BEST PRACTICES FOR INSTALLATION OF RECTANGULAR RAPID FLASHING BEACONS WITH AND WITHOUT MEDIAN REFUGE ISLANDS

Final Report

PROJECT SPR 814

Oregon Department of Transportation

BEST PRACTICES FOR INSTALLATION OF RECTANGULAR RAPID FLASHING BEACONS WITH AND WITHOUT MEDIAN REFUGE ISLANDS

SPR 814

FINAL REPORT

by

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16. Abstract: Over the last decade, Oregon jurisdictions have systematically installed pedestrian crossing enhancements (PCEs) at crosswalks including RRFBs, which have been widely used in many jurisdictions, typically at mid-block locations. However, the design details vary widely. The objectives of this research are to develop guidance that practitioners need about the placement of RRFB beacons in combination with median refuges on three-lane roadways by exploring the effect of refuge medians mounted RRFB displays on driver yielding behavior. This study also developed methods for pedestrian volume estimation at midblock locations and reanalyzed the SPR 778 RRFB data to produce more robust estimates of the safety effectiveness of RRFBs. This study explored driver and pedestrian behavior at 23 RRFB sites with and without median islands and beacons. Generally, high yielding rates were observed at all sites and these rates provide evidence that the RRFB is a useful tool alerting drivers to the presence of pedestrians at crosswalks.The data and analysis do generally indicate that the yielding rates increase with the addition of the median beacons. However, the difference is not a large increase (<5%) and is also not statistically significant. The findings suggest that a median refuge beacon could be considered optional on 3-lane roadways with volumes ≤ 12,000 ADT. Similarly, the data generally show that for the > 12,000 ADT groups, the addition of the median refuge increases yielding. In addition to driver yielding behavior, there are other reasons to install median islands including pedestrian comfort which should be considered. A linear regression model for estimating pedestrian demand was developed and significant predictors included the percent of low wage workers at the home and work locations, intersection density in terms of multi-modal intersections having four or more legs per square mile, intersection density in terms of auto-oriented intersections per square mile, gross population density, and proportion of census block group employment within ¼ mile of transit stop. CMF's were developed for pedestrian and rear-end crashes. With the simple-before analysis, CMF's of 0.84 (standard error=0.25) and 1.42 (standard error=0.12) were obtained for pedestrian and rear-end crashes respectively. A CMF of 0.71 (standard error=0.20) and a CMF of 1.11 (standard error of 0.06) were obtained for pedestrian and rear-end crashes using the empirical Bayes method.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	millimeters squared	mm^2
ft^2	square feet	0.093	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometers squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3
NOTE: Volumes greater than 1000 L shall be shown in m^3.				
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celsius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometers squared	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celsius temperature	1.8 + 32	Fahrenheit	°F

* SI is the symbol for the International System of Measurement

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DISCLAIMER

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1.0 INTRODUCTION

Over the last decade, Oregon jurisdictions have systematically installed pedestrian crossing enhancements (PCEs) at crosswalks such as continental markings, median refuge islands, curb bulb-outs, pedestrian-activated flashing beacons, overhead signs, advanced stop bars and more recently Rectangular Rapid Flash Beacons (RRFB). RRFBs are proving to be a cost-effective way to improve driver yielding and, hopefully, safety. FHWA first granted interim approval for the optional use of rectangular rapid flashing beacons (RRFBs) as a warning beacon to supplement standard pedestrian signs at crosswalks at uncontrolled locations, including school crosswalks in 2008 (IA-11). RRFBs have been shown to improve driver yielding rates and, most recently, reduce the number of pedestrian-vehicle crashes. RRFBs have been widely used in many jurisdictions, typically at mid-block locations. The design details of each crossing are unique but RRFBs are always accompanied by marked crosswalks and some locations also have raised medians or crossing islands at some locations. In December 2017, FHWA rescinded IA-11 due to patent issues. However, on March 20, 2018, FHWA issued Interim Approval for *Optional Use of Pedestrian-Actuated Rectangular Rapid-Flashing Beacons (RRFBs) at Uncontrolled Marked Crosswalks* (IA-21) that once again allowed the use of the RRFB beacons by request.

In Oregon, practitioners have expressed desire for guidance on the improved safety, driver yielding, and operations by using pedestrian refuge islands with or without RRFB beacons (median vs. far-side) on three lane roadways. In some cases, installing median mounted beacons on three-lane roadways (one lane in each direction with a two-way left-turn lane) can lead to conflicts with over-dimensional freight (oversize loads may need 25 feet of clearance). Beacons are typically installed on median islands but it is not clear if they are needed since left-side beacons can be seen by oncoming traffic unless occluded by large vehicles.

A previous ODOT research project (SPR 778) collected data on many different types of PCEs on state and non-state highways in Oregon with an objective to establish the safety effectiveness of these improvements. The SPR 778 research data set included 39 RRFB locations with a pedestrian refuge island and and 29 without a pedestrian refuge island (15 locations were on three-lane roadways). The data set included detailed information about the installations. Using crash data from 2007-2015, a CMF of 0.64 +/- 0.26 was obtained for pedestrian crashes at RRFBs (i.e., installing an RRFB reduces pedestrian crashes by 36% on average). However, this was developed using only a simple before-after method due to insufficient data (primarily a lack of pedestrian volumes and crash counts). The research did not address the impact of median refuge islands directly.

1.1 RESEARCH OBJECTIVES

This research had three objectives. First, the research intended to develop information that practitioners need about the placement of RRFB beacons in combination with median refuges on three-lane roadways. This research also aimed to provide empirical evidence about the effect of refuge medians mounted RRFB displays on driver yielding behavior. Second, this project sought to develop methods of pedestrian volume estimation at midblock locations. Finally, this project planned to reanalyze the SPR 778 RRFB data with more recent crash data and volume estimates to produce more robust estimates of the safety effectiveness.

1.2 ORGANIZATION OF FINAL REPORT

This remainder of this report contains the following. Chapter 2 is a review of policies and procedures related to RRFB installation. Chapter 3 describes the data collection and reduction methods. The analysis chapters follow, with Chapter 4 on driver yielding at RRFB locations, Chapter 5 on pedestrian volume estimation, Chapter 6 on estimating the safety effectiveness of RRFBs from SPR 778. Finally, Chapter 7 presents the report summary and recommendations.

2.0 REVIEW OF POLICIES AND PROCEDURES

A recent ODOT project (SPR 778) contained a significant review of the literature on the safety effectiveness of pedestrian crossings and pedestrian volume estimation. To avoid duplication of efforts, the focus of this review was of policies RRFB installation policies and procedures related to RRFB placement. Since RRFBs are primarily used at mid-block crossings, the first decision an agency often faces is whether to mark the crossing or not. Subsequent decisions for the agencies include the level of crossing enhancement to install and whether RRFBs are suitable. The following section first reviews guidance on the decision to mark a crosswalk, the guidance for conditions when an RRFB device is a preferred treatment, and then guidance on design-related topics.

2.1 DECISION TO MARK CROSSWALKS

Crosswalk markings are used to designate pedestrian crossing locations at intersections or other sites. According to the Uniform Vehicle Code, crosswalks are defined as:

1. That part of a roadway at an intersection included within the connections of the lateral lines of the sidewalks on opposite sides of the highway measured from the curbs or, in the absence of curbs, from the edges of the traversable roadway; and in the absence of a sidewalk on one side of the roadway, that part of a roadway included within the extension of the lateral lines of the existing sidewalk at right angles to the centerline.

2. Any portion of a roadway at an intersection or elsewhere distinctly indicated for pedestrian crossing by lines or other markings on the surface (UVC, 2000).

UVC guidelines indicate that motorists should yield the right-of-way to pedestrians at crosswalks regardless of marking (marked and unmarked). In Oregon, every intersection is considered as a crosswalk irrespective of marking, and drivers are required to yield to pedestrians.

McGrane and Mitman found that many jurisdictions rely on engineering judgment prior to deciding whether to mark crosswalks (McGrane and Mitman, 2013). Historically, the decision on whether or not mark a crosswalk was influenced by studies that suggested marked crosswalks were unsafe. A study that has since been found to have significant methodological flaws conducted in 1972 by Herms at uncontrolled locations in San Diego found that marked crosswalks had twice the risk of pedestrian-involved collisions as compared to unmarked crosswalks (Herms, 1972). More recently, Jones and Tomcheck conducted a study to review crosswalk marking guidelines in Los Angeles and found that pedestrian-vehicle collisions decreased by 61% at intersections following the removal of a marked crosswalk, and no increases in collisions at adjacent intersections were recorded (Jones and Tomcheck, 2000). However, this study did not consider important factors that affect safety, such as traffic volumes, speeds or a number of lanes.

A 2001 seminal study by Zegeer et al. analyzed data from 1,000 marked and 1,000 unmarked crosswalk sites in 30 U.S. cities and found that at uncontrolled locations on two-lane roads and multi-lane roads with ADT less than 12,000 vehicles, presence of a marked crosswalk alone made no statistically significant difference to the crash rate (Zegeer et al. 2001). On multi-lanes roads with ADT greater than 12,000 vehicles (without a raised median) and 15,000 vehicles (with a raised median), the presence of a marked crosswalk alone led to a statistically significant higher rate of pedestrian crashes compared to sites with an unmarked crosswalk (Zegeer et al. 2001). Zeeger's work was incorporated into the FHWA report titled, "*Safety Effects of Marked versus Unmarked Crosswalks at Uncontrolled Locations*," published in 2005.

This research and subsequent recommendation table for installing marked crosswalks and other needed pedestrian improvements at uncontrolled locations are relied upon by many agencies for making crosswalk marking decisions. A replication of the table can be seen in Table 2.1 below. The table identifies locations where marked crosswalks alone are sufficient (C), locations where a possible increase in pedestrian crash risk may occur if crosswalks only are used (P), and locations where marked crosswalks alone are insufficient, since the pedestrian crash risk may be increased by providing marked crosswalks alone (N). The table is stratified by the posted speeds, the number of lanes the pedestrian must cross (including the presence of medians), and the vehicle volume. For marked crosswalks, the table recommends "a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or children pedestrians) be confirmed at a location before placing a high priority on the installations of a marked crosswalk alone". Importantly, the table does not specify what types of enhancements are suitable to improve the "P" and "N" locations such that the crossing may be safely used. The report has does not mention RRFBs, as it predates the interim approval in 2008 of the devices.

The guidance has been incorporated into the MUTCD. The document urges caution against the use of crosswalk markings indiscriminately and recommends that an engineering study is performed prior to installing a marked crosswalk. The factors that should be considered during the engineering study are the number of lanes, the presence of a median, the distance from adjacent signalized intersections, the pedestrian volumes and delays, the average daily traffic (ADT), the posted or statutory speed limit or 85th-percentile speed, the geometry of the location, the possible consolidation of multiple crossing points, the availability of street lighting, and other appropriate factors. MUTCD recommends against installing crosswalks alone without other measures designed to reduce traffic speeds or increase pedestrian visibility along roadways with four or more travel lanes without a raised median and ADT of 12,000 vehicles per day or greater or roadways with four or more travel lanes with raised median and ADT of 15,000 vehicles per day or greater (MUTCD, 2009).

Table 2.1: FHWA Recommendations for Installing Marked Crosswalks and other Pedestrian Enhancements at Uncontrolled Locations*

Roadway Type (Number of Travel Lanes and Median Type)	Vehicle ADT 9,000			Vehicle ADT > 9,000 to 12,000			Vehicle ADT > 12,000 to 15,000			Vehicle ADT > 15,000		
	Speed Limit**											
	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph	30 mph	35 mph	40 mph
Two lanes	C	C	P	C	C	P	C	C	N	C	P	N
Three lanes	C	C	P	C	P	P	P	P	N	P	N	N
Multilane (four or more lanes) with raised median* **	C	C	P	C	P	N	P	P	N	N	N	N
Multilane (four or more lanes) without a raised median)	C	P	N	P	P	N	N	N	N	N	N	N

* These guidelines include intersection and midblock locations with no traffic signals or stop signs on the approach to the crossing. They do not apply to school crossings. A two-way center turn lane is not considered a median. Crosswalks should not be installed at locations that could present an increased safety risk to pedestrians, such as where there is poor sight distance, complex or confusing designs, a substantial volume of heavy trucks, or other dangers, without first providing adequate design features and/or traffic control devices. Adding crosswalks alone will not make crossings safer, nor will they necessarily result in more vehicles stopping for pedestrians. Whether or not marked crosswalks are installed, it is important to consider other pedestrian facility enhancements (e.g., raised median, traffic signal, roadway narrowing, enhanced overhead lighting, traffic-calming measures, curb extensions), as needed, to improve the safety of the crossing. These are general recommendations; good engineering judgment should be used in individual cases for deciding where to install crosswalks.
** Where the speed limit exceeds 40 mph, marked crosswalks alone should not be used at unsignalized locations.
*** The raised median or crossing island must be at least 1.2 m (4 ft) wide and 1.8 m (6 ft) long to serve adequately as a refuge area for pedestrians, in accordance with MUTCD and American Association of State Highway and Transportation Officials (AASHTO) guidelines.

C = Candidate sites for marked crosswalks. Marked crosswalks must be installed carefully and selectively. Before installing new marked crosswalks, an engineering study is needed to determine whether the location is suitable for a marked crosswalk. For an engineering study, a site review may be sufficient at some locations, while a more in-depth study of pedestrian volume, vehicle speed, sight distance, vehicle mix, and other factors may be needed at other sites.

