland, Texas; Marshall, Texas; Waco, Texas; Federal Way, Washington; Kirkland, Washington; Milwaukee, Wisconsin).
Site	Site Identification	Unique site identification that consists of two-number code for the site within the state and city.
Period	Period Identification	For some sites, data were collected during different periods in accordance to the study design used for that project. This variable combined the site identification with the period number.
Site-Period	Unique Site-Period Identifier	Unique site-period identifier that consists of two-letter code for state, two-letter code for city, two-number code for the site within the state and city, and one-number code for the period.
Source	Source of Data	Source of the driver yielding data (A/B, CvR, FP, TxDOT, TTI CTS).
A:CD	Crossing Distance	Approach variable. Crossing distance (in ft) for the far side or near side approach (near and far is a function of which side of the street the pedestrian crossing begins).
A:Near_Far	Near or Far Crossing	Approach variable. Identifies if the "A:" data are for the near approach or the far approach.
A:Num Lanes (per dir)	Number of Lanes per Direction	Approach variable. Maximum number of lanes for the approach to the crossing.
A:Stil_Acc	Is Vehicle Still Accelerating?	Approach variable. Provides an appreciation of whether the research team believes drivers may still be accelerating for the approach (yes = less than or equal to 250 ft, no > 250 ft).
A:Vol (1 min/ lane)	One-Min Volume	Approach variable. Number of vehicles per lane for one minute nearest pedestrian crossing. Data only available for a subset of the crossings.
I:Bea_RS_OV	Beacon Location at Crossing	Placement of RRFB (Rt_Only = right side only, both = both right and left sides, B+Ov_Be = both sides plus overhead beacons, B+Ov_NB = both sides plus overhead sign with no beacons).
I:Config	Intersection Configuration	Intersection configuration (number of legs).
S:ST	School Type	School variable. What is the type of school? (EM = elementary or middle, HS = high school, Un = university, or none)
Sch_w/.5	Distance between Crosswalk and School	School variable. Is a school within ½ mile? (yes or no)

Table 6. Potential major street variables for analysis

Variable Name	Variable	Description
M:Ad_Line	Advance Line	Are advance stop or yield lines present at the crosswalk? (no, yes = w/sign or wo/sign)
M:ADT	Average Daily Traffic	Average daily traffic for the major street near the crosswalk.
M:ADT/LN	Average Daily Traffic/Lane	Average daily traffic for the major street divided by the number of through lanes near the crosswalk.
M:Adv_War	Advance Warning	Type of advance warning present on approach to crosswalk (no_adv = no advance warning, nonflash = warning sign with no flashing beacon, flash = speed limit with beacons activated when RRFB is activated).
M:CroDis	Crossing Distance	Total crossing distance for the pedestrian crossing the major street (ft).
M:Dis_Trans	Distance to Transit Stop	Distance between the crosswalk and the nearest transit stop, later refined to two categories—either within 200 ft or more than 200 ft.
M:MT	Median Type	Median type for the major street at the crosswalk (flush, none, raised, Sh_Ref_Is = short refuge island, TWLTL = two-way left-turn lane).
M:O_T	One Way or Two Way	Does the major street have one-way traffic or two-way traffic?
M:PSL	Posted Speed Limit	Posted speed limit on the major street (mph).
M:Refuge	Refuge	Is there pedestrian refuge available on the major street? (no = flush, none, or TWLTL; yes = raised or Sh_Ref_Is)
M:Sign_Face	Sign Face	Face of the crossing warning sign (either pedestrian, bike.B&P [for bicycle or bicycle and pedestrian], or school).
M:Sup_Sign	Supplemental Signing	Is a supplemental yielding sign present at crosswalk? (yes or no)
M:Trail	Trail Present	Does a trail cross the major road? (yes or no)

Variable Refinements

A driver may be more likely to yield if the crossing communicates that pedestrians should be expected. Having several pedestrian-related traffic control devices can help to communicate the presence of the pedestrian crossing, for example, advance warning signs and advance stop or yield lines, perhaps supplemented with overhead signs or roadside signs at the crossing with or without beacons. Therefore, details of the pedestrian-related traffic control devices present prior to and at the crossing were also gathered for all sites. The type of crossing warning sign—either pedestrian, school, or bicycle related—was also identified.

The presence of a pedestrian refuge in the center of the road could also communicate the potential presence of pedestrians, so details about the median treatment were collected. The width of the median and the type of median were identified. Median types included none when it was a one-way street or flush when the separation between the two directions of travel was just centerline markings. If a two-way left-turn lane (TWLTL) was present at the crossing, the median was classified as being TWLTL. In some locations, a median refuge island was created just at the crossing (see example in Figure 3), and these sites were classified as having a short

refuge island. When a raised median was present on the approach and at the crosswalk, the median was classified as being raised. Based on preliminary evaluations, a new variable was created to identify when a refuge in the median was provided for pedestrians. Those sites with either a raised median or a short median island were categorized as having a refuge. The sites with flush (or no) medians or a TWLTL were categorized as not having a refuge present.

Source: Marcus Brewer

Figure 3. Example of short median refuge island at site NC-CH-05

The distance to the nearest transit stop was measured because transit could be an indication of high pedestrian activity. Because some of the distances were in excess of 1 mi, this variable was refined to reflect whether a transit stop was within 200 ft of the crosswalk. The presence of a school could also communicate that pedestrians might be present, so the distance between the crosswalk and the school along with the type of school (elementary, middle, high, or college) was noted. Again, because of the large range of distances present, this variable was modified to whether the school was within 0.5 mi.

The distance between the pedestrian crosswalk and the nearby signalized intersection could influence whether a driver is more (or less) likely to stop. The distance to the nearest signalized intersection or stop sign on the major street was measured for each approach. When drivers are

still accelerating away from a signal or stop, they might be less willing to stop. This variable was refined to be whether a signal or stop sign was within 250 ft.

Vehicle volume, either daily or within a few minutes of the pedestrian crossing the street, and daily or hourly pedestrian volume are of high value for this type of analysis. Unfortunately, pedestrian counts are rare and, if obtained as part of a research project, would limit the number of sites that could be included in the study. Therefore, the research team focused on gathering daily vehicle volume, typically provided by the city, and vehicle volume during the minute prior to the pedestrian crossing, from a video recording done at the site.

STUDY SITE IDENTIFICATION

Sites from Previous Studies

Data from previous FHWA and TxDOT studies were available for this research effort, but to increase the likelihood of identifying underlying relationships, additional data were needed. Supplemental funding from the TTI CTS provided the opportunity to collect additional data.

Additional Sites: Outreach to Specific Colleagues

Because the research team has experience with testing pedestrian-related traffic control devices on previous projects, researchers have established connections with practitioners who have expressed interest in being a part of upcoming research efforts. For this project, researchers contacted a number of these practitioners to ask whether they had existing RRFB sites and whether they would be willing to facilitate the team's data collection by helping to coordinate efforts with local law enforcement and other stakeholders as needed. Some practitioners were in attendance at a presentation made by the research team to the NCUTCD in June 2015, which included a request for site information. Other practitioners have participated in previous research projects as peer reviewers, panel members, or interested third parties.

Through this focused effort, the research team received responses from 20 cities across the country. Many cities in Washington contacted the research team as a result of an initial request for sites through a listserv for traffic engineers in the state of Washington. The cities responding to the focused outreach are listed in Table 7.