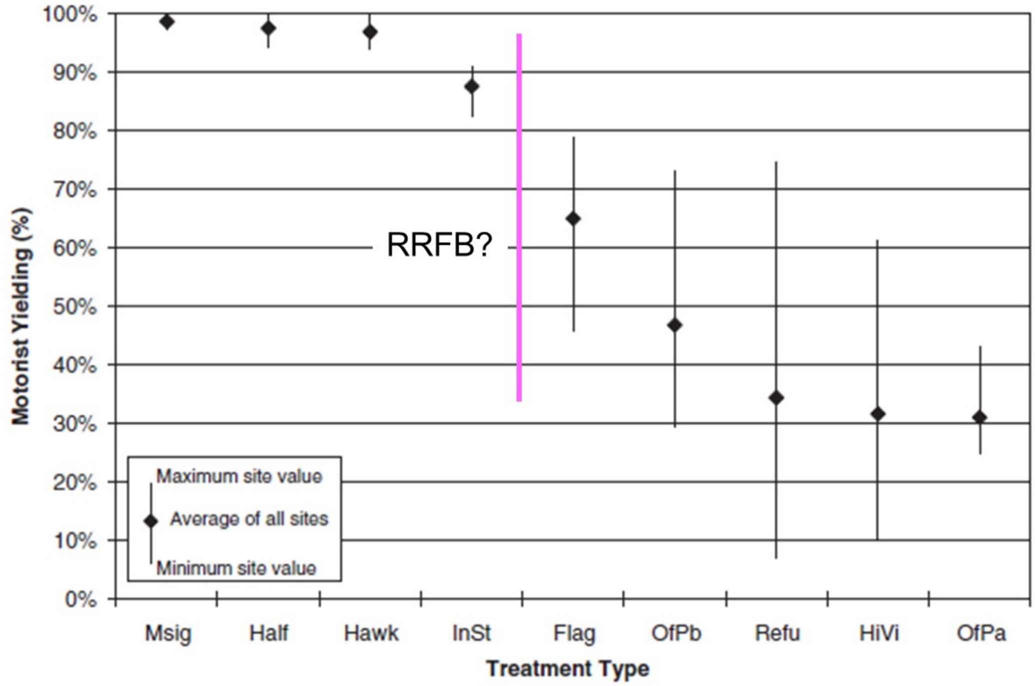
It is recommended that a minimum utilization of 20 pedestrian crossings per peak hour (or 15 or more elderly and/or children pedestrians) be confirmed at a location before placing a high priority on the installations of a marked crosswalk alone.

P = Possible increase in pedestrian crash risk may occur if crosswalks are added without other pedestrian facility enhancements. These locations should be closely monitored and enhanced with other pedestrian crossing improvements, if necessary, before adding a marked crosswalk.

N = Marked crosswalks alone are insufficient, since pedestrian crash risk may be increased by providing marked crosswalks alone. Consider using other treatments, such as traffic-calming treatments, traffic signals with pedestrian signals where warranted, or other substantial crossing improvement to improve crossing safety for pedestrians.

NCHRP Report 562, titled "*Improving Pedestrian Safety at Unsignalized Crossings*," includes a selection methodology for pedestrian crossings. A selection methodology is a delay-based approach. A primary assumption in the procedure is the anticipated driver yielding rates for the pedestrian crossing enhancement. At the time of the report, RRFBs were not in widespread use and the yielding rates were not yet established. Most recently, Appendix H of NCHRP 841 "Effects of Pedestrian Treatments at Unsignalized Crossings: A Summary of Available Research" summarized the yielding rates of drivers that have been published in the literature. The information from this report is shown in Table 2.2. There is a wide range of yielding rates observed. The yielding rates range from 35% to nearly 92% (though there are some differences in how yielding is defined). These studies also involved a wide variety of crossing designs and contexts. Figure 2.1 shows the summary figure produced from NCHRP 562 with additional information about RRFB yielding rates superimposed.

Research Fitzpatrick et al. (2016) found that when yield or stop lines were present at the crosswalk, more drivers did not yield which is surprising. However, the authors thought that the non-yielding was probably more due to the speed limit than the presence of yield lines as 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. However, posted speed limit was also not significant in their study which indicates that the relationship between speed limit and yielding is complex and not fully explained with their evaluation.



Abbreviations: Msig=midblock signal; Half=half signal; Hawk=HAWK signal beacon; InSt=in-street crossing signs; Flag=pedestrian crossing flags; OfPb=overhead flashing beacons (pushbutton activation); Refu=median refuge island; HiVi=high-visibility signs and markings; OfPa=overhead flashing beacons (passive activation)

Figure 2.1: Yielding rates in NCHRP 562 (RRFB range added by authors)

Table 2.2: Summary of RRFB Yielding Rates

Study	Before	After	# Sites	Location
Van Houten, Ellis, & Marmolejo (2008)	0	65	1	Miami-Dade County, Florida
	1	92	1	
Pecheux, Bauer & McLeod (2009)	2	35	2	Miami, FL
Hua, J., et al. (2004)	70	80	1	San Francisco, CA
Hunter, W. W., R. Srinivasan, and C. A. Martell. (2009)	2	54	1	St. Petersburg, FL
Shurbutt and Van Houten (2011)	4	84	22	St. Petersburg, FL Washington, D.C. Mundelein, IL
Ross, Serpico & Lewis (2011)	23-25	83	2	Bend, OR
Fitzpatrick et al. (2014)	n.a.	34 to 92	22	Texas
Foster, Monsere & Carlos (2014)	n.a.	91 to 92	2	Portland, OR

A valuable graphical solution is presented in NCHRP 562, relating pedestrian volume crossing a major road, and the major road vehicle volume is shown in Figure 2.2. The type of crossing enhancement is stratified by "Enhanced" "Active" and "Red" and the delay thresholds used to prepare the figure. From the report, these categories are defined as:

- Enhanced - This category includes those devices that enhance the visibility of the crossing location and pedestrians waiting to cross. Warning signs, markings, or beacons in this category are present or active at the crossing location at all times.

- Active - Also called "active when present," this category includes those devices designed to display a warning only when pedestrians are present or crossing the street.

- Red - This category includes those devices that display a circular red indication (signal or beacon) to motorists at the pedestrian location.

- Signal - This category pertains to traffic control signals.

As the installation of a pedestrian crossing treatment alone does not necessarily result in more vehicles yielding to pedestrians, Figure 2.2 suggests that at high vehicle and pedestrian crossing volumes, red indications are recommended. RRFBs would fall into the E/A and E/A HC region of Figure 2.2.

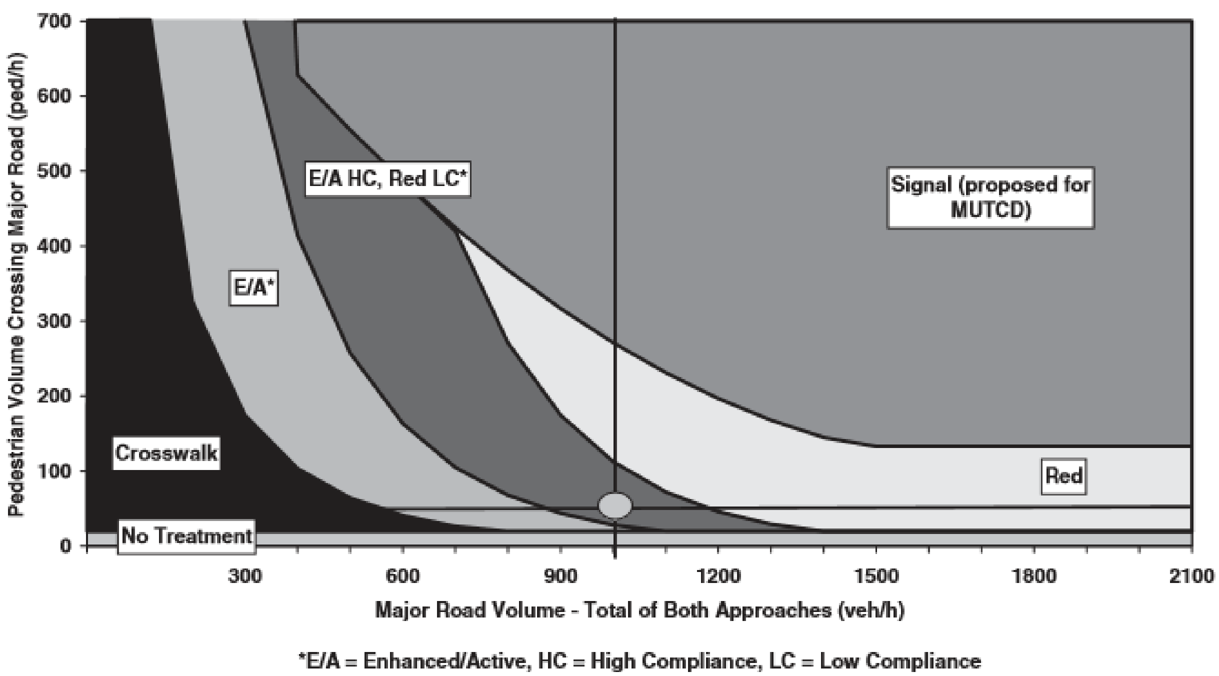


Figure 2.2: Graphical solution presented as an example in NCHRP Report 562.

Other studies have also compared motorist behavior at marked and unmarked crosswalks. Knoblauch and Raymond studied uncontrolled intersections in Maryland, Virginia, and Arizona and found that a marked crosswalk with no pedestrians present led to a 2.6 mph reduction in vehicle speeds, which was statistically significant. The presence of a pedestrian also led to reduced vehicular speeds. In a later study, Knoblauch found differences in motorist behavior at marked and unmarked crosswalks (Knoblauch et al. 2001). Motorist speeds reduced and pedestrian volumes increased after the installation of markings (Knoblauch et al. 2001). Mitman and Ragland found there was ample confusion regarding the right of way at crosswalks especially in complex scenarios (Mitman and Ragland, 2009). Finally, pedestrian behavior at marked and unmarked crosswalks has been evaluated. While Knoblauch did not find any evidence of aggressive pedestrian behavior following the installation of marked crosswalks, Mitman et al. found that pedestrians at unmarked crosswalks waited for a larger gap prior to the crossing (Mitman et al. 2008).

2.2 RRFB AS PREFERRED TREATMENT

RRFBs are used at uncontrolled crosswalks as warning beacons to supplement any standard pedestrian crossing or school crossing signs. Beginning in 2008, the FHWA provided interim approval for the usage of RRFBs on a state by state basis following each state's application. In December 2017, the interim approvals were rescinded due to an ongoing patent case; however, FHWA recommended that installed RRFBs may remain in service and need not be removed. In March 2018, FHWA issued Interim Approval for *Optional Use of Pedestrian-Actuated Rectangular Rapid-Flashing Beacons (RRFBs) at Uncontrolled Marked Crosswalks* (IA-21) that once again permitted installation of RRFB beacons.

A review of guidance documents was conducted to determine the state of practice with respect to RRFB installation and design. Websites of state DOTs, counties, and cities were explored to study the guidelines and best practices for RRFB installations. In addition to reviewing the websites, the research team also conducted an extensive internet search and contacted various listservs (e.g., APBP) to gather the relevant information. Specific bike-ped coordinators at state DOTs and other agencies were also contacted. While it is unlikely that the current review is exhaustive and includes all guidance documents, it does serve to document the current state of practice.

FHWA's "Guide to Improving Pedestrian Safety and Uncontrolled Crossing Locations" provides a summary of crossing treatments by roadway configuration, posted speed, and volume ranges (Blackburn et al. 2018). For the 3-lane configurations with a raised median, RRFBs should be considered for all categories except 9,000 ADT and <= 30 mph through 15,000 ADT and >= 40 mph. For 3- lane configurations without a raised median RRFB are not recommended for 9,000 ADT and >= 40 mph, 9,000-15,000 ADT and >= 40 mph, and >15,000 ADT and >= 35mph.

Roadway Configuration	Posted Speed Limit and AADT								
	Vehicle AADT <9,000			Vehicle AADT 9,000–15,000			Vehicle AADT >15,000		
	≤30 mph	35 mph	≥40 mph	≤30 mph	35 mph	≥40 mph	≤30 mph	35 mph	≥40 mph
2 lanes (1 lane in each direction)	❶ 2 4 5 6	❶ 5 6 7 9	① 5 6 ❼ ❾	❶ 4 5 6	❶ 5 6 7 9	① 5 6 ❼ ❾	❶ 4 5 6 7 9	① 5 6 7 9	① 5 6 ❾
3 lanes with raised median (1 lane in each direction)	❶ 2 3 4 5	❶ ❸ 5 7 9	① ❸ 5 ❼ ❾	① 3 4 5 7 9	① ❸ 5 ❼ ❾	① ❸ 5 ❼ ❾	① ❸ 4 5 7 9	① ❸ 5 ❼ ❾	① ❸ 5 ❾
3 lanes w/o raised median (1 lane in each direction with a two-way left-turn lane)	❶ 2 3 4 5 6 7 9	❶ ❸ 5 6 7 9	① ❸ 5 6 ❾	① 3 4 5 6 7 9	① ❸ 5 6 ❼ ❾	① ❸ 5 6 ❾	① ❸ 4 5 6 7 9	① ❸ 5 6 ❾	① ❸ 5 6 ❾
4+ lanes with raised median (2 or more lanes in each direction)	❶ ❸ 5 7 8 9	❶ ❸ 5 7 8 9	① ❸ 5 8 ❾	① ❸ 5 7 8 9	① ❸ 5 ❼ 8 ❾	① ❸ 5 8 ❾	① ❸ 5 ❼ 8 ❾	① ❸ 5 8 ❾	① ❸ 5 8 ❾
4+ lanes w/o raised median (2 or more lanes in each direction)	❶ ❸ 5 6 7 8 9	① ❸ 5 ❻ 7 8 9	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ 7 8 9	① ❸ 5 ❻ ❼ 8 ❾	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ ❼ 8 ❾	① ❸ 5 ❻ 8 ❾	① ❸ 5 ❻ 8 ❾

Given the set of conditions in a cell,

- \# Signifies that the countermeasure is a candidate treatment at a marked uncontrolled crossing location.
- ● Signifies that the countermeasure should always be considered, but not mandated or required, based upon engineering judgment at a marked uncontrolled crossing location.
- ○ Signifies that crosswalk visibility enhancements should always occur in conjunction with other identified countermeasures.*

The absence of a number signifies that the countermeasure is generally not an appropriate treatment, but exceptions may be considered following engineering judgment.

1 High-visibility crosswalk markings, parking restrictions on crosswalk approach, adequate nighttime lighting levels, and crossing warning signs
2 Raised crosswalk
3 Advance Yield Here To (Stop Here For) Pedestrians sign and yield (stop) line
4 In-Street Pedestrian Crossing sign
5 Curb extension
6 Pedestrian refuge island
7 Rectangular Rapid-Flashing Beacon (RRFB)**
8 Road Diet
9 Pedestrian Hybrid Beacon (PHB)**

*Refer to Chapter 4, 'Using Table 1 and Table 2 to Select Countermeasures,' for more information about using multiple countermeasures.