Additional Sites: Outreach to Institute of Transportation Engineers (ITE) Traffic Engineering Community

In addition to the focused contacts with practitioners, the research team wanted to broadcast the request for sites to a wider audience, so an announcement of the research project and the need for sites was posted to the ITE Traffic Engineering Community listserv. The announcement, which was posted on July 7, 2015, generated responses from an additional 45 jurisdictions across the country, representing roughly 130 existing or planned RRFB installations (see Table 7).

Table 7. Cities responding to outreach

Cities Responding to Focused Outreach	Cities Responding to Outreach to ITE Traffic Engineering Community	
• Alexandria, VA	• Albany, NY	• Lakewood, CO
• Des Moines, WA	• Ann Arbor, MI	• Larkspur, CA
• Edmonds, WA	• Atlanta, GA	• Loudoun County, VA
• Everett, WA	• Atlantic County, NJ	• Loudonville, NY
• Federal Way, WA	• Brookhaven, NY	• Maggie Valley, NC
• Gig Harbor, WA	• Canandaigua, NY	• Marietta, GA
• Kenmore, WA	• Cary, NC	• Montclair, NJ
• Kennewick, WA	• Chandler, AZ	• Morrisville, NC
• Kirkland, WA	• Chanhassen, MN	• Newark, NJ
• Liberty Lake, WA	• Chapel Hill, NC	• New Rochelle, NY
• Lynnwood, WA	• Davidson, NC	• Rockville, MD
• Mercer Island, WA	• Douglas County, CO	• Roswell, GA
• Mountlake Terrace, WA	• Farmingdale, NY	• Rye, NY
• Portland, OR	• Fayetteville, NC	• San Bernardino County, CA
• Puyallup, WA	• Floral Park, NY	• San Francisco, CA
• Redmond, WA	• Franklin, VA	• San Jose, CA
• Renton, WA	• Gilbert, AZ	• St. Francis, MN
• Seattle, WA	• Hamptons, NY	• St. Mary's County, MD
• Tukwila, WA	• Harrisburg, NC	• St. Paul, MN
• Washington, DC	• Indian Trail, NC	• Suffolk, VA
	• Islip, NY	• West Hartford, CT
	• Johnson City, NY	• Wilmington, NC
	• King's Mountain, NC	

The research team summarized the responses and supporting information provided by the contacts and compiled the summary into a database that would be used to facilitate the selection of study sites.

Additional Sites: Study Site Selection

Researchers had several criteria they desired to meet when selecting field study sites for this project. A key variable was location; selected sites needed to be in different regions of the country and preferably expand on the geographical diversity already found in the sites used in previous studies. Also, there needed to be enough sites within a given area to justify the cost of traveling to that area since researchers sought to visit at least 10 sites within a one-week trip. Given those parameters within the context of the project's timeline and budget, researchers decided to collect data in two regions, with a data collection team spending roughly one week in each location.

The tremendous response from cities in Washington to the focused outreach made the Seattle region an early candidate, and support from a variety of cities in North Carolina responding to the ITE Community request for sites provided an area with a natural geographic contrast, so those areas were explored further. Beyond the geographic location, researchers considered the following variables of particular interest in selecting specific sites:

- Posted speed limit.
- Pedestrian crossing distance.

Considering the characteristics of the sites recommended to the research team, along with constraints of time, distance, and weather during data collection, 12 sites in Washington (Federal Way and Kirkland) and 13 sites in North Carolina (Chapel Hill, Cary, Davidson, Fayetteville, Indian Trail, and Morrisville) were chosen for use as study sites. An example of one of these sites, from Chapel Hill, is shown in Figure 4.

Source: Marcus Brewer

Figure 4. View of site NC-CH-01

DATA COLLECTION AND REDUCTION

Study Periods

Data collected from 2012 to 2015 were included in the study. The data from the TxDOT study sites reflected the fall of 2012. The CvR data were collected in the fall of 2013 or spring 2014. Data for all of the FP sites were collected in February 2014. The most recent data were collected in the summer of 2015 for the TTI CTS sites. The A/B data were collected between October 2014 and April 2015. Data used in this evaluation were collected during the daytime.

Staged Pedestrian Protocol

The research team used a staged pedestrian protocol to collect driver yielding data such that oncoming drivers received a consistent presentation of approaching pedestrians. Under this protocol, a member of the research team acted as a pedestrian using the crosswalk, to stage the conditions under which driver yielding would be observed. Each staged pedestrian wore similar clothing (gray t-shirt, blue jeans, and gray tennis shoes) and followed specific instructions in crossing the roadway. The staged pedestrian was accompanied by a second researcher, who

observed and recorded the yielding data on pre-printed datasheets. Additional details on the staged pedestrian protocol are provided in previous studies (for example, see *13*).
The protocol calls for the completion of a minimum of 20 (30 desirable) staged crossing maneuvers in each direction of travel for a total of 40 crossings (60 desirable). Observation periods were chosen such that vehicle traffic was heavy enough to create frequent yielding situations but not heavy enough for congestion to affect vehicle speeds. Researchers always collected data during daylight and in good weather, avoiding rain, wet pavement, dusk or dawn, or other conditions that affect a driver's ability to see and react to a waiting staged pedestrian.

Driver Yielding

After completing the data collection, researchers entered the crossing data and the site characteristics data from the field worksheets into an electronic database. The average yielding rate for a site was calculated as shown in the equation below to provide an overview of driver behavior during preliminary reviews. Data for individual crossings, however, were used in the statistical evaluation.

$$Yielding\ rate = \frac{number\ of\ yielding\ vehicles}{number\ of\ yielding\ vehicles + number\ of\ non\text{-}yielding\ vehicles}$$

Near or Far Approach

Evaluations considered the data by near and far approaches. A driver will see a moving pedestrian within the near side while approaching the pedestrian crosswalk on the far side. The additional time that the pedestrian is moving may affect a driver's decision to yield; therefore, whether the pedestrian was on the near or far approach was considered. Which approach is the near or the far approach depends on the side of the street where the pedestrian begins the crossing. Figure 5 shows an example of the near and far approaches when the pedestrian starts on the south side of the street, while Figure 6 shows the near and far approaches when the pedestrian starts on the north side of the street.

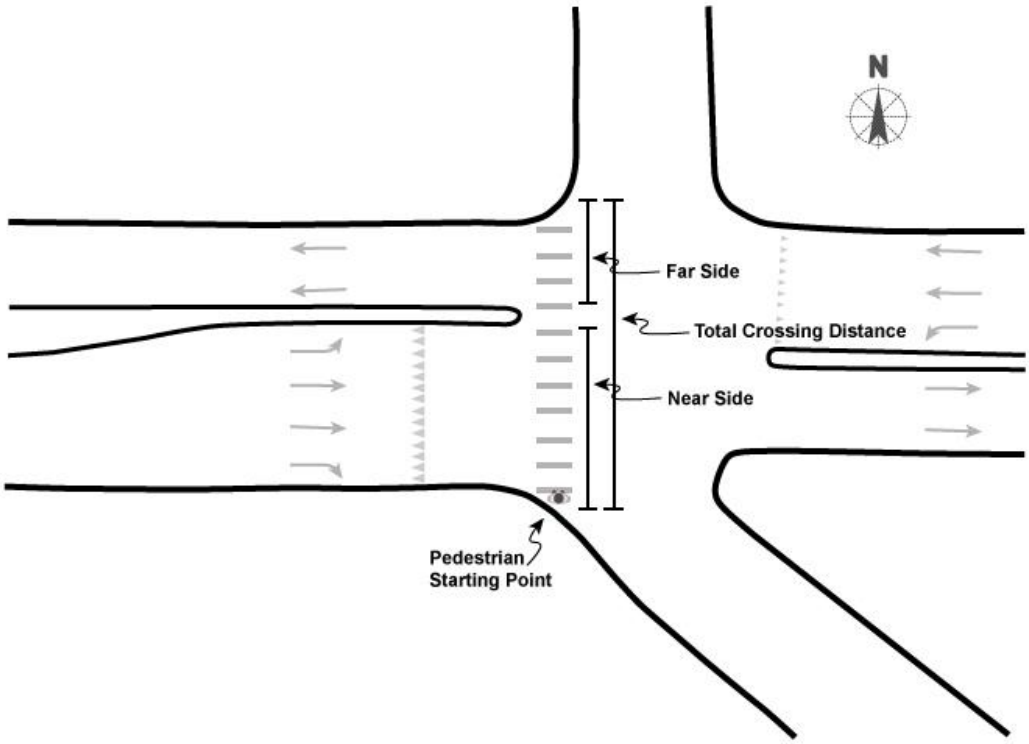

Figure 5. Example of near and far approaches when the pedestrian is crossing from south to north

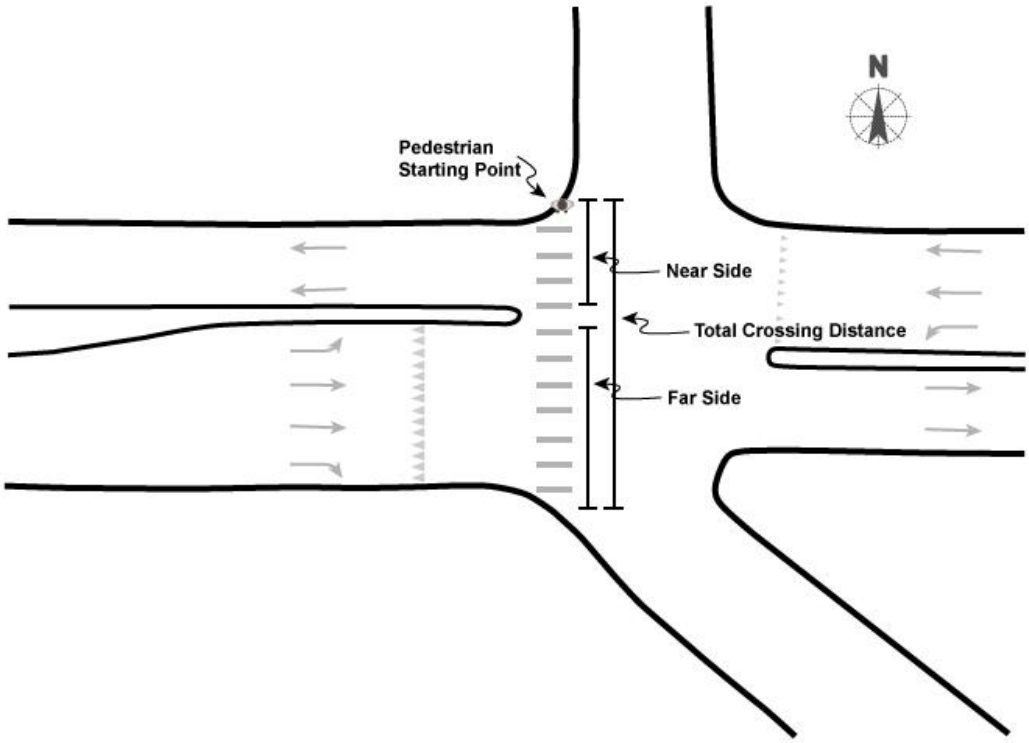

Figure 6. Example of near and far approaches when the pedestrian is crossing from north to south

Datasets for Analyses

Two datasets were created for this study—a full dataset and a one-minute dataset. Table 8 summarizes the size of the full dataset available for the evaluation. It reflects 128 unique site-periods. For the data coming from the CvR, A/B, and FP studies, data were collected for more than one time period for each site. For example, the above/below study collected data when the beacons were located below the crossing warning sign and then again when the beacons were above the crossing warning sign. Because most of these studies found no significant difference for the study conditions, data from all time periods were included in this analysis. The one exception was for the FP study, which found the type of equipment to be statistically significant (*17*). The equipment was either the equipment installed by the city or the TTI equipment, which was the beacon/controller developed by TTI so that the research team could control the type of flash pattern being shown. The finding that equipment was significant indicates that some component of the beacons affected driver yielding; however, what that component was, and whether multiple components had an effect, is not known. The research team suspects that the brightness of the beacons may have been the main contributor, but sufficient data were not available to test that theory. A previous study (*3*) did find brightness to be a factor during nighttime (but not daytime) conditions. To minimize the potential influence of beacon brightness and because more daytime data are available from previous studies, only daytime data were used in this evaluation.

Table 8. Full dataset sample size

Source	State	Site-Periods	Average Driver Yielding	Number of Per-Side Crossings	Number of Vehicles Not Yielding	Number of Vehicles Yielding
TxDOT	TX	22	85%	1267	360	1964
CvR	AZ	6	93%	740	68	929
CvR	TX	8	54%	689	540	640
CvR	WI	10	45%	781	833	688
A/B	AZ	4	59%	339	359	507
A/B	CO	12	87%	1032	185	1261
A/B	IL	6	33%	589	936	466
A/B	TX	4	85%	308	50	273
FP	TX	31	78%	1929	711	2536
TTI CTS	NC	13	75%	1164	435	1325
TTI CTS	WA	12	88%	1168	199	1451
Grand Total		**128**	**72%**	**10,006**	**4676**	**12,040**

A total of 10,006 staged pedestrian per-side crossings were available for the evaluation, with an overall average driver yielding for the RRFB of 72 percent. Table 8 shows the average driver yielding by state within the source of the data, which demonstrates the large range in yielding, from 35 percent for Illinois in the A/B study to 92 percent for Arizona in the CvR study. Data were also collected in a different Arizona city as part of the A/B study, with results much lower (53 percent) than what was found in the CvR study (92 percent)—an indication that the city behavior norms may be more of a contributor than aggregating that information to a state level. Within some of the studies, video recordings were made during data collection. From those recordings, vehicle volume counts were gathered for a selection of the sites. Table 9 summarizes

the one-minute dataset size. This dataset included crossings when one-minute vehicle volume count was available for the pedestrian crossing.

Table 9. One-minute dataset sample size

Source	State	Site-Periods	Average Driver Yielding	Number of Per-Side Crossings	Number of Vehicles Not Yielding	Number of Vehicles Yielding
CvR	AZ	3	86%	167	39	234
CvR	TX	7	53%	538	449	501
CvR	WI	5	39%	251	316	202
A/B	AZ	1	94%	51	4	61
A/B	CO	7	86%	507	97	620
A/B	IL	6	33%	589	936	466
A/B	TX	3	80%	193	40	164
FP	TX	1	46%	80	96	81
TTI CTS	NC	13	75%	1129	426	1297
TTI CTS	WA	12	88%	1165	199	1447
Grand Total		**58**	**66%**	**4670**	**2602**	**5073**

Description of Study Sites

Several variables were considered for the analysis. Table 10 provides the number of sites and the number of site-periods along with the number of per-side crossings collected for those variables considered as traffic control device related. Table 11 provides similar data for the traffic categories, while Table 12 reflects intersection geometry.