**It should be noted that the PHB and RRFB are not both installed at the same crossing location.

This table was developed using information from: Zegeer, C.V., J.R. Stewart, H.H. Huang, P.A. Lagerwey, J. Feaganes, and B.J. Campbell. (2005). Safety effects of marked versus unmarked crosswalks at uncontrolled locations: Final report and recommended guidelines. FHWA, No. FHWA-HRT-04-100, Washington, D.C.; FHWA. Manual on Uniform Traffic Control Devices, 2009 Edition. (revised 2012). Chapter 4F, Pedestrian Hybrid Beacons. FHWA, Washington, D.C.; FHWA. Crash Modification Factors (CMF) Clearinghouse. http://www.cmfclearinghouse.org/; FHWA. Pedestrian Safety Guide and Countermeasure Selection System (PEDSAFE). http://www.pedbikesafe.org/PEDSAFE/; Zegeer, C., R. Srinivasan, B. Lan, D. Carter, S. Smith, C. Sundstrom, N.J. Thirsk, J. Zegeer, C. Lyon, E. Ferguson, and R. Van Houten. (2017). NCHRP Report 841: Development of Crash Modification Factors for Uncontrolled Pedestrian Crossing Treatments. Transportation Research Board, Washington, D.C.; Thomas, Thirsk, and Zegeer. (2016). NCHRP Synthesis 498: Application of Pedestrian Crossing Treatments for Streets and Highways. Transportation Research Board, Washington, D.C.; and personal interviews with selected pedestrian safety practitioners.

Figure 2.3: Application of pedestrian crash countermeasures by roadway feature (FHWA 2018)

The review for this research also found specific RRFB guidance at six DOTs (District of Columbia, Washington, Utah, Colorado, Minnesota, Florida, and Virginia) and four cities (Denver, Boulder, Sacramento, and Portland). A majority of the guidance documents and county/city guidelines add RRFB guidance to the existing FHWA framework as shown previously in Table 2.1. Table 2.3 shows a summary of the specific guidance found from our review that mostly follows the FHWA recommendation table stratified by vehicle volume, posted speed and number of lanes to cross. The shaded cells represent the recommendations as they apply to roadways with and without a median respectively.

In general, most jurisdictions recommend RRFBs for two and three-lane roads at speeds of 40 mph or higher at lower ADTs. Some guidelines have distinct recommendations for roads with medians, as well. Jurisdictions begin to differ in standard as the lane count goes up to four or more, as shown by the variety of recommendations in Table 2.3. As an example, Figure 2.8 shows the guidelines from the Portland Bureau of Transportation (PBOT) which include specific recommendations for three lanes and multi-lanes with and without raised median with and without raised medians. Figure 2.8 shows that RRFBs are not recommended at locations with higher speeds and without the presence of a raised median where the pedestrians have to cross 3 or more lanes. There is some difference in the language of the guidance. For example, the Washington State DOT (WSDOT) *requires* RRFB on state roadways in Washington state with two or more lanes and a median at 40 mph and on roadways with two or more lanes going one way at 40 mph while the New York State Department of Transportation (NYSDOT) *recommends* RRFBs on state roadways in NY state with two or more lanes at speeds ranging from 30 mph to 45 mph.

Some agencies have also adapted the NCHRP 562-delay based charts to include RRFBs. Figure 2.4 and Figure 2.5 show the guidance from the City of Boulder regarding the installation of RRFBs and other crossing enhancements. These recommendations suggest that RRFBs are not suitable at locations with high vehicular and pedestrian volumes on both low and high-speed roadways. Figure 2.6 and Figure 2.7 show similar guidance from the Florida Traffic Engineering Manual for both high speed and low-speed roadways.

Table 2.3: Recommendations for Installation/Use of RRFBs

Lanes	ADT	Speed (mph)	DDOT		Utah DOT		Colorado DOT		Minnesota DOT		Virginia DOT		City of Denver		City of Sacramento		City of Boulder		PBOT	
			NM	MP	NM	MP	NM	MP	NM	MP	NM	MP	NM	MP	NM	MP	NM	MP	NM	MP
2	≤ 9,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 9,000 to ≤ 12,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 12,000 to ≤ 15,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 15, 000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
3	≤ 9,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 9,000 to ≤ 12,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 12,000	≤ 30																		
		35																		

Lanes	ADT	Speed (mph)	DDOT		Utah DOT		Colorado DOT		Minnesota DOT		Virginia DOT		City of Denver		City of Sacramento		City of Boulder		PBOT	
	to ≤ 15,000	40																		
		45+							-	-			-	-						
	> 15, 000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
4+	≤ 9,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 9,000 to ≤ 12,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 12,000 to ≤ 15,000	≤ 30																		
		35																		
		40																		
		45+							-	-			-	-						
	> 15, 000	≤ 30					-	-												
		35					-	-												
		40					-	-												
		45+					-	-	-	-			-	-						

NM – No median on roadway; MP – Median present on roadway; - Not specified

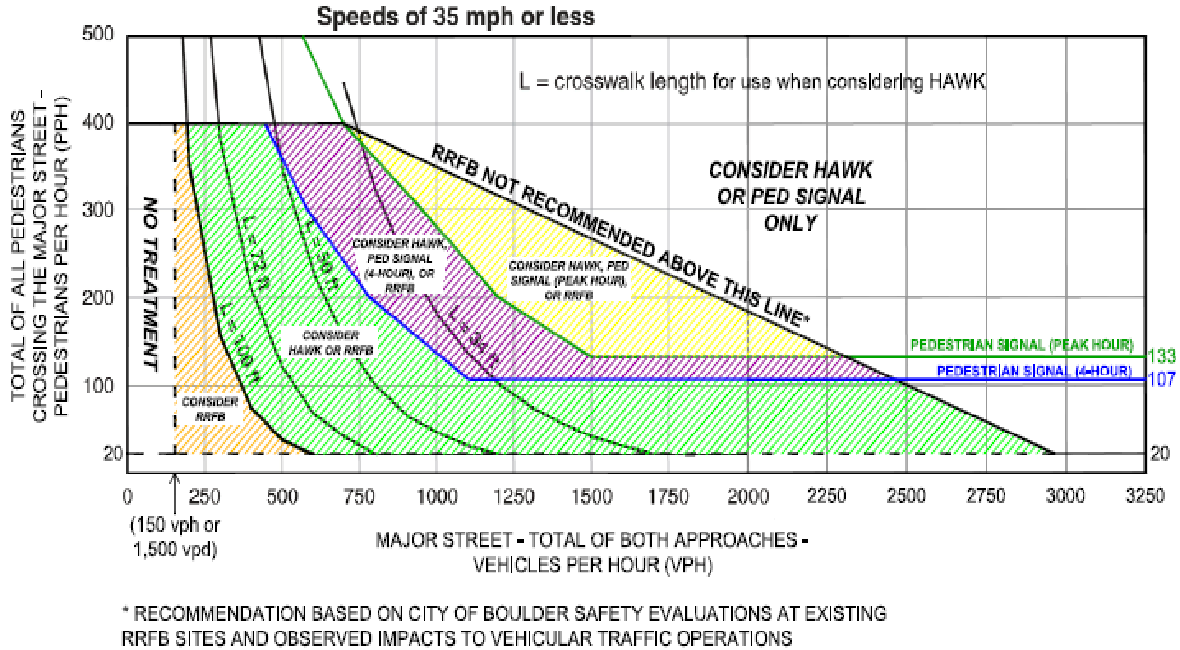


Figure 2.4: Sample volume-based guidelines from Boulder for RRFB Installations on low-speed roads (Source: City of Boulder Pedestrian Crossing Treatment Installation Guidelines, 2011)

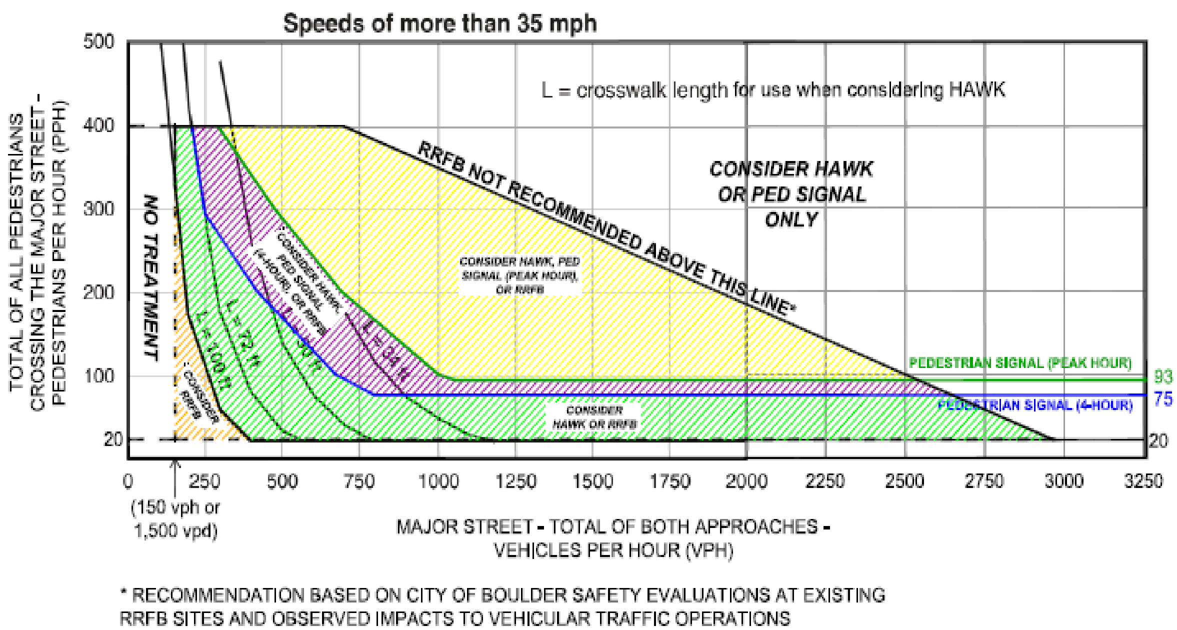


Figure 2.5: Sample volume-vased guidelines from Boulder for RRFB Installations on high-speed roads (Source: City of Boulder Pedestrian Crossing Treatment Installation Guidelines, 2011)

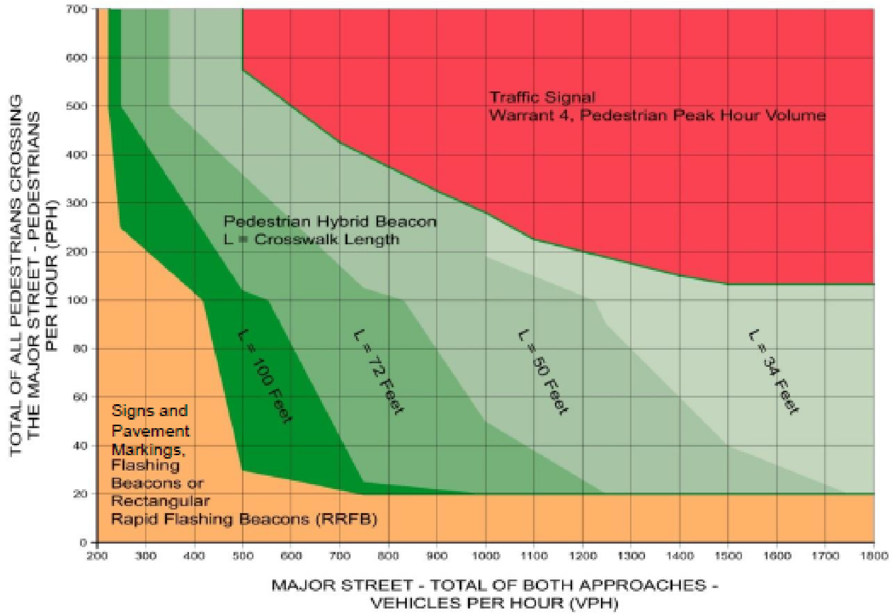


Figure 2.6: Guidelines for RRFB and other pedestrian countermeasure installation on low-speed roads (Source: Traffic Engineering Manual, FDOT, 2020)

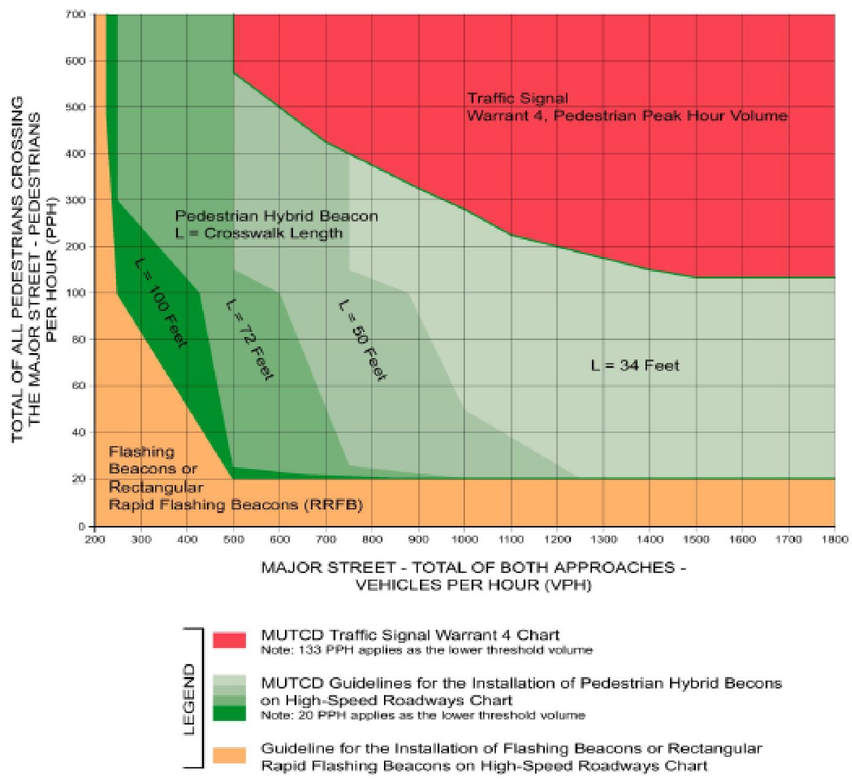


Figure 2.7: Guidelines for RRFB and other pedestrian countermeasure installation on high-speed roads (Source: Traffic Engineering Manual, FDOT, 2020)

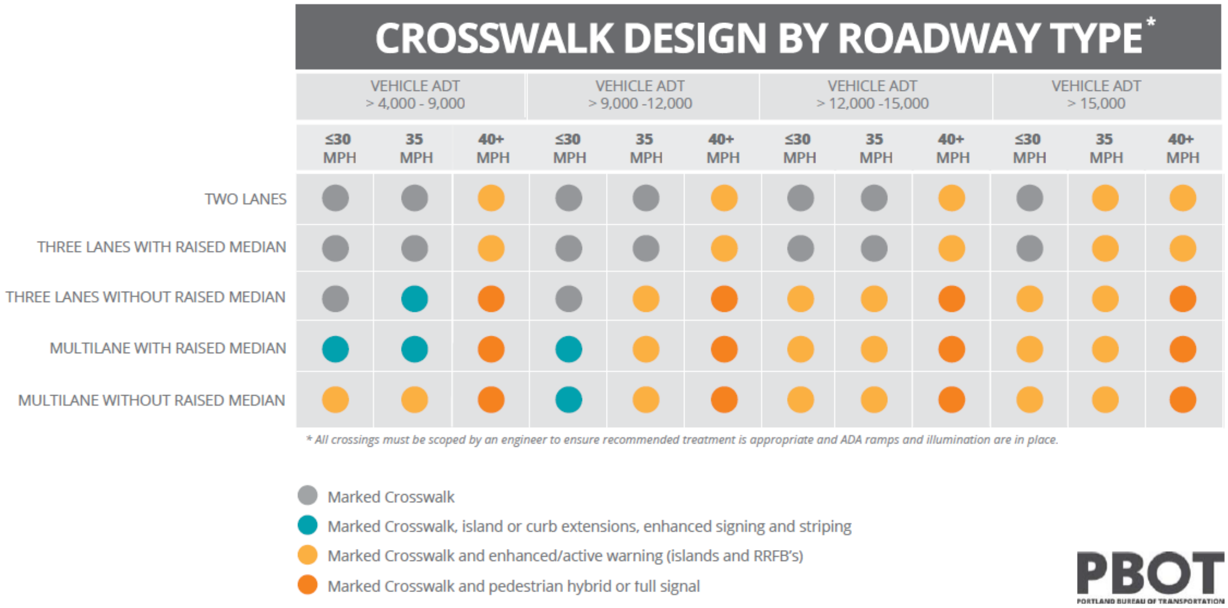


Figure 2.8: PBOT guidance for crossing enhancements by type (Source: Crosswalk Guidelines for Portland, PBOT, n.d.)