Table 10. Number of per-side crossings by traffic control device categories

Category	Levels within the Category	Full Dataset			Subset When One-Minute Vehicle Count Available		
		Sites	**Site-Periods**	**Per-Side Crossings**	**Sites**	**Site-Periods**	**Per-Side Crossings**
Posted Speed Limit (mph)	22[a]	3	6	574	3	3	285
	30	15	29	2147	12	15	781
	35	31	39	3526	23	27	2493
	40	15	41	2796	4	6	572
	45	9	13	963	7	7	539
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Advance Line Present?	No	28	46	3736	24	31	2105
	Yes	45	82	6270	25	27	2565
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Sign Face	Bike.or.B&P (Bike or Bike&Pedestrian)	4	7	711	4	6	603
	Ped (Pedestrian)	39	66	5876	37	44	3447
	School	30	55	3419	8	8	620
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Supplemental Sign Present?	No	62	112	8433	38	46	3494
	Yes	11	16	1573	11	12	1176
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Beacon Location at Site	B+Ov_Be (Both sides of road plus overhead sign with flashing beacons)	9	9	458	0	0	0
	B+Ov_NB (Both sides of road plus overhead sign)	3	4	322	3	3	258
	Both (Both sides of roadway)	59	112	8984	44	52	4175
	Rt_Only (Right side of roadway only)	2	3	242	2	3	237
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Advance Warning Type	Flash (Advance warning sign includes a flashing beacon)	3	6	574	3	3	285
	No_adv (No advance warning device)	40	71	5045	20	26	2032
	Nonflash (Advance warning sign)	30	51	4387	26	29	2353
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**

[a] See discussion associated with Figure 2.

Table 11. Number of per-side crossings by traffic categories

Category	Levels within the Category	Full Dataset			Subset When One-Minute Vehicle Count Available		
		Sites	Site-Periods	Per-Side Crossings	Sites	Site-Periods	Per-Side Crossings
One-Way or Two-Way Traffic	OW (One-way traffic)	6	8	414	2	2	116
	TW (Two-way traffic)	67	120	9592	47	56	4554
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
ADT/Lane (grouped in 1000 increments for display, actual ADT/lane considered in evaluation)	0–1000	1	2	141	1	1	26
	1000–2000	9	17	1064	8	9	438
	2000–3000	10	21	1477	7	9	725
	3000–4000	11	20	1510	6	7	492
	4000–5000	25	48	3735	12	16	1407
	5000–6000	7	8	798	5	5	524
	6000–7000	2	2	214	2	2	211
	7000–8000	4	5	523	4	5	523
	8000–9000	3	3	315	3	3	315
	9000–10000	1	2	229	1	1	9
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
ADT (grouped in 10,000 increments for display, actual ADT considered in evaluation)	1357–11,356	25	48	3299	21	26	1779
	11,357–21,356	34	63	4957	18	21	1719
	21,357–31,356	12	15	1573	9	10	1064
	31,357–41,356	2	2	177	1	1	108
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**

Table 12. Number of per-side crossings by intersection geometry categories

Category	Levels within the Category	Full Dataset			Subset When One-Minute Vehicle Count Available		
		Sites	Site-Periods	Per-Side Crossings	Sites	Site-Periods	Per-Side Crossings
Intersection Configuration	2Leg	16	23	2262	15	16	1297
	3Leg	28	43	3376	18	22	1781
	4Leg	26	59	4112	14	18	1375
	4LegO[a]	3	3	256	2	2	217
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
School within 0.5 mi of the Crosswalk?	No	38	61	5235	31	39	3151
	Yes	35	67	4771	18	19	1519
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Median Refuge Island Present	No	32	54	3821	20	27	1880
	Yes	41	74	6185	29	31	2790
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Number of Lanes per Approach	1	10	16	1092	9	12	745
	2	27	41	3721	23	25	2036
	3	26	60	4523	16	20	1875
	4	10	11	670	1	1	14
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Approach Crossing Distance (ft) (grouped in 10-ft increments for display, actual distance used in evaluation)	20–30	23	30	2922	21	22	1942
	30–40	22	51	3697	14	18	1467
	40–50	16	25	1692	7	8	462
	50–60	5	5	355	4	4	300
	60–70	5	15	1212	3	6	499
	70–80	2	2	128	0	0	0
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**
Trail Crossing?	No	66	118	9061	42	49	3833
	Yes	7	10	945	7	9	837
	Grand Total	**73**	**128**	**10,006**	**49**	**58**	**4670**

[a] Four legs, with one of the approaches offset from other approach.

CHAPTER 4. RESULTS

STATISTICAL APPROACH

The total number of drivers who do yield and total number who do not yield for a given staged pedestrian crossing are inherently discrete values, positive numbers, and often small. There are two outcomes from each crossing: the number of vehicles that yield and the number of vehicles that do not yield. A logistic regression approach is the natural choice to model such variables, but the important implication of such an approach is that the expected value of the response variable should not depend on the total number of observed vehicles in a particular crossing. The model naturally weights the crossings proportionally to the number of observed vehicles, but the estimation rarely contains an exposure component among the predictors of proportions.

However, codependence is unavoidable between yielding rate and the total number of observed vehicles, given the way the experiment is conducted. On the one hand, the number of drivers who yield can never exceed the total number of lanes in one direction; any driver behind the driver yielding must stop due to the previous vehicle stopping, so those vehicles can make no decision about yielding to the crossing pedestrian. On the other hand, the number of vehicles not yielding is not constrained in such a way.

NEGATIVE BINOMIAL MIXED-EFFECTS MODEL

The following example illustrates the limitation of modeling yielding rates with the traditional logistic model, and it justifies adopting a negative binomial model (NB) alternative. If a large platoon of vehicles is observed at a location with two lanes in each direction, only two yielding vehicles can be recorded per direction, even if there are more than two vehicles in the platoon that would yield; in contrast, the number of observed non-yielding vehicles is not limited as long as two yielding vehicles have not yet been observed. Therefore, large numbers of observed vehicles tend to associate with more non-yielding vehicles.

Given this correlation between low yielding rates and the total number of vehicles in a crossing, the research team considered using a frequency model, rather than a yielding rate model. An expected advantage of this approach is that the model can better capture and explain variability emerging from the experiment design. Such variability might be captured as unexplained variance in the logistic regression model.

The research team determined that the negative binomial model was most adequate since the structure in the data clearly resembled a negative binomial experiment. A negative binomial experiment involves collecting consecutive Bernoulli trials with equal probabilities of success until a predetermined number of failures occurs. This definition very closely resembled the experiment at hand, where non-yielding vehicles were observed until a predetermined number of yielding vehicles was observed.

Under the NB model specification, the response variable was the number of vehicles not yielding. The number of lanes entered the model in the shape parameter of the NB distribution of

non-yielding vehicles. This feature of the model allowed modeling a higher dispersion at sites with fewer lanes because a bigger constraint existed for the observed number of non-yielding vehicles at those sites.

The analysis was done on a per-side crossing basis. For example, a staged pedestrian crossing at a site with two-way traffic had a nearside crossing and a farside crossing. Per-side crossings that did not have at least one vehicle were dropped from the analysis. For example, when a vehicle was present on the near side but no vehicles were present on the far side, the analysis retained the nearside crossing but dropped the farside crossing.

The grouping structure in the data was explicitly considered in the model as nested random effects (REs). These random effects treat data from different levels of aggregation as potentially correlated. The nested random effects structure treated the aggregation levels as follows: data were structure by state first, and then by city within a state, by site within a city, by period within a site, and by individual crossing within a period.

ADDITIONAL ADJUSTMENTS TO VARIABLES

Because negative binomial regression involved evaluating the number of drivers who did not yield to the crossing pedestrian, the model considered the total number of drivers that made a decision. A new variable—A.TotCars—was created as the sum of the number of drivers that did and did not yield for a given staged pedestrian crossing.

Preliminary modeling revealed several correlations that required adjusting variables within the dataset. The trail variable indicated whether the pedestrian crosswalk was an extension of a walking and/or biking trail. All the sites with trails for this dataset had a bicycle crossing warning (W11-1) sign or a bicycle/pedestrian crossing warning (W11-15) sign (see example in Figure 7); therefore, the trail variable was dropped from the analysis. School type was removed because most of the schools within 0.5 mi were elementary schools. The following variables were also removed due to correlations with other variables: advance warning sign, and whether the vehicle was still accelerating.

Source: Marcus Brewer

Figure 7. Example of approach warning sign at NC-CY-01

MODEL RESULT FOR FULL DATASET

Table 13 shows the results of the linear mixed-effects model using the selected variables. The dataset contained 10,006 records (i.e., per-side crossings). The model quantified the expected number of vehicles not yielding on an approach for a given staged pedestrian crossing. In case of a categorical variable, a negative estimate for a model coefficient indicated that fewer drivers did not yield when that level of categorical variable was present. In the case of a continuous variable, a negative coefficient estimate indicated that as that variable increased, the number of drivers not yielding decreased. For example, when a refuge island was present at the crosswalk (M.Refuge:Yes), fewer drivers did not yield to the crossing pedestrian. The positive estimate for approach crossing distance revealed that as the crossing distance increased, more non-yielding was observed.

Fixed Effects

The variables that had at least one of their components significant (at the 0.10 level) included the following:

- **Number of vehicles per crossing.** The number of vehicles for the given staged pedestrian crossing (A.TotCars) was included in the model to control for vehicle exposure and was found to be significant, as expected.
- **Intersection configuration.** Intersection configuration was subdivided into four levels with a two-leg configuration (could also be called a midblock configuration) as the reference level. When the estimate in Table 13 was positive, as it was for I.Config:4LegO, more drivers did not yield, which is an undesirable situation. For this dataset, better yielding was observed for the midblock sites compared to the four-leg intersections.
- **Refuge presence.** If a raised median or a short refuge island was present, then fewer cars did not yield, which could also be interpreted as more drivers deciding to yield to the crossing pedestrian when a median refuge was present at the site.
- **Crossing distance.** As the distance being crossed on the approach increased, drivers were less likely to stop for the crossing pedestrian.
- **One-way or two-way traffic.** More drivers chose not to yield on a two-way street compared to a one-way street. All of the one-way streets had the lower posted speed limits (30 or 35 mph) and more narrow street crossing widths.
- **Approach (near or far).** The evaluation considered whether the staged pedestrian was on the near approach or the far approach (see examples of near and far in Figure 5 or Figure 6). The model results indicated that drivers were less likely to yield to a waiting pedestrian on the near approach compared to the far approach. Perhaps the far-approach drivers being able to see a moving pedestrian on the street for the initial portion of the crossing encouraged them to yield.

Table 13. Generalized linear mixed-effects model results for full model

Variable	Estimate	Std. Error	DF	t-value	p-value[a]
(Intercept)[b]	−4.131827	0.606442	6471	−6.81323	<0.0001***
log(A.TotCars)	1.767041	0.0270163	3405	65.40652	<0.0001***
I.Config:3Leg	0.039358	0.1934497	36	0.20345	0.8399
I.Config:4Leg	0.401375	0.2453283	36	1.63607	0.1105
I.Config:4LegO	0.76292	0.4104246	36	1.85886	0.0712~
M.PSL_Factor22	0.121042	0.5063773	36	0.23904	0.8124
M.PSL_Factor30	0.467102	0.2885567	36	1.61875	0.1142
M.PSL_Factor40	0.093381	0.2366891	36	0.39453	0.6955
M.PSL_Factor45	0.291445	0.2718591	36	1.07205	0.2908
M.Refuge:yes	−0.435611	0.1700658	36	−2.56143	0.0148*
M.Ad_Line:yes	0.201739	0.2077072	36	0.97127	0.3379
M.Sup_Sign:yes	−0.332821	0.2990113	36	−1.11307	0.2731
M.Dis_Trans:200 ft +	0.131466	0.1410764	36	0.93187	0.3576
Sch_w/.5:Yes	0.012685	0.2251392	36	0.05634	0.9554
Sign_Face:Ped	−0.334708	0.3503825	36	−0.95526	0.3458
Sign_Face:School	0.039229	0.4558795	36	0.08605	0.9319
Bea_RS_OV:B+Ov_Be	0.146252	0.4780322	36	0.30595	0.7614
Bea_RS_OV:B+Ov_NB	0.231569	0.350822	36	0.66007	0.5134
Bea_RS_OV:Rt_Only	0.815197	0.6279256	36	1.29824	0.2025
Near_Far:Near	0.344665	0.02393	3405	14.40303	<0.0001***
A.CD	0.010419	0.0033406	3405	3.11886	0.0018**
M.O_T:TW	0.728927	0.2961758	36	2.46113	0.0188*

Note: Column headings:

Variable = variables included in model.

Estimate = natural logarithm of the ratio: Odds(coefficient level) / Odds(reference level) . In the case of reference level, the estimate is the log-odds of the average yielding rate at the reference level.

Std. Error = standard error of value.

DF = degree of freedom.

t-value = conservative estimate of the z-value, which is the standard normal score for estimate, given the hypothesis that the actual odds ratio equals 1.

p-value = probability that the observed log-odds ratio be at least as extreme as the estimate, given the hypothesis that the actual odds ratio equals 1.

[a] Significance values are as follows: ~ = p < 0.10; * = p < 0.05; ** = p < 0.01; and *** = p < 0.001.

[b] Reference levels: I.Config = two legs; M.PSL = 30 mph; M.Refuge = no (no pedestrian refuge present); M.Ad__Line = no (advance stop or yield line not present); M.Adv_Warn = no (advance warning signs are not present); M.Sup_Sign = no (supplemental signs are not present at crosswalk); M.Dis_Trans = within 200 ft (transit stop is within 200 ft of the crosswalk); Sch_w.5 = no (a school is not within 0.5 mi); Sign_Face = Bike & B.P. (bicycle or bicycle/pedestrian combination warning crossing sign present); Bea_RS_OV = RRFBs are on both sides of the road (left roadside and median); Near_Far = far (reference level is the farside approach); M.O_T = OW (one-way traffic present).

Several variables were anticipated to be statistically significant but were not, including the following:

- **Posted speed limit**. Initial investigation into the posted speed limit variable revealed that a linear relationship with drivers yielding was not present. As shown in Figure 8, the posted speed limit between 30 and 45 mph with the highest average driver yielding was 40 mph, with a 78 percent yielding rate. The 22-mph posted speed limit

did have a higher overall driver yielding of 88 percent; however, that posted speed limit category was created to represent those sites where the regulatory speed limit changed to 25 mph when the RRFB was active (see Figure 2). The posted speed limit variable within this dataset may have been accounting for other site characteristics than just the numeric speed value posted on the sign. For example, the higher speed limit sites may also have had a more rural feel or had fewer driveways. The posted speed limit variable was converted from a continuous variable to a categorical variable for additional analysis; however, it was still found to be not significant. For the model shown in Table 13, the 35-mph posted speed limit was used as the reference level since most of the data were collected at sites with a 35-mph posted speed limit.