2.2.1 Number and Location of Beacons

There has been limited research about the primary design details of the RRFB, the optimal number of and placement of beacons and the use of medians. According to the MUTCD, for any approach for which RRFBs are used, the beacons along with the crossing warning signs, shall be installed at the crosswalk, one each on the right-hand side and left-hand side of the roadway. On a divided highway, MUTCD recommends that the left-hand side beacon is installed on the median, rather than the far left side of the roadway. As an example, Figure 2.9 and Figure 2.10 shows standard WashDOT drawings for the placement of beacons with and without a median.

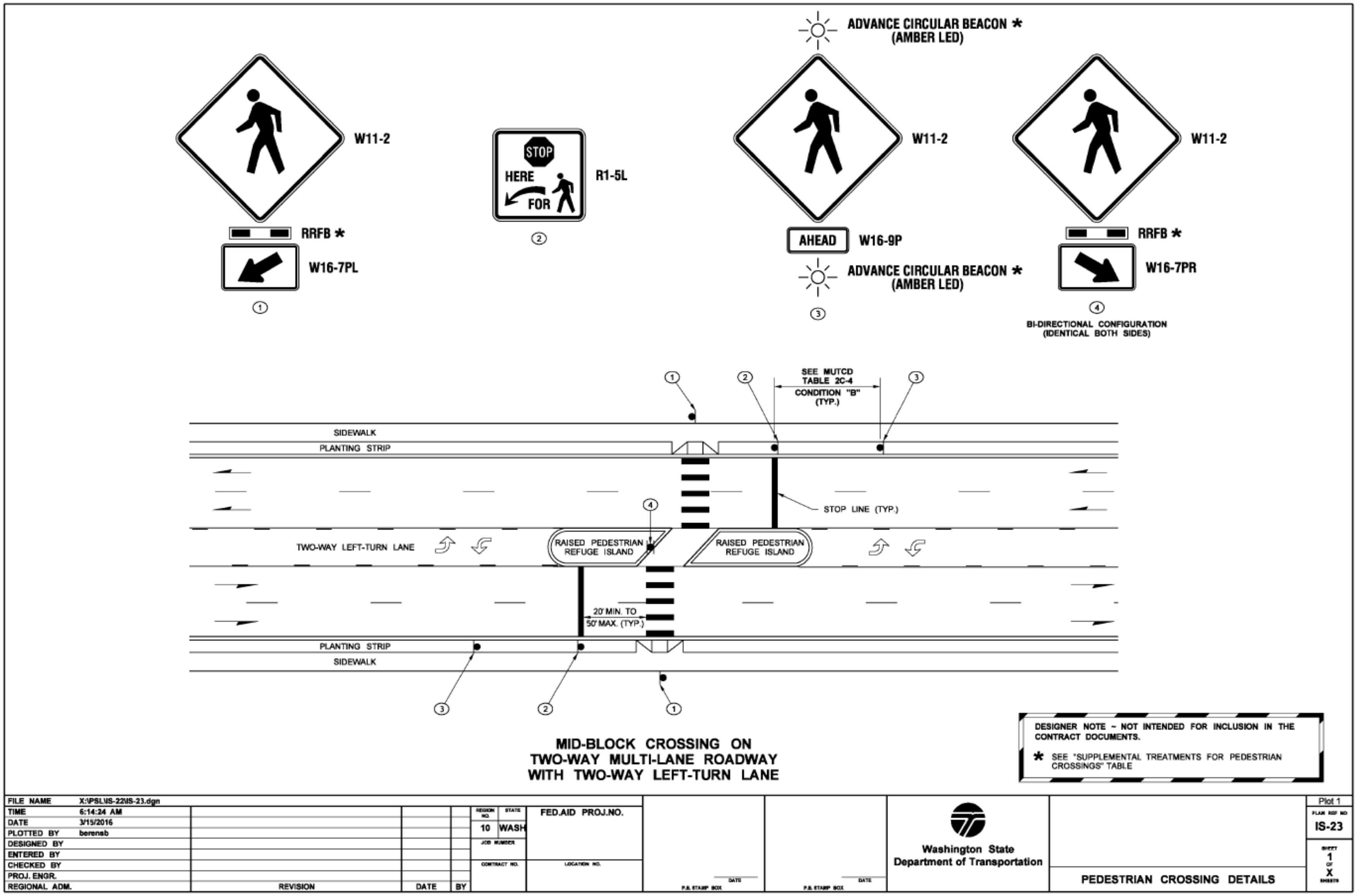


Figure 2.9: WashDOT standard drawings for RRFB beacon placement on roadways with median

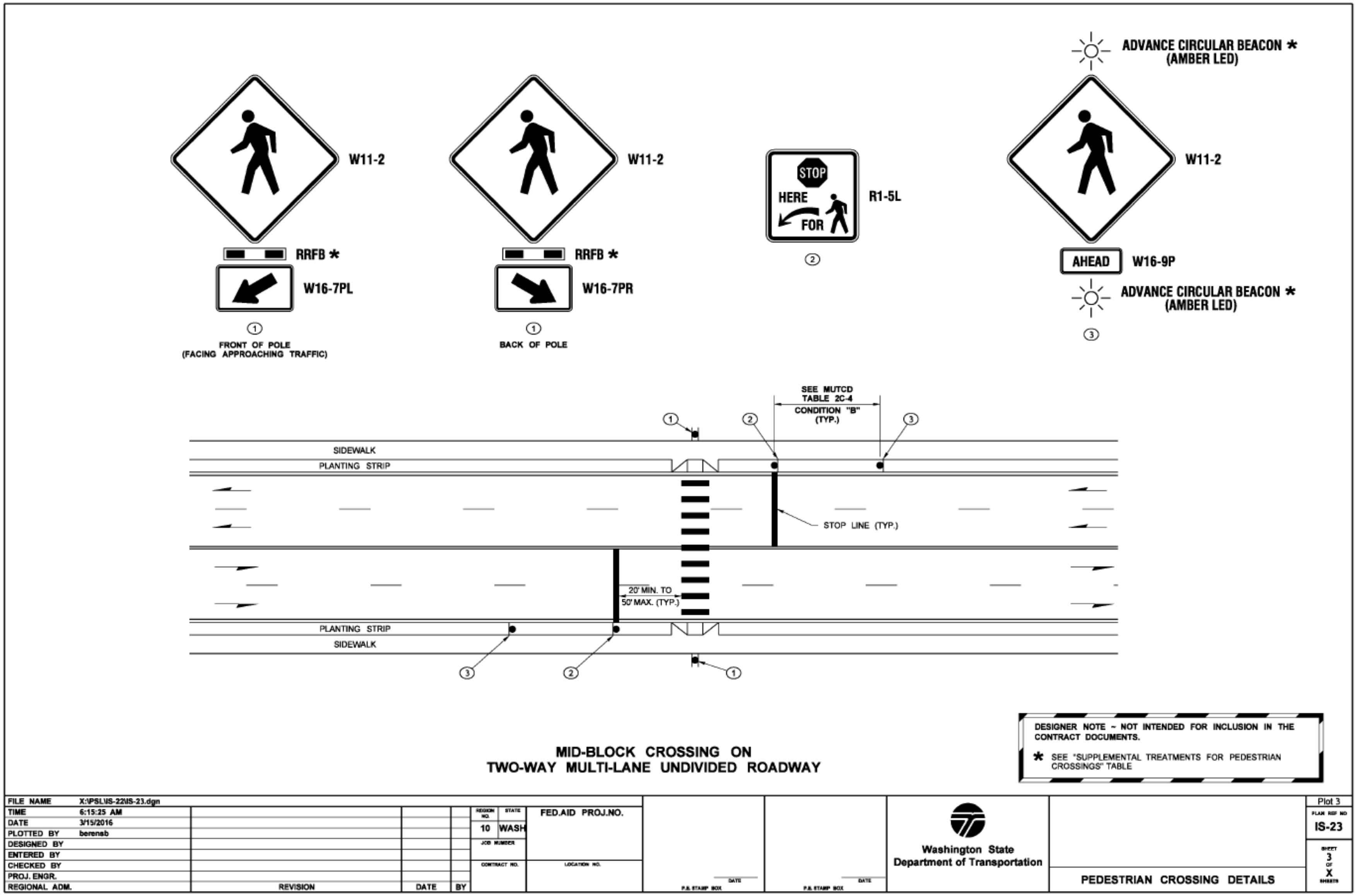


Figure 2.10: WashDOT standard drawings for RRFB beacon placement on roadways without median

2.2.2 Use of Raised Medians or Crossing Islands

A median is an area between opposing lanes of traffic and in urban areas; these medians are often raised to provide separation between motorized and non-motorized users. The combined effect of the median and RRFB beacons have not been studied in significant detail. Research by Zegeer et al. has shown that the presence of a raised median or raised crossing island led to a significantly lower pedestrian crash rate along multi-lane roadways at both marked and unmarked crosswalk locations (Zegeer et al. 2001). Other research has also demonstrated safety benefits for pedestrians from raised medians and refuge islands (Bowman and Vecellio, 1994; Garder, 1989; Gan et al. 2005; ITE, 2004).

According to the AASHTO guide for the planning design, and operation of pedestrian facilities, refuge islands or raised medians are recommended at midblock locations where the crossing width exceeds 60 feet, and there are limited gaps in traffic. They are strongly recommended on collectors with moderate to high speeds and volumes, and on multi-lane arterials at midblock locations (AASHTO, 2004). FHWA recommends that agencies should consider medians or crossing islands in sections of urban and suburban multi-lane roadways, particularly in areas with a significant mix of pedestrian and vehicle traffic and intermediate or high travel speeds (FHWA).

2.3 SUMMARY

A review of the policies and procedures regarding RRFB installation indicates that most agencies followed the general guidelines outlined by FHWA and NCHRP Report 562. The consensus followed by most state, county, and city DOTs are that RRFBs are recommended treatment when conditions do not require a red-indication (e.g., Pedestrian Hybrid Beacons or a full traffic signal). On roadways with fewer lanes and a higher ADT, RRFBs are recommended at lower speeds.

3.0 DATA COLLECTION AND REDUCTION

This chapter documents the research data collection and data reduction methods. The data collection had two objectives. First, RRFB installations were identified on three-lane roadways with crosswalks in three categories for three-lane roadways:

1. no median and RRFBs placed outside the vehicle travel lanes
2. with a median refuge island and RRFBs placed outside the vehicle travel lanes
3. with a median refuge island and RRFBs placed in the median and outside the vehicle travel lanes.

These sites were used to determine motor vehicle yielding rates. Second, sites from the SPR 778 database of locations were selected to count pedestrian activity. These data were used to update the estimate of the safety effectiveness by including pedestrian exposure. This chapter describes the criteria for site selection, data collection, and data reduction methodology for yielding and pedestrian activity.

3.1 DRIVER YIELDING EXPERIMENT

3.1.1 Identification of Potential Sites

The ODOT SPR 778 research project previously identified 39 RRFB locations with a pedestrian refuge median island and 29 RRFB locations without a pedestrian refuge island. To add to this inventory, the research team contacted multiple jurisdictions throughout Oregon and specifically requested information on RRFB installations on 3-lane roadways to add to the pool of potential locations for data collection. Table 3.1 lists the agencies that were contacted and the number of locations provided per jurisdiction. In addition to the sites provided by agencies, other RRFB locations were identified by the research team from local knowledge.

Table 3.1: Agencies that Provided Potential RRFB Locations for Study

City/County	Number of Locations Provided	Number of Locations on 3 lane roadways
Portland	74	6
Tigard	12	6
Hillsboro	17	8
Medford	3	2
ODOT	126	39

Each three-lane roadway site fell into one of three categories of interest developed by the research team:

1. No median refuge, RRFBs placed outside the roadway (NMR-OO) (Figure 3.1)

2. Median refuge, RRFBs placed outside the roadway (MR-OO) (Figure 3.2).

3. Median refuge, RRFBs placed on the island and outside the roadway (MR-IO) (Figure 3.3).

Figure 3.1: Category 1-NMR-OO: RRFB with no pedestrian refuge median island. Location: NE Walker Rd. Source: Google Maps (2019)

Figure 3.2: Category 2 MR-OO: RRFB with median island. Location US 101 in Lincoln City. Source: Google Maps (2019)

Figure 3.3: Category 3 MR-IO: RRFB with median island and median beacon. Location NE Glisan St. Source: Google Maps (2019)

3.1.2 Selection Criteria

Several criteria were outlined for selecting study locations based on significant factors that influenced yielding and driver behavior from literature. Since each jurisdiction had a distinct method of tracking RRFB locations and their associated characteristics, the research team extracted the most important characteristics relative to this study. Table 3.2 lists variables collected and used in the site selection process. These variables were obtained either from the jurisdiction or use of Google Maps and confirmed in the field.