- **Traffic control devices.** The presence of traffic control devices in addition to the RRFB should help communicate that drivers should expect pedestrians. None of the additional traffic control device variables were significant, however, including advance stop or yield lines or supplemental signs at the crosswalk.
- **Presence of transit stop within 200 ft**. Initially, this variable was a continuous variable that represented the actual distance to the nearest transit stop. Because some crosswalks were more than a mile from a transit stop, the variable was reorganized. Based on preliminary reviews, having the variable subdivided into two groups to reflect whether a transit stop was within 200 ft appeared to have a potential relationship with driver yielding decision; however, the variable was found to be not significant.
- **Presence of a school within 0.5 mi**. This variable was included to reflect where drivers could reasonably expect school children to be present at the crossing. It was not significant for this dataset.
- **Location of the beacons,** such as overhead or on both sides of the roadway. The preliminary results (see Table 14) implied that higher yielding was present when rapid-flashing beacons were located overhead in addition to being on both sides of the roadway (93 percent yielding as compared to an overall yielding for all the sites of 72 percent). Sample size may limit the importance of the finding since only 5 percent of the collected staged pedestrian crossings occurred at sites with beacons overhead as well as on both sides of the street.
- **Sign face.** Preliminary evaluations implied that lower yielding was present for those sites with either the bicycle or bicycle/pedestrian crossing warning sign (see the Bike or Bike&Ped row in Table 15) as compared to pedestrian or school symbols. The sample size may have affected the significance of this variable (only 711 of the more than 10,000 crossings occurred at the sites with bicycle or bicycle/pedestrian crossing warning signs).

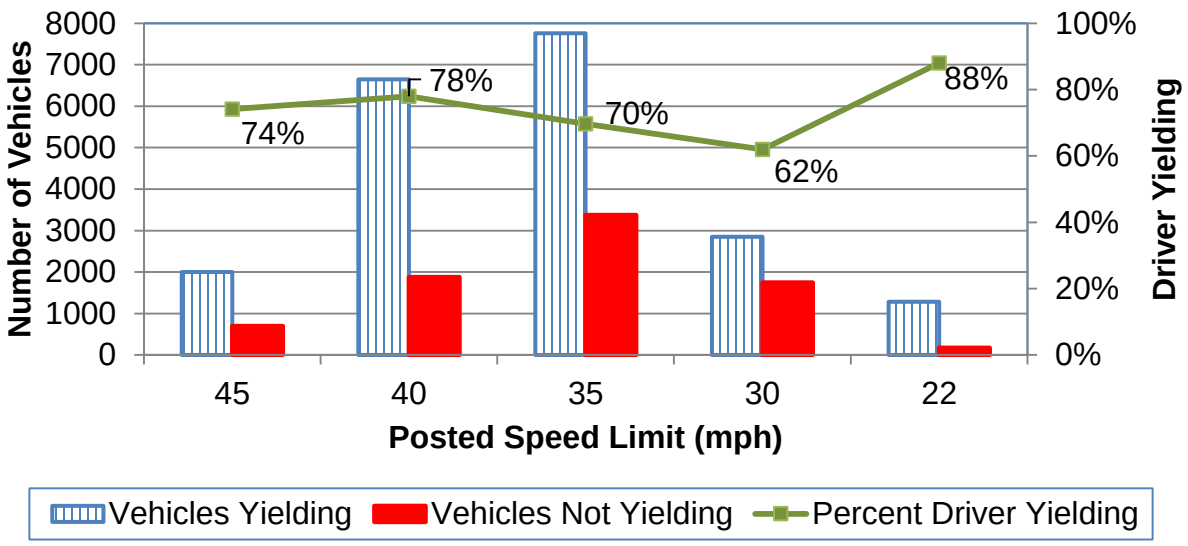

Figure 8. Average driver yielding results (percent values shown on graph) by posted speed limit along with the number of drivers that did and did not yield

Table 14. Results by beacon location

Bea_RS_OV[a]	Average Driver Yielding (%)	Count of Per-Side Staged Pedestrian Crossings	Near Not Yielding	Near Yielding	Far Not Yielding	Far Yielding
B+Ov_Be	90%	458	64	725	54	327
B+Ov_NB	70%	322	168	305	29	163
Both	72%	9039	4747	9991	2550	8731
Rt_Only	53%	242	140	183	120	110
Grand Total	**72%**	**10,061**	**5119**	**11,204**	**2753**	**9331**

[a] Rt_Only = right side only; Both = both right and left sides; B+Ov_Be = both sides plus overhead beacons; B+Ov_NB = both sides plus overhead sign with no beacons.

Table 15. Results by sign face

Sign Face on Warning Sign	Average Driver Yielding (%)	Count of Per-Side Staged Pedestrian Crossings	Near Not Yielding	Near Yielding	Far Not Yielding	Far Yielding
Bike or Bike&Ped	46%	711	817	743	776	600
Pedestrian	71%	5931	3255	6270	1420	5254
School	83%	3419	1047	4191	557	3477
Grand Total	**72%**	**10,061**	**5119**	**11,204**	**2753**	**9331**

Random Effects

In addition to the variables included as fixed effects, the model was specified with a structure of nested random effects to account for correlations in clustered data, as explained earlier. It was of interest to this research to assess how much variability in the data was being captured by the nested random effects; as such, variability was expected to capture the impact of unobserved or unmeasured variables.

To provide an intuitive metric of the variation explained by the different levels of the model, observed yielding rates were compared to predicted yielding rates from the model. First, the fitted values were calculated for each data point. Since these fitted values represented the expected number of vehicles not yielding for a given per-side crossing, they were combined with the observed number of yielding vehicles to obtain the predicted yielding rates.

The mean squared error (MSE) was computed by averaging the squared difference between observed and predicted yielding rates across the complete dataset. The root mean square error (RMSE) was then computed by taking the square root of the MSE.

The computations of the MSE and RMSE were repeated for partial yielding-rate predictions, systematically removing random effects from the full prediction in order to assess the improvement that each level of random effect brought to the overall accuracy of the predicted yielding rate. The results of this assessment are shown in Table 16.

Table 16. Variability accounted for by model random effects

Model Level	MSE	RMSE (%)	Change in RMSE (%)
FE Only	131.0579	11.4481	Not applicable
FE + State	131.0509	11.4477	−0.0003
FE + State + City	119.6775	10.9397	−0.5080
FE + State + City + Site	119.5882	10.9356	−0.0041
FE + State + City + Site + Period	119.0180	10.9095	−0.0261
FE + State + City + Site + Period + Crossing	52.5874	7.2517	−3.6578

Note: FE = fixed effects, MSE = mean squared error, RMSE = root mean square error.

The results shown in Table 16 indicate that the average deviation between the predicted and observed yielding rate is 11.45 percent when the prediction is based only on the fixed effects from the model (i.e., first row of Table 16). In comparison, the average deviation between predicted and observed yielding rates drops to 7.25 percent when the FE and the complete structure of random effects are used (last row of Table 16). The research team considers such an improvement in accuracy to be scientifically significant.

Table 16 also illustrates how the accuracy improves gradually with each additional random effect. The two REs contributing the most significant improvements are crossing (a reduction of 3.66 percent in model RMSE) and city (a reduction of 0.51 percent in model RMSE).

MODEL RESULT FOR SUBSET OF DATA WITH ONE-MINUTE VOLUME

For a subset of the data, vehicle volume counts were available for the minute closest to when the staged pedestrian was crossing. Table 17 shows the results of the linear mixed-effects model using the selected variables. Similar to the previous discussion, this model analyzed the number of vehicles not yielding on an approach for a given staged pedestrian crossing.

Table 17. Generalized linear mixed-effects model results for subset of data with one-minute per-lane volume

Variable	Estimate	Std. Error	DF	t-value	p-value[a]
(Intercept)[b]	−2.76668	0.5287934	2950	−5.23206	<0.0001***
log(A.TotCars)	1.73073	0.0333025	1658	51.97009	<0.0001***
I(One.min.Count/M.NumLn)	0.06382	0.0388788	2950	1.64154	0.1008
I((One.min.Count/M.NumLn)^2)	−0.00563	0.002913	2950	−1.93163	0.0535~
I.Config3Leg	0.08334	0.1804857	16	0.46176	0.6505
I.Config4Leg	0.38331	0.2029303	16	1.88887	0.0772~
I.Config4LegO	0.70062	0.3813303	16	1.83731	0.0848~
M.PSL_Factor22	0.55101	0.364376	16	1.51221	0.15
M.PSL_Factor30	0.82497	0.2031206	16	4.06147	0.0009***
M.PSL_Factor40	−0.70652	0.2619406	16	−2.69727	0.0159*
M.PSL_Factor45	0.34504	0.2125173	16	1.62358	0.124
M.Refugeyes	−0.32184	0.1878703	16	−1.71308	0.106
M.Ad_Lineyes	0.44116	0.2046924	16	2.15523	0.0467*
M.Sup_Signyes	−0.32581	0.1926841	16	−1.6909	0.1102
M.Dist_Trans:200 ft +	0.36405	0.1846598	16	1.97146	0.0662~
Sch_w..5Yes	−0.63098	0.1948201	16	−3.2388	0.0051**
Sign_Face..3.groups.Bike.or.B&P	−0.68382	0.2452023	16	−2.78878	0.0131*
Sign_Face..3.groups.School	−0.11339	0.358861	16	−0.31596	0.7561
Bea_RS_OVBoth	0.54208	0.3657074	16	1.48228	0.1577
Bea_RS_OVRt_Only	1.08697	0.4322186	16	2.51485	0.023*
Near_FarNear	0.15364	0.0434216	1658	3.53843	0.0004***
A.CD	0.01600	0.0053579	1658	2.98714	0.0029**
M.O_T:TW	−0.47345	0.384935	16	−1.22994	0.2365

Note: Column headings:

Variable = variables included in model.

Estimate = natural logarithm of the ratio: Odds(coefficient level) / Odds(reference level) . In the case of reference level, the estimate is the log-odds of the average yielding rate at the reference level.

Std. Error = standard error of value.

DF = degree of freedom.

t-value = conservative estimate of the z-value, which is the standard normal score for the estimate, given the hypothesis that the actual odds ratio equals 1.

p-value = probability that the observed log-odds ratio be at least as extreme as the estimate, given the hypothesis that the actual odds ratio equals 1.

[b] Significance values are as follows: ~ = p < 0.10; * = p < 0.05; ** = p < 0.01; and *** = p < 0.001.

[c] Reference levels: I.Config = two legs; M.PSL = 22 mph (represents Colorado sites with regulatory speed change when the RRFB is active); M.Refuge = no (no pedestrian refuge present); M.Ad__Line = no (advance line not present); M.Sup_Sign = no (supplemental signs are not present at crosswalk); Sch_w..5 = no (a school is not within 0.5 mi); Sign_Face = Ped (pedestrian warning crossing sign present); Bea_RS_OV = RRFBs are on both sides plus an overhead sign is present (with no beacons); Near_Far = far (reference level is the farside approach); M.O_T = OW (one-way traffic present).

The unit of analysis in the model was per-side, with each crossing containing either a nearside or farside reading. Although the dataset contained 6060 records (i.e., per-side crossings) with one-minute counts available, 1390 of those records did not have any vehicles recorded as traveling through the crossing. These records were present because the corresponding per-side crossing

(far or near) did have at least one car recorded. Since a term for exposure was part of the predictors, it was required that at least one vehicle be observed per record. Therefore, 4670 records with one-minute counts and at least one vehicle observed were available for the analysis.

Fixed Effects

The variables that had a least one of their components significant (at the 0.10 level) included the following:

- **Number of vehicles during crossing.** The number of vehicles for the given staged pedestrian crossing (A.TotCars) was included in the model to control for vehicle exposure. Similar to the evaluation using all crossing data (i.e., full dataset), the number of vehicles observed during the crossing was found to be significant with the smaller dataset.
- **One-minute per-lane count.** While the quadratic coefficient for this variable was negative, the linear coefficient was positive. This indicates a concave curve. The vertex of this curve occurred at 5.9 vehicles per minute per. This indicates that the number of non-yielding vehicles increased with the one-minute volume up to 5.9, but fewer non-yielding vehicles were expected as the one-minute volumes increased beyond that point. About 75 percent of the data were in the range of this trend that corresponded to an increase of non-yielding vehicles with increasing one-minute count (i.e., 6 veh/min/lane or less). The trend for increasing traffic volume appears to flatten after 6 veh/min/lane, suggesting that higher traffic volumes may similar impact on the decision of yielding.
- **Intersection configuration.** Similar to the previous analysis, four-leg intersection configurations had significantly fewer drivers yielding compared to the two-leg (midblock) configuration.
- **Crossing distance.** As the distance being crossed on the approach increased, drivers were less likely to stop for the crossing pedestrian.
- **Transit within 200 ft.** When the nearest transit stop was more than 200 ft from the crosswalk, more drivers did not yield.
- **School within 0.5 mi.** When a school was within 0.5 mi of the crosswalk, fewer drivers did not yield, which may indicate that drivers are more willing to yield at a crossing where school children may be present.
- **Sign face.** When the sign face showed a bicycle or was a combination bicycle/pedestrian crossing warning sign, more drivers did not yield, as compared to when the sign face was a pedestrian crossing warning sign. The number of drivers yielding was similar for the pedestrian and school crossing warning signs.
- **Beacon location.** In this analysis, the reference beacon location was RRFBs on both sides (i.e., on the right roadside and in the median) plus an overhead sign (with no beacons). The analysis found that when the RRFBs were located only on the right side of the roadway, compared to the reference level, more drivers did not yield.
- **Approach (near or far).** The model considered whether the staged pedestrian was on the near approach or the far approach (see examples of near and far in Figure 5 or Figure 6). Similar to the previous analysis, these results indicated that drivers were less likely to yield to a waiting pedestrian on the near approach compared to the far

approach. Again, perhaps the far-approach drivers being able to see a moving pedestrian on the street for the initial portion of the crossing encouraged them to yield.

- **Advance yield or stop lines.** Surprisingly, the analysis found that when yield or stop lines were present at the crosswalk, more drivers did not yield. About half of the sites with advance yield or stop lines had 40 or 45 mph speed limits while only 14 percent of the sites without the lines had those speed limits.
- **Posted speed limit.** Interestingly, when the greater amount of crossing data was available, posted speed limit was not significant (see Table 13). In the smaller dataset that only reflected crossings where a one-minute count was available, however, the data for posted speed limits of 40 and 30 mph were significantly different from the data for a posted speed limit of 35 mph. Table 17 shows the raw data and average driver yielding per posted speed limit value. The analysis indicated that more drivers yielded at the 40-mph sites compared to the 35-mph sites, and fewer drivers yielded at the 30-mph sites compared to the 35-mph sites—a counterintuitive finding. These observations indicate that the relationship between speed limit and yielding is complex and not fully explained with this evaluation.

Variables that were statistically significant in the previous analysis but found to be not significant with the smaller dataset were presence of refuge and one-way and two-way traffic, although the presence of refuge was just barely not significant.