Table 3.2: Data Collected for RRFB Selection Screening

Variable Name	Description
Median Type	Crosswalks were coded as (1- NMR-OO).No median refuge, RRFBs placed outside the roadway. (2-MR-OO.) Median refuge, RRFBs placed outside the roadway (3-MR-IO) Median refuge, RRFBs installed on the island and outside the roadway.
ODOT Facility	RRFB located on ODOT facility? (Yes or No)
Posted Speed	Posted speed of the major street (mph)
Traffic Volume	Vehicle volume on roadway (ADT)
Volume Count Date	Date motor vehicle volume was collected
Volume Count Location	Location of motorist volume collection, sometimes taken further away from the RRFB location but on the same roadway
General Land Use	Designated the general land use type surrounding the RRFB location. Possible options were: urban, rural, residential, suburban, or commercial
Install Date	Installation date of RRFB
Number of RRFB Beacons	The number of RRFB beacons visible to a driver on the approach to the crossing
Measured Crossing Distance (feet)	Measured crossing distance of crosswalk, curb to curb
Measured Crossing Distance to Median (if present)	Measured crossing distance of crosswalk to median, curb to curb. Some locations had no pedestrian refuge island and were not given a value for this variable
Advanced Yield Lines	Presence of advanced yield lines at crosswalk? (Yes or No)
Adjacent to School	Presence of adjacent school noted. (Yes or No)
Midblock Location	Location of crosswalk with RRFB at midblock (Yes or No)
School Grade Level	If presence of an adjacent school was noted, the grade level was recorded.

After dividing the RRFB locations into the three median type categories, the project team further classified the locations into a chart to match the FHWA's recommendations for installing marked crosswalks and other pedestrian enhancements at uncontrolled locations, as seen in Table 2.1. Only those locations on 3-lane roadways with known ADT and that were primarily present at midblock locations were included. This classification framed the locations that were comparable vehicle speed and volume categories so that they could be examined strictly for any differences resulting from the median type. Four vehicle ADT levels were categorized: <9,000 ADT , >=9,000 to 12,000 ADT, >=12,000 -15,000 ADT and >=15,000 ADT. There were 23 locations that fit the criteria as shown in Table 3.3. Figure 3.4 shows a map of these 23 locations that were considered for this study. Figure 3.5 and Figure 3.6 show the zoomed in map for the RRFB locations in Portland and Albany.

Twenty-three locations were chosen using the criteria listed in Table 3.2, along with additional criteria such as geographical representation. These locations are shown in Table 3.4 along with site characteristics. At least one location was chosen within each ADT category and each group category (pedestrian refuge island and RRFBs installed in the island and sidewalk, two-way left-turn lane and RRFBs installed on the sidewalk, pedestrian refuge island with RRFBs installed only on the sidewalks) was selected. The number of RRFB beacons visible to an approaching driver is noted.

Table 3.3: RRFB Location Decision Matrix with Vehicle Volume and Posted Speed

Roadway Type (Median Type)	Vehicle ADT											
	< 9,000			>= 9,000 to 12,000			>= 12,000 to 15,000			>=15,000		
	30 mph	35 mph	40+ mph	30 mph	35 mph	40+ mph	30 mph	35 mph	40+ mph	30 mph	35 mph	40+ mph
1-NMR-OO		3	-	1	1	1	1	-	-	-	-	-
2-MR-OO	-	-	-	1	-	-	-	2	1	2		1
3-MR-IO	1	1	1	1	1	-	-	1	1		2	

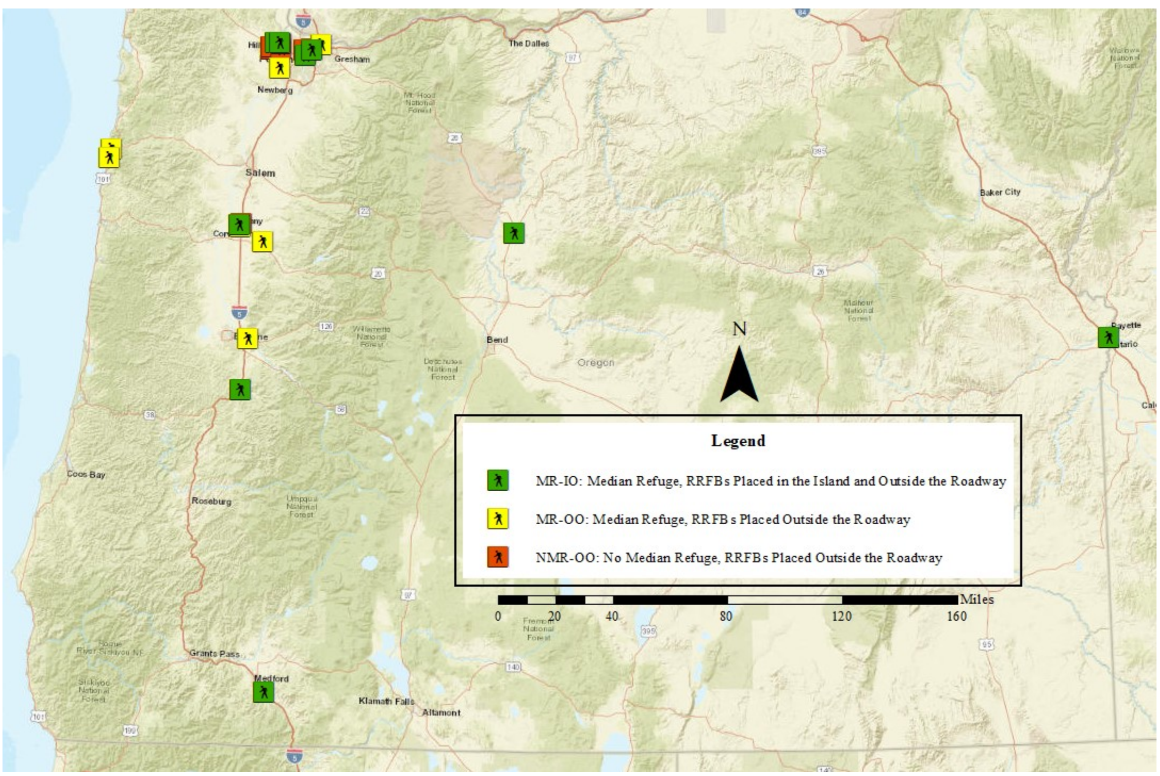


Figure 3.4: RRFB locations on 3-lane roads (Statewide)

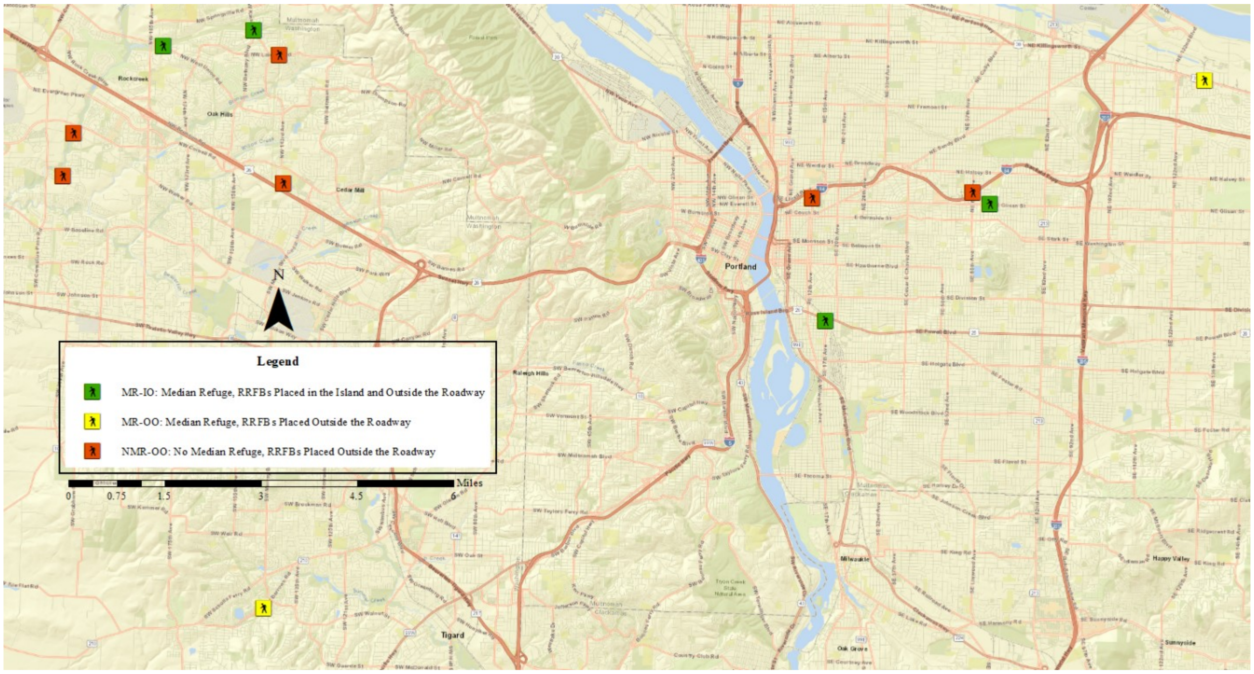


Figure 3.5: RRFB locations on 3-lane roads (Portland area zoom)

RRFB locations on 3-lane roads (Albany area zoom)

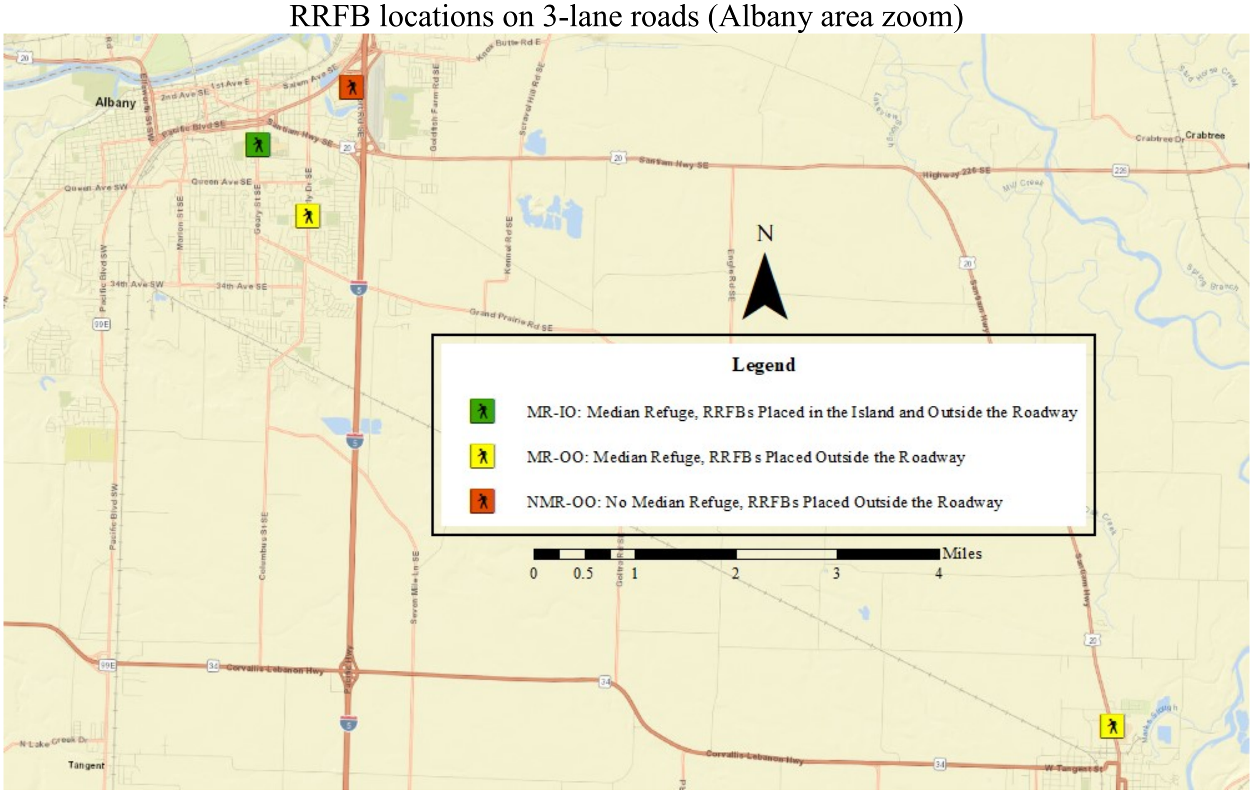


Figure 3.6: RRFB locations on 3-lane roads (Albany area zoom)

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Table 3.4: Final Sites Selected for Yielding Study

Location	City/County	Category	ADT (2018)	Posted Speed (mph)	Crossing Distance (ft)	Number of RRFB Beacons	Advance Yield (Y/N)	Adjacent to School (Y/N)	Video Data Collection
Killdeer & Costco/Kohls/Winco	Albany	1-NMR-OO	3,200	35	40	1	Y	N	10/4/18
NE Wilkins St & NW Trail Walk Dr.	Hillsboro	1-NMR-OO	6,192	35	45	1	N	N	7/31/18
NE Amberwood Dr. & Footpath	Hillsboro	1-NMR-OO	8,545	35	45	1	N	N	9/6/18
NW Laidlaw Rd W of Skycrest Pwy.	Wash.Cnty	1-NMR-OO	9,000-10,000	40	42	1	N	Y	8/23/18
NE 12th Ave & Benson High School	Portland	1-NMR-OO	10,366	30	45	1	N	Y	8/9/18
60th & Willow St	Portland	1-NMR-OO	12,000-13,000	30	50	1	N	N	10/16/18
SW Barrows Rd W of Walnut St	Beaverton	1-NMR-OO	14,615	35	45	1	Y	N	9/6/18
Waverly & 22nd Ave	Albany	1-NMR-OO	13,000-15,000	40	55	1	N	N	9/20/18
NW Science Park Drive	Portland	2-MR-OO	8,347	35	35	1	N	N	8/30/18
US 20 & Samaritan Hospital	Lebanon	2-MR-OO	8,600	30	55	1	Y	N	9/20/18
Olympic St & Winco/Sonic	Springfield	2-MR-OO	11,440	35	55	1	N	N	10/2/18
US 101 MP 116.56	Lincoln City	2-MR-OO	17,000-19,000	30	50	1	N	N	9/27/18
Sandy Blvd & 131st Place	Portland	2-MR-OO	19,800	35	52	1	N	N	10/6/18
US 101, NW 33rd NW 43rd St.	Lincoln City	2-MR-OO	20,900	30	55	1	Y	N	9/27/18
17th & Pershing	Portland	3-MR-IO	3,000-4,000	30	50	2	N	N	8/9/18
Oregon St & NW 8th Street	Ontario	3-MR-IO	4,300	45	45	2	Y	N	10/11/18

Location	**City/County**	**Category**	**ADT (2018)**	**Posted Speed (mph)**	**Crossing Distance (ft)**	**Number of RRFB Beacons**	**Advance Yield (Y/N)**	**Adjacent to School (Y/N)**	**Video Data Collection**
Main & Bear Creek Dr	Phoenix	3-MR-IO	8,200	35	50	2	N	N	9/25/18
NE Glisan St. & NE. 65th Avenue	Portland	3-MR-IO	8,389	30	60	2	N	N	7/26/18
NW Kaiser Rd N of Bethany Blvd	Wash.Cnty.	3-MR-IO	9,000-10,000	35	60	2	Y	N	8/23/18
NW West Union & Rock Creek Trail	Hillsboro	3-MR-IO	12,526	40	50	2	N	N	8/30/18
Cottage Grove I-5 Conn	Cottage Gr.	3-MR-IO	14,000	35	46	2	Y	N	10/2/18
Dalles-California Hwy, near Fairgrounds Rd	Madras	3-MR-IO	17,700	35	50	2	N	N	8/17/18
Geary & Heritage Mall	Albany	3-MR-IO	18,500	35	60	2	N	N	10/4/18

3.1.3 Video Data Collection

The research team contracted with a vendor (Quality Counts) to set up cameras at the sites identified for the yielding study and re-estimation of the SPR 778 models. The video data for the entire study was collected between July – October 2018 on good weather days only, so as to prevent any data quality issues and to allow the research team to derive metrics from the video later on. At the yielding sites, the vendor was instructed to capture the crosswalk and both approaches in the field of view. Depending on the location, two or three cameras were used to achieve captures of the crosswalk and surroundings. Figure 3.7 shows the screen capture at the RRFB on SW Barrows Rd. for the yielding study.

The video data provides an opportunity to confirm the characteristics of crossing, including whether the pedestrian used the push button to activate the beacons and the vehicle yielding behavior. It also allows observers to gather vehicular and pedestrian volumes. The cameras were set up on a Tuesday, Wednesday or Thursday from 7 AM – 7 PM.

Figure 3.7: Screen capture of video image at RRFB on SW Barrows Rd.

3.1.4 Use of Staged Pedestrian for Yielding Experiment

The methodological approach that was used to determine yielding was based on prior work by Fitzpatrick et al. 2015. The project team used a staged pedestrian protocol to collect driver yielding data to ensure that oncoming drivers receive a consistent presentation of approaching pedestrians (Fitzpatrick et al., 2016). If a naturalistic crossing was observed in the video during the time period when the staged crossings were collected, it was included in the analysis. A member of the project team approached the crosswalk as a pedestrian intending to cross. Each staged pedestrian was uniformly clothed (gray T-shirt, blue jeans, and gray tennis-shoes) and crossed the roadway, in the same manner, every time. For the first few sites, a second member of the project team observed and recorded the yielding data on standardized sheets that were later coded into a digital spreadsheet. While the manual observations were recorded for the initial sites, the project team decided that it would be more accurate to capture the metrics via video, and hence these manual observations are not recorded at the later sites.

The protocol prescribed by Fitzpatrick et al. required that the stopping sight distance on each roadway be marked with cones or markers. As vehicles approach the SSD marker, the staged pedestrian approached the crosswalk and activated the push button. The staged pedestrian waited to cross until the approaching drivers yielded or until all the drivers traveled through the crosswalk. Data collection crews obtained a minimum of 60 (30 each direction) staged pedestrian interactions at each site during daytime light conditions. After each staged crossing, the project team member walked away from the crosswalk so as not to confuse the driver's about intent to cross. The project team collected the staged pedestrian 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. The staged crossings were also performed during non-peak hours (between 9 AM – 4 PM) to avoid traffic congestion and queues potentially blocking the crosswalk. Performing the data collection during the non-peak hours also provided an opportunity for vehicles to make the decision to yield/not yield as opposed to the peak periods, where there was a possibility of the vehicles queuing. Figure 3.8 shows a screen capture of a staged pedestrian crossing at the RRFB on US 101.

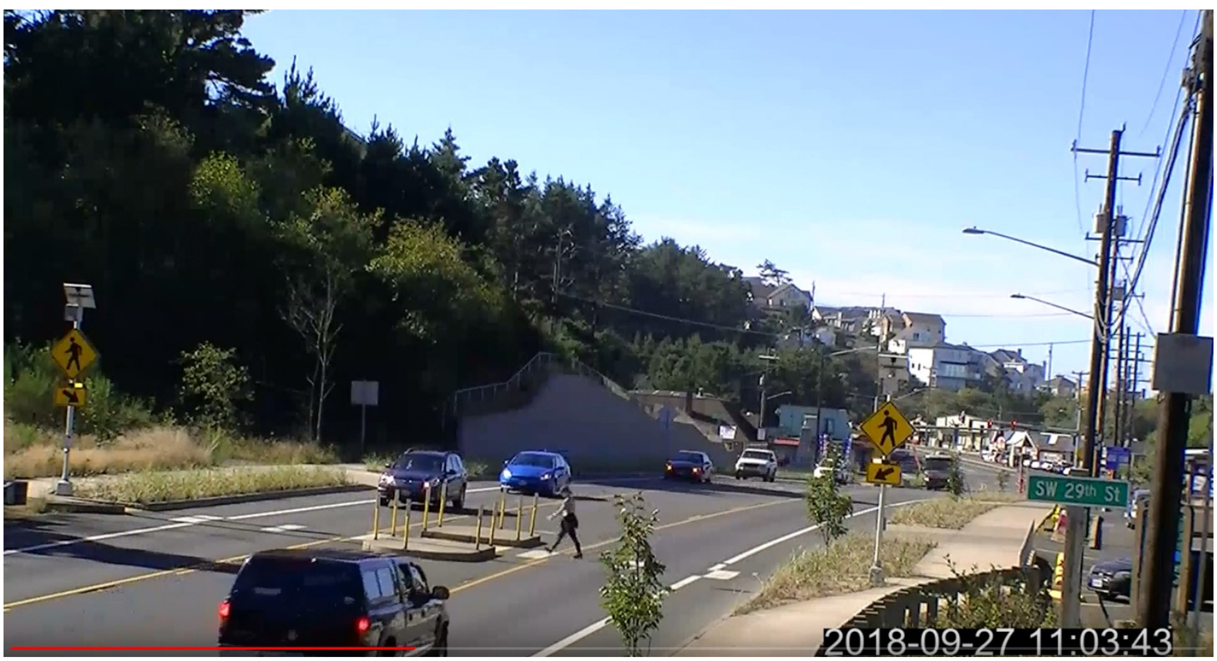

Figure 3.8: Screen capture of staged pedestrian crossing at the RRFB on US 101

3.1.5 Data Reduction

Table 3.5 lists of metrics that were coded during the video data reduction. In addition to capturing specifics about the pedestrian crossing including number, direction, waiting time, crossing time, and whether the pushbutton was activated, the coding scheme also collected driver yielding behavior on near and far-side, number of vehicles in queue, position where the driver stopped and one-minute vehicular volume prior to the pedestrian crossing. Table 3.4 listed the summary details of the data collected for the yielding study from the 23 RRFB locations of 3-lane roadways with and without median and median beacons, including the date and number of hours of video collected at each location.

Initially, the research team planned to code all 12 hrs of video at each location. However, each hour of video was taking between 2-3 hrs to fully code due to the large number of data elements that were being coded for each category. Since there were a large number of sites that needed to be coded, the research team decided to code the time period when the staged crossings took place. If there were any naturalistic observations that occurred during this time period, they were also coded along with the staged observations.

After the video coding was complete, the research team cleaned and reviewed the datato ensure that the data elements were coded correctly. All inconsistent data entries were identified and fixed. The collected data was used to calculate the following metrics:

$$\textit{Ped Delay at Start} = \textit{Time Ped Started Crossing} - \textit{Time Ped Arrived at Crosswalk} \tag{3-1}$$

$$\textit{Ped Delay in Median} = \textit{Time Ped Reached Median} - \textit{Time Ped Started Crossing} \tag{3-2}$$

$$\textit{Ped Crossing Time} = \textit{Time Ped Finished Crossing} - \textit{Time Ped Started Crossing} \tag{3-3}$$

$$\textit{Yielding Rate} = \frac{\textit{Total number of vehicles yielding}}{(\textit{Total number of vehicles yielding} + \textit{Total number of vehicles not yielding})} \tag{3-4}$$

Table 3.5: Summary Details of Video Data Processing

Variable	Description
Observation ID	Sequential ID for each observation of a pedestrian.
Staged Pedestrian (Y/N)	Y for a staged pedestrian crossing, N for a regular pedestrian.
Time pedestrian arrived at the crosswalk	The time the pedestrian arrives at the c/w and stops at the curb, signaling an intent to cross.
Did pedestrian activate the pushbutton (Y/N)	Y if the pedestrian pushes the button prior to crossing and N if not.
Direction of crossing	The direction of the crossing pedestrian
Time pedestrian started crossing	The time when the pedestrian steps off the curb to begin crossing
Driver yielded near-side (Y/N)	When the pedestrian arrives at the crosswalk, Y if the first vehicle that is at/near the SSD marker yielded and N if not. A vehicle is considered to yield if the driver slows down or stops for the purpose of allowing the pedestrian to cross.
Did near-side driver stop behind the stop bar (Y/N)	For the vehicle that yields on the near-side, Y, if the vehicle stops behind the stop bar marking, N otherwise. NA, if an advance stop bar is not present.
Number of vehicles in queue on near-side	Once the pedestrian has finished crossing, count of the number of vehicles in queue on the near-side, including the first vehicle that has yielded. If a median is present, count of the number of vehicles in queue on the near-side once the count the number of vehicles in queue on the near-side reaches the median.
If median present, time pedestrian reached median	If median is present, the time the pedestrian reached the median.
If median present, time pedestrian started crossing from median	If median is present, the time the pedestrian started crossing from the median.
Driver yielded far-side (Y/N)	Y if the driver on the far-side yielded, N if not.
Did far-side driver stop behind the stop bar (Y/N)	For the vehicle that yields on the far-side, Y, if the vehicle stops behind the stop bar marking, N otherwise. NA, if an advance stop bar is not present.
Number of vehicles in queue on far-side	Once the pedestrian has finished crossing, count of the number of vehicles in queue on the far-side, including the first vehicle that has yielded.
Time pedestrian finishes crossing	The time the pedestrian finishes crossing and reaches the other side.
One-minute volume on near-side	For one minute prior to when the pedestrian reached the crossing, count of the volume of cars on the near-side.
One-minute volume on far-side	For one minute prior to when the pedestrian reached the crossing, count the volume of cars on the far-side.
Number of pedestrians crossing	The number of pedestrians crossing in the same direction at the same time.

3.2 PEDESTRIAN VOLUMES

3.2.1 Site Selection

In addition to exploring the yielding behavior at locations on 3-lane roadways with and without median beacons, another objective of this study is to re-estimate the safety effectiveness of the RRFB locations an include pedestrian exposure. To accomplish this task, additional locations were also selected from the previous dataset of locations from SPR 778. All 26 locations where pedestrian crashes occurred were chosen for pedestrian volume data collection. However, due to construction and crosswalk closure at one location, video data was only collected at 25 locations, which are shown in Table 3.6.

Table 3.6: Sites of Pedestrian Volume Data Collection

Location	City/County	Number of Lanes	Posted Speed Limit	Raised Median	Pedestrian Refuge	Beacon in Median	Midblock	Date of Video Data Collection
12th Street	Marion	4	30	Yes	Yes	Yes	Yes	9/17/18 - 9/19/18
NE 12th St & Greenwood Ave	Deschutes	4	45	Yes	Yes	Yes	No	10/10/18 – 10/12/18
Bend Pkwy & Badger Rd	Deschutes	4		Yes	Yes	Yes	Yes	10/10/18 – 10/12/18
US 199 btwn Lister St & Watkins St	Cave Junction	4	30	No	No	No	Yes	9/24/18 – 9/26/18
SE 82nd Ave & Se Center St	Multnomah	5	35	Yes	Yes	Yes	Yes	10/3/18 – 10/5/18
SW Kelly Ave	Multnomah	3		Yes	Yes	Yes	Yes	10/3/18 – 10/5/18
US 26 & 141 St	Multnomah	2	40	No	No	No	No	10/10/18 – 10/12/18
NE Sandy & 131st Pl	Multnomah	3	40	No	Yes	No	No	10/10/18 – 10/12/18
Main St East	Lane	5	35	Yes	Yes	Yes	Yes	10/1/18 – 10/3/18
Main St West	Lane	5	35	Yes	Yes	Yes	Yes	10/1/18 – 10/3/18
OR 214 & Park Ave	Marion	4	35	No	Yes	Yes	No	9/17/18 – 9/19/18
Siskiyou Blvd & Bridge St	Jackson	5	25	Yes	No	Yes	Yes	9/24/18 – 9/26/18
Siskiyou Blvd. & Garfield St	Jackson	4	25	Yes	Yes	Yes	Yes	9/24/18 – 9/26/18
NE 33rd & Klickitat St.	Multnomah	2	30	No	Yes	No	No	10/3/18 – 10/5/18
SE Foster Rd	Multnomah	4	35	No	Yes	Yes	Yes	10/3/18 – 10/5/18
Commercial St & Bellevue St.	Marion	3	25	No	No	No	No	9/17/18 – 9/19/18
NE Jackson School Rd. & NE Estate Dr	Washington	3	35	No	No	No	No	10/3/18 – 10/5/18
Beaverton Hillsdale Hwy & 62nd Ave	Washington	5	40	No	Yes	Yes	Yes	10/3/18 – 10/5/18
Se Stark St & SE 126th Ave	Multnomah	4	30	Yes	Yes	Yes	Yes	10/10/18 – 10/12/18
NE 60th & Willow St	Multnomah	4	25	No	No	No	Yes	10/3/18 – 10/5/18
SE 122nd Ave & SE Morrison St	Multnomah	5	35	Yes	Yes	Yes	Yes	10/10/18 – 10/12/18
SE Division St & SE 129th Ave	Multnomah	4	35	No	Yes	Yes	Yes	10/10/18 – 10/12/18
SE Foster Rd & SE 121st St	Multnomah	4	35	No	Yes	Yes	Yes	10/10/18 – 10/12/18
NE 122nd Ave & Oregon St	Multnomah	4	35	Yes	Yes	Yes	Yes	10/10/18 – 10/12/18
Siskiyou Blvd. & Beach St	Ashland	4	25	Yes	Yes	Yes	Yes	9/24/18 – 9/26/18

3.2.2 Video Data Collection

At the twenty-five sites where pedestrian crashes were observed, for the purposes of counting pedestrians, cameras were set up on any weekday and captured a 48-hour period. Generally, the cameras captured video from midday of the first day to the mid-day of the third day. The cameras at the three locations on Siskiyou Blvd. only recorded about 36 hours of video due to insufficient memory. At these locations, the cameras were focused on the crosswalk and only one camera angle was captured.