Table 18. Results by posted speed limit for crossing data when one-minute volume counts were available

Posted Speed Limit (mph)	Average Driver Yielding (%)	Count of Per-Side Staged Pedestrian Crossings	Near Not Yielding	Near Yielding	Far Not Yielding	Far Yielding
45	65%	539	317	440	122	376
40	66%	572	442	684	246	660
35	67%	2493	1444	2714	1069	2451
30	58%	781	513	601	172	327
22	85%	285	42	324	64	300
Grand Total	**67%**	**4670**	**2758**	**4763**	**1673**	**4114**

Random Effects

Similar to the assessment of random effects for the full model, the research team repeated the computations of the MSE and RMSE for the yielding-rate predictions implied by the one-minute model. The results of this assessment are shown in Table 19.

Table 19. Variability accounted for by model random effects for model with one-minute volume counts

Model Level	MSE	RMSE (%)	Change in RMSE (%)
FE Only	125.5608	11.20539	Not applicable
FE + State	125.5608	11.20539	0.0000002
FE + State + City	125.5608	11.20539	0.0000000
FE + State + City + Site	120.2920	10.96777	−0.2380000
FE + State + City + Site + Period	121.9499	11.04309	0.0753000
FE + State + City + Site + Period + Crossing	121.9499	11.04309	−0.0000001

These results in Table 19 indicate that the average deviation between the predicted and observed yielding rate is 11.20 percent when the prediction is based only on the fixed effects (i.e., first row of Table 19) and only drops to 11.04 percent when the prediction is based on both the fixed effects and the complete structure of random effects (last row of Table 19). This is an almost imperceptible improvement in contrast with the clear improvement that the random effects brought in the full model. The research team speculates that an important factor for this reduced improvement stems from lower overall variability in the one-minute model compared to the full model. The full model included data from 19 cities and 127 sites within those cities, while the one-minute model included 16 cities and only 57 sites within those cities. The research team considers that, to a lesser extent, the inclusion of the one-minute counts may have captured some variability that was previously attributed to the random effects.

Table 19 shows how the accuracy does not necessarily improve with each additional random effect, an indication that some levels of the random effects reduce the parsimony of the model, rather than contribute to explaining variability. The only two REs that improved the accuracy of the prediction were site (a reduction of 0.238 percent in model RMSE) and crossing (an almost imperceptible reduction of 8.37×10^{-8} percent in model RMSE).

CHAPTER 5. SUMMARY AND DISCUSSION

SUMMARY

The rectangular rapid-flashing beacon is a relatively recent pedestrian crossing treatment that has shown great potential in improving driver yielding to pedestrians compared to more traditional treatments that also use yellow beacons. While the RRFB is not currently described in the MUTCD, FHWA has provided interim approval for the optional use of the treatment at uncontrolled pedestrian and school crosswalks. Though observed results from RRFB treatments have been generally promising, results from several studies showed widely varying yielding rates (19 to 98 percent), indicating that there are variables other than the RRFBs that have an effect on driver yielding.

Previous studies were limited in the number of sites that could be studied and the number of variables that could be analyzed. In this project, researchers combined data from four previous TxDOT and FHWA projects along with data from new sites to create a larger dataset that would be better suited to identify characteristics related to driver yielding. Funding from the TTI CTS permitted both the collection of additional field data and the analysis of that dataset to identify variables associated with driver yielding.

Based on the results from previous studies, researchers identified several variables for consideration in this analysis, divided into two broad categories: variables associated with the region, nearby school, or specific approach (Table 5); and variables related to the major street at the crosswalk (Table 6).

The research team also used a two-pronged effort to identify additional study sites: a targeted outreach to specific colleagues who had previously expressed interest in being a part of upcoming research efforts, and a broad outreach to the ITE Traffic Engineering Community. From those two outreach activities, researchers received responses from 65 jurisdictions across the country, representing over 300 existing and planned RRFB installations.

The research team chose 12 sites in Washington (Federal Way and Kirkland) and 13 sites in North Carolina (Chapel Hill, Cary, Davidson, Fayetteville, Indian Trail, and Morrisville) for use as study sites. These sites not only provided geographical contrast and a reasonable nucleus of sites in each study region but also good variety in posted speed limit, pedestrian crossing distance, and other variables of interest. Data for these sites were collected during the summer of 2015. Data collection methodology for these 25 sites, as well as sites studied in previous research, included a staged pedestrian protocol during daytime periods with free-flowing vehicles. A total of 128 site-periods were included in the final dataset for analysis.

A negative binomial mixed-effects model was used to analyze the more than 10,000 pedestrian crossings. Results from statistical analysis of staged pedestrian crossings indicated that intersection configuration (number of legs), presence of median refuge, crossing distance, approach for the crossing, and direction of vehicle travel (i.e., one-way or two-way) were statistically significant. More drivers yielded at midblock locations than at four-leg intersections,

more drivers yielded when a raised median or short refuge island was present, more drivers yielded on the far approach (i.e., second half) of the crossing than on the near approach, and more drivers yielded on a one-way street than on a two-way street. Several variables were anticipated to be statistically significant but were not, including posted speed limit, supplemental traffic control devices, distance to transit, presence of a school within 0.5 mi, location of the beacons, and legend on the face of the crossing sign.

A subset of the data was analyzed and included 4670 per-side crossings where vehicle volume for the one minute prior to the pedestrian crossing was available. Variables that had at least one level shown as significant included the one-minute count of vehicles per lane, the intersection configuration, the posted speed limit, the presence of a median refuge, the presence of a school within 0.5 mi of the crosswalk, the legend on the sign face, the location of beacons, the near or far side of the approach, presence of advance yield or stop lines, and the crossing distance.

DISCUSSION

Through numerous studies, the rectangular rapid-flashing beacon has clearly demonstrated that it is associated with higher driver yielding compared to no pedestrian treatment. Unfortunately, the amount of improvement in yielding is not consistent, and there is clearly a large range of yielding among sites (19 to 98 percent per site driver yielding). This study attempted to identify which roadway and traffic control device variables are associated with more drivers yielding to the crossing pedestrians.

The analysis found that more drivers are yielding to the pedestrian on the far side – or second half – of the crosswalk, perhaps because of the additional time that the driver can see the moving pedestrian. A review of the random effects from the full model found that city accounted for significant amounts of variability. Differences between crossings account for an even larger amount of variation which is an indication that conditions present during a specific crossing – perhaps number of vehicles or number of pedestrians – could be influencing the driver's decision. The model of the subset of data that included one-minute counts resulted in the amount of variability attributed to individual crossings and cities virtually disappearing. In that model, differences between sites emerged as most influential, after accounting for one-minute counts and other variables.

The evaluation revealed that the following roadway and traffic control device conditions are associated with higher yielding:

- When the distance being crossed is shorter.
- When a median refuge is present.
- When the crossing has only two legs (rather than four legs).

These findings support the general belief that pedestrian-friendly designs are associated with traffic operating conditions that are more supportive of walking.

More drivers yielded at crosswalks within 0.5 mi of a school, perhaps an indication that drivers are more willing to yield when there is a higher likelihood of children. Fewer drivers yielded when the crosswalk had a bicycle or bicycle/pedestrian crossing warning sign as compared to a

pedestrian crossing warning sign, an indication that those types of crossing may need additional treatments to adequately inform drivers of the need to stop for crossing pedestrians. An additional significant traffic control device variable was beacon location; when the RRFBs were located on both sides of the roadway as well as overhead, compared to when the RRFBs were located only on the right side of the roadway, more drivers yielded.

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