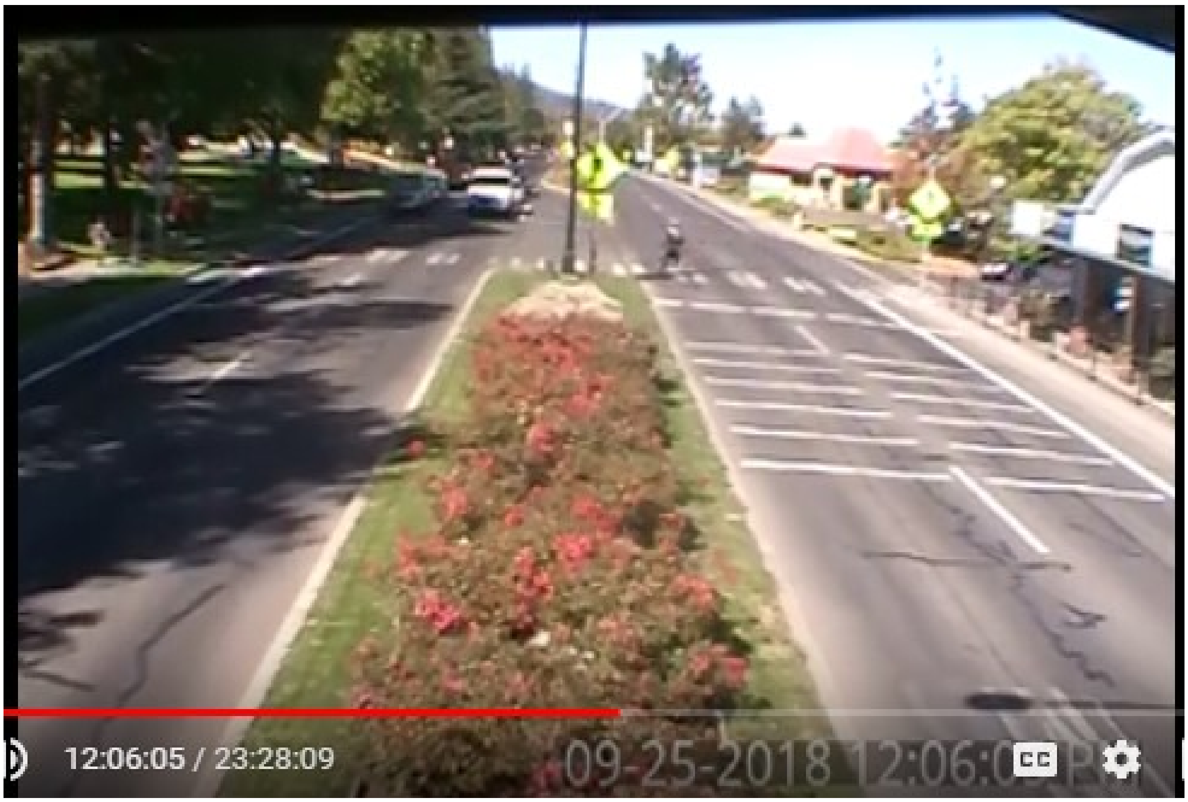

Figure 3.9: Pedestrian volume camera setup at Siskiyou Blvd near Bridge St

3.2.3 Data Reduction

Using the 48-hr video from the sites, researchers manually coded the counts of crossing pedestrians in 15-min intervals. The pedestrian counts were not separated by crossing direction. The 15-min counts were later aggregated to produce hourly and daily count estimates.

3.3 SUMMARY

This chapter presented data collection and reduction methods for both the yielding experiment and the pedestrian volume extraction. A list of selected sites, along with pertinent characteristics, was also presented. Descriptions of the data collection methodology and list of sites for pedestrian volume estimation are also included.

4.0 ANALYSIS: DRIVER YIELDING

This chapter presents the results of the yielding analysis of 1,556 crossings corresponding to 1,621 pedestrians at the categories of RRFBs crossings on three-lane roadways. The chapter includes a descriptive summary, a comparison of yielding rates by various groupings, and a statistical analysis of the yielding rates.

4.1 DESCRIPTIVE SITE SUMMARY

Table 4.1 shows the descriptive statistics at each of the twenty-three sites with RRFB's on three-lane roadways. The total number of crossing pedestrians observed was 1,556. A total of 1,338 of the crossings were staged (86%), and 218 were naturalistic crossings (14%). The number observed at each location varied from a low of 25 at the Dalles California Hwy in Madras site to a high of 104 at Oregon and NW 8th in Ontario Due to the long queues and traffic congestion at the Dalles-California Hwy site, the data collection effort was not able to get to the desired minimum of 60 staged crossings. At the Oregon and NW 8th location, the staged crossings were performed by the vendor setting up the video, who was trained regarding the staged protocol for crossing. The vendor performed extra staged crossings at this location, which were also coded.

Since naturalistic pedestrians were also coded if they crossed during the same period, the percent of staged pedestrians observed varied from 64% at the Dalles California Hwy in Madras to 100% at the Sandy Blvd and Lincoln City locations. A rate of 100% implies that all the crossing pedestrians observed in the sample were staged. The pushbutton activation rate varied between 88% and 100%. This rate is only to give context to the yielding rates since all of the staged crossing the beacons were activated. For the non-staged crossings, 170 out of the 218 crossings (78%) used the button to activate the beacon.

Delay is measured as the difference between the time the pedestrian started crossing and the time they arrived at the crosswalk. The highest average pedestrian delay prior to crossing of 13 sec was observed at the NE Glisan St and NE 65th Ave location. At most locations, the average pedestrian delay at the start was below 5 seconds. Average pedestrian delay in the median was also low typically, except at the location of Main and Bear Creek in Phoenix, OR. At this location, a median island was present. However, the pushbuttons for each of the crossings were not synched. An additional set of pushbuttons were present in the median, which the pedestrian had to activate after reaching the median, to finish the crossing. This led to an additional delay in the median. The average crossing time varied between 7 and 18 seconds. Note these crossing times also include the time spent waiting in the median.

4.2 YIELDING COMPARISON ANALYSIS

Table 4.2 summarizes the observed yielding rates for each location, including the average 1-minute volumes and vehicles in the queue for both near-side and far-side. Yielding rates were calculated for the near side and far-side vehicles. As shown in the table, high yielding rates were observed overall for both the near-side and far-side approaches. For the majority of sites, yielding rates were over 95%, with seven of the 24 sites showing a 100% yielding rate for both near and far-side approaches. Additionally, at 18 of the 24 sites, the observed yielding rate on the far-side was 100%. Loweryielding rates were observed on the near-side for US 20 and Samaritan hospital and NE Glisan and 65^{th} when compared to the other sites. At NE Glisan and 65^{th}, the majority of the non-yielding observations occurred when the pedestrian was crossing south to north. It is hypothesized that the grade at this location (uphill for cars traveling eastbound) coupled with the faded crosswalk marking especially on the eastbound leg of the approach (near-side for the pedestrians crossing south-north) may have caused difficulties for some of the vehicles to perceive the pedestrians and stop in time. At the US 20 and Samaritan hospital, the majority of the non-yielding observations on the near-side occurred when the pedestrian was crossing west to east and the vehicles were traveling southbound.

Table 4.1: Descriptive Metrics at RRFB Yielding Analysis Sites

Site Location	Cat.	AADT Group	Posted Speed (mph)	No of Crossings	% of Staged Crossings	Push button Use (%)	Avg Delay at Start (s)	Avg Delay in Median (s)	Avg Crossing Time (s)
NE Wilkins Rd	1	< 9,000	35	80	88.75	92.50	4	--	9
Kildeer & Costco	1		35	66	95.50	98.50	2	--	9.4
Walker Road	1		35	81	82.70	91.36	3	--	9.4
17th & Pershing	3		30	69	97.10	98.55	4	2	10
Main & Bear Creek	3		35	62	93.54	96.77	5	7	16.7
Oregon St & NW 8th	3		45	104	93.27	90.38	4	3	18
Benson & 12th	1	>=9,000-12,000	30	50	94.00	98.0	5	--	7.5
NW Laidlaw Rd	1		40	65	98.50	98.50	5	--	7
NE Science Park Drive	1		35	94	69.00	88.30	4	--	7.6
US 20 & Samaritan Hospital	2		30	83	72.29	97.59	7	1	10
NE Glisan & 65th	3		30	78	76.92	100.0	13	1	11
Kaiser Rd	3		35	71	92.96	100.0	4	2	11
60th & Willow St	1	>=12,000-15,000	30	26	76.90	92.31	5	--	10.3
Barrows & Walnut	2		35	87	74.70	94.25	3	1	8
Olympic St & Winco	2		35	82	74.40	98.78	4	2	11
Sandy Blvd.	2		40	28	100.0	100.0	5	2	8.8
West Union & Rock Creek Trail	3		40	74	87.84	100.0	5	2	12.3
Cottage Grove	3		35	68	95.58	92.65	2	2	8
Lincoln City US 101	2	>=15,000	30	54	100.0	100.0	5	1	9
Waverly Dr	2		40	69	95.70	98.55	4	4	11
US 101 between 33rd & 34th St	2		30	73	80.82	98.63	4	2	11
Dalles-California Hwy, near Fairgrounds Rd	3		35	25	64.00	96.00	3	3	10
Geary & Heritage	3		35	67	80.59	91.04	2	2	11.3

Note: -- No observations.

Table 4.2: Yielding Rates By Location

Site Location	Cat.	AADT Group	Posted Speed (mph)	No of Crossings	Avg-1 Min Volume		Avg No. of Veh in Queue		Yielding Rate	
					Near-side	Far-side	Near-side	Far-side	Near-side	Far-side
NE Wilkins Rd	1	< 9,000	35	80	3	5	1	1	100	100
Kildeer & Costco	1		35	66	3	3	2	1	94.74	87.88
Walker Road	1		35	81	2	3	1	1	98.63	100
17th & Pershing	3		30	69	2	3	1	2	93.85	95.45
Main & Bear Creek	3		35	62	8	8	3	2	98.39	100
Oregon St & NW 8th	3		45	104	3	3	2	1	94.12	100
Benson & 12th	1	>=9,000-12,000	30	50	5	7	4	3	100	96.77
NW Laidlaw Rd	1		40	65	4	5	3	2	95.31	96.88
NE Science Park Drive	1		35	94	5	5	3	2	100	100
US 20 & Samaritan Hospital	2		30	83	6	7	4	3	90.28	100
NE Glisan & 65th	3		30	78	9	10	5	5	85.92	100
Kaiser Rd	3		35	71	9	8	4	3	98.53	100
60th & Willow St	1	>=12,000-15,000	30	26	6	6	4	3	95.24	100
Barrows & Walnut	2		35	87	6	6	2	1	96.25	100
Olympic St & Winco	2		35	82	10	10	4	4	97.06	98.48
Sandy Blvd.	2		40	28	13	12	5	4	100	100
West Union & Rock Creek Trail	3		40	74	5	6	3	2	98.57	100
Cottage Grove	3		35	68	4	4	3	2	100	100
Lincoln City US 101	2	>=15,000	30	54	16	16	5	5	97.83	100
Waverly Dr	2		40	69	7	7	3	3	100	100
US 101 between 33rd & 34th St	2		30	73	15	14	6	7	97.26	100
Dalles-California Hwy, near Fairgrounds Rd	3		35	25	15	16	5	7	100	100
Geary & Heritage	3		35	67	7	7	2	2	100	100

4.2.1 By ADT Grouping

Table 4.3 shows the average yielding rates by the RRFB category and the ADT group. Figure 4.1 shows a plot of these data (lighter shading of the same color is the far-side rate). Recall that no sites were identified in Category 2-MR-OO for sites with ADT less than 9,000 ADT or Category 1-NMR-OO for sites with ADT greater than 15,000 ADT. The >=9,000-12,000 ADT observations for Category 2-MR-OO and 3-MR-IO contain the two sites identified earlier with the lowest yielding rates. Those locations bring the average values for the 2-MR-OO and 3-MR-IO categories in the >=9,000-12,000 ADT group to 90.28 and 92.23. All of the other yielding rates for the groups are above 95%.

Table 4.4 shows the difference in yielding rates for the "base" case for each ADT group labeled with a ***. Cells in red represent yielding rates lower than the base case in that category. In all cases except two, the far-side yielding rate exceeds the near-side rate. For all locations with a median refuge, the far-side yielding increases (whether or not there are RRFB beacons on the island. It is also clear that for the higher volume categories (>=12,000 -15,000 and >= 15,000), the addition of a median refuge island and the beacons on the island result in an increase in driver yielding on the near-side as well. For the lower volume categories, the results are more mixed. Generally, the far-side yielding increases with the refuge and beacon, but the near-side results are less clear.

Table 4.3: Average Yielding Rates by RRFB Category and ADT

Category	ADT							
	<9,000		>=9,000 to 12,000		>=12,000 - 15,000		>= 15,000	
	Near-side	Far-side	Near-side	Far-side	Near-side	Far-side	Near-side	Far-side
1-NMR-OO	97.79	95.56	98.44	97.88	95.24	100.00	--	--
2-MR-OO	--	--	90.28	100.00	97.77	99.49	98.36	100.00
3-MR-IO	95.45	98.48	92.23	100.00	99.29	100.00	100.00	100.00

Table 4.4: Difference in Base Yielding Rates by RRFB Category and ADT

Category	ADT							
	<9,000		>=9,000 to 12,000		>=12,000 - 15,000		>= 15,000	
	Near-side	Far-side	Near-side	Far-side	Near-side	Far-side	Near-side	Far-side
1-NMR-OO	**	-2.23	**	-0.56	**	4.76	--	--
2-MR-OO	--	--	-8.16	1.56	2.53	4.25	**	1.64
3-MR-IO	-2.34	0.69	-6.21	1.56	4.05	4.76	1.64	1.64

Notes:
** base yielding rate
– no observations

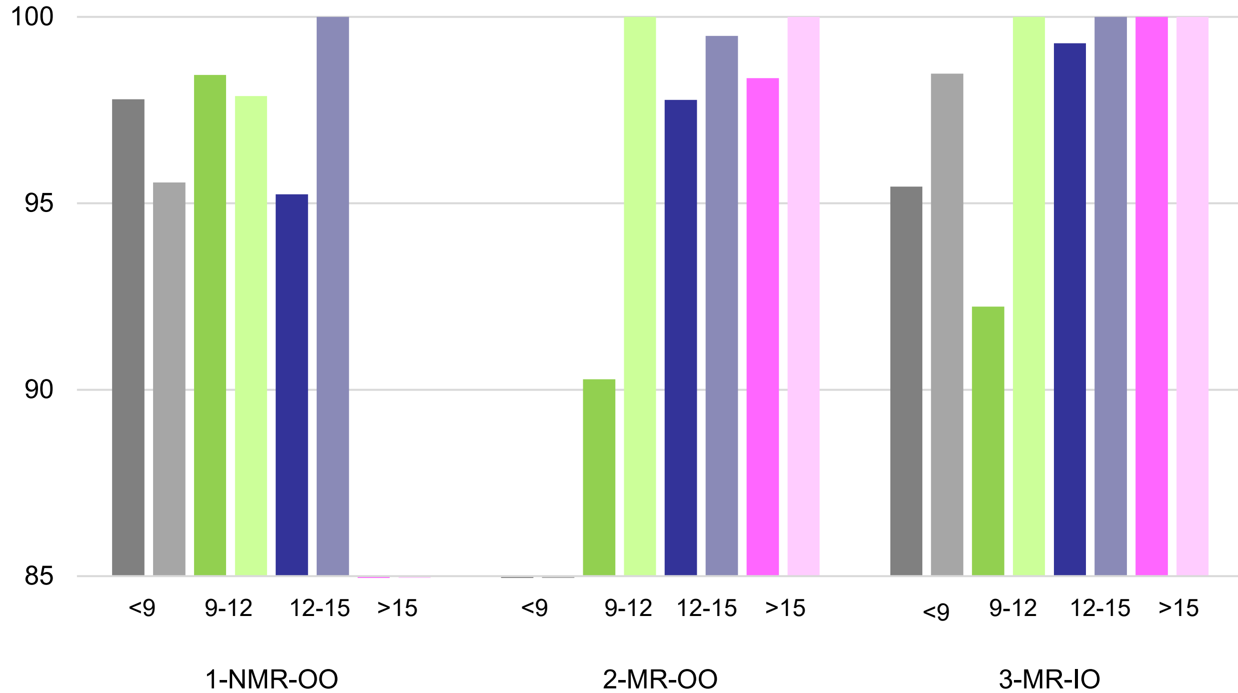

Figure 4.1: Average yielding rates by RRFB category and ADT

4.2.2 By 1-Minute Volume

One variable that may influence the driver's decision to yield is traffic volume (i.e. in higher volumes a driver may feel pressure from following vehicles not to stop). Table 4.2 presented the average 1-minute volume, the average number of vehicles in the queue, and yielding rates observed near-side and far-side. The 1-minute volume ranges from 2 to 16 vehicles per minute (120 to 960 vehicles per hour) for the near-side crossing and from 3 to 16 vehicles for the far-side crossing (120 to 960 vehicles per hour). The highest 1-minute volume both near and far-side was observed at the Lincoln City location (16 vehicles per min) . Figure 4.2 and Figure 4.3 plots the yielding rates near and far-side and the average 1-minute vehicle volumes. No apparent trend is visible in the figures (and simple linear regression hasR^2 values <= 0.05) .

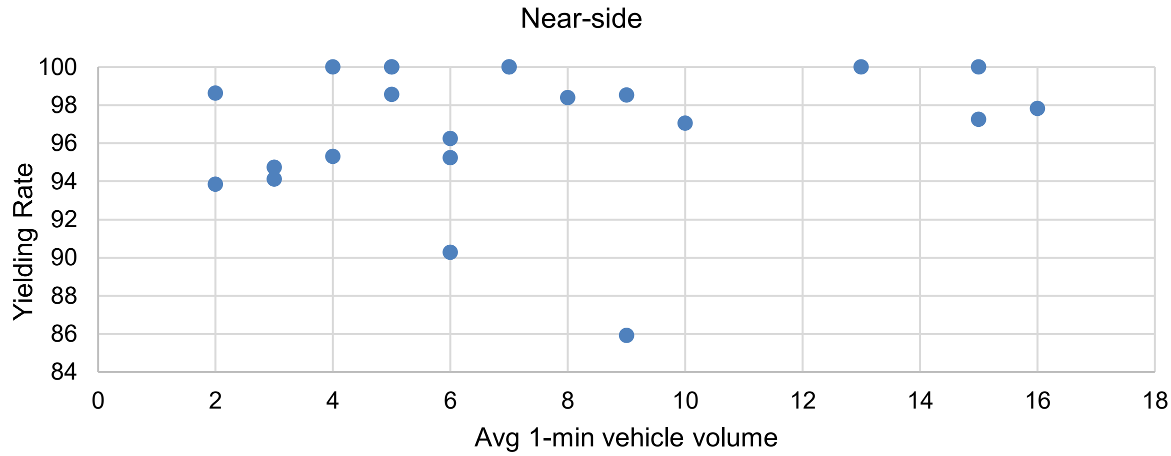

Figure 4.2: Yielding rate near-side vs. average 1-minute vehicle volume

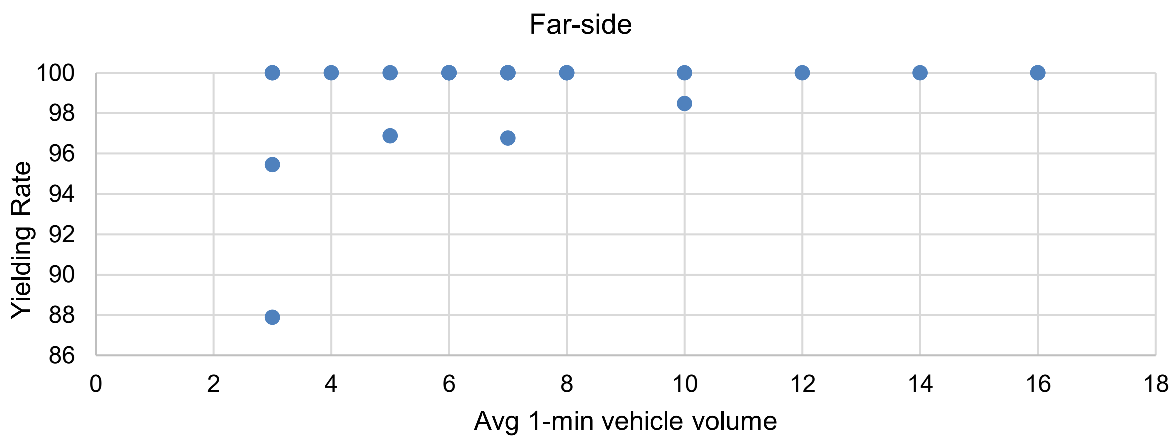

Figure 4.3: Yielding rate far-side vs. average 1-minute vehicle volume

4.2.3 By Posted Speed

Table 4.5 presents the yielding rates by ADT and posted speed limit. The missing values in the table occur because no locations with RRFBs on 3-lane roadways were found that fit into a particular ADT and speed category. As the twenty-three sites are broken into all categories, it is difficult to make additional inferences. Figure 4.4 plots the yielding rates by posted speed. For the 30 mph to 40 mph groups, there is an increasing trend but it is not strong. All but one of the 40 and 45 mph sites have a median refuge, which contributes to the increased yielding.

Table 4.5: Yielding Rates by Speed Limit and ADT

Cat.	ADT											
	<9,000						>=9,000 to 12,000					
	Speed Limit											
	30		35		40+		30		35		40	
	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS
1-NMR-OO	-	-	97.79	95.96	-	-	100.00	96.77	100	100	95.31	96.88
2-MR-OO	-	-	-	-	-	-	90.28	100	-	-	-	-
3-MR-IO	93.85	95.45	98.39	100	94.12	100	85.92	100	98.53	100	-	-

Cat.	ADT											
	>=12,000 to 15,000						>= 15,000					
	Speed Limit											
	30		35		40		30		35		40	
	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS	NS	FS
1-NMR-OO	95.24	100	-	-	-	-	-	-	-	-	-	-
2-MR-OO	-	-	96.66	99.24	100	100	97.55	100	-	-	100	100
3-MR-IO	-	-	100	100	98.57	100	-	-	100	100	-	-

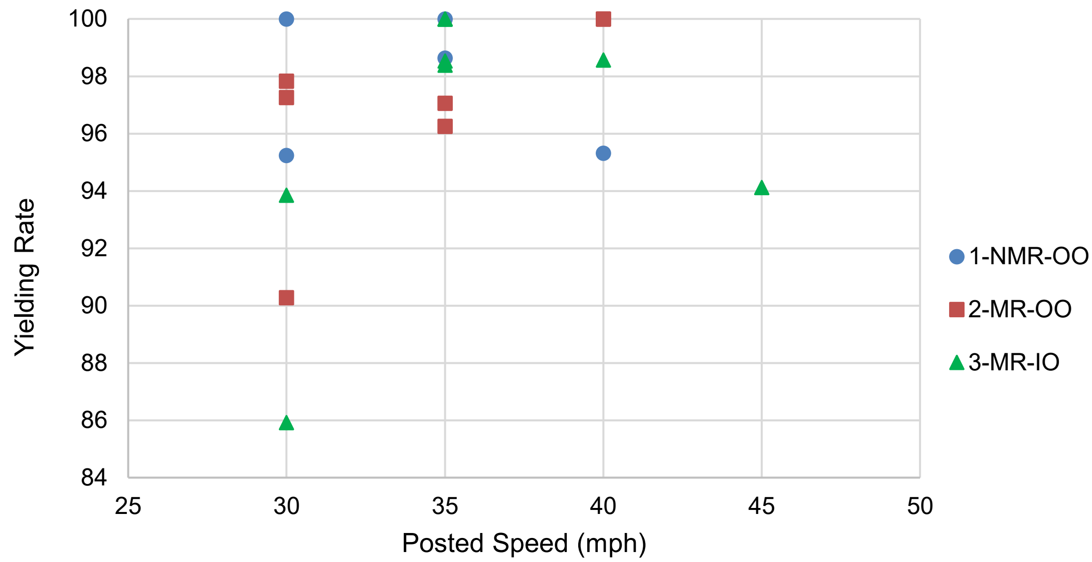

Figure 4.4: Yielding rate vs. posted speed limit

Table 4.6 shows the near and far-side yielding rates collapsed by speed limit and type of crossing. Generally the far-side yielding rate is higher than the near-side yielding rate across speed limit categories (except for two instances in the 35 mph category), mirroring a trend observed earlier.Table 4.7 shows the difference in yielding rates compared to the base yielding rates (1-NMR-OO). Results appear to be mixed, but for the 40+mph locations, the yielding rates are generally higher compared to base case, indicating that the addition of the median and median beacon both have a positive impact at higher speeds.

Table 4.8 shows the difference in base yielding rate by speed limit, with the base category being the 30 mph sites.Results are again mixed. For type 1 locations, an increase in the speed limit generally resulted in a decrease in yielding rates compared to the base case. For type 2 and type 3 locations, higher yielding rates were observed at the higher speed locations compared to the base case.

Table 4.6: Yielding Rates by Speed Limit

Cat.	Speed Limit (mph)					
	30		35		40+	
	NS	FS	NS	FS	NS	FS
1-NMR-OO	97.62	98.39	98.34	96.97	95.31	96.88
2-MR-OO	95.12	100	96.66	99.24	100	100
3-MR-IO	89.89	97.93	99.38	96.35	94.12	100

Table 4.7: Difference in Base Yielding Rates by RRFB Category

Cat.	Speed Limit (mph)					
	30		35		40+	
	Near-side	Far-side	Near-side	Far-side	Near-side	Far-side
1-NMR-OO	*	*	*	*	*	*
2-MR-OO	-2.5	1.61	-1.68	2.27	4.69	3.12
3-MR-IO	-7.73	-0.46	1.04	-0.62	-1.19	3.12

Table 4.8: Difference in Base Yielding Rates by Speed Limit

Cat.	Speed Limit (mph)					
	30		35		40+	
	Near-side	Far-side	Near-side	Far-side	Near-side	Far-side
1-NMR-OO	*	*	0.72	-1.42	-2.31	-1.51
2-MR-OO	*	*	1.54	-0.76	4.88	0.00
3-MR-IO	*	*	9.49	-1.58	4.23	2.07

4.2.4 By One-Minute Volume and Vehicles in Queue

Table 4.9 shows the average number of vehicles in queue and the average one-minute volume for the near-side and far-side yield and no yield scenarios. The average number of vehicles in the queue was low and expected considering that the data collection was performed during the non-peak hours. The highest values were observed at the location on US 101 in Lincoln City and at the location on Dalles California Hwy. It is apparent that yielding occurs at the higher observed one-minute volumes, as seen at the Lincoln City US 101, US 101 between 33rd and 34th St, and the Dalles California highway locations. There also seems to be no apparent correlation between one-minute volumes and yielding behavior.

Table 4.9: Comparison of Average One Minute Volume and Number of Vehicles in Queue Between Yield and No Yield Scenarios

Site Location	Near-side				Far-side			
	Yield		No Yield		Yield		No Yield	
	Avg. Number of Veh in Queue	Avg. One Min Volume	Avg. Number of Veh in Queue	Avg. One Min Volume	Avg. Number of Veh in Queue	Avg. One Min Volume	Avg. Number of Veh in Queue	Avg. One Min Volume
NE Wilkins Rd	1	3	--	--	1	4	--	--
Kildeer & Costco	2	3	1	4	1	3	--	--
Walker Road	1	2	3	2	1	3	--	--
17th & Pershing	1	2	1	3	2	3	2	1
Main & Bear Creek	1	8	5	4	1	8	--	--
Oregon St & NW 8th	1	3	1	2	1	3	--	--
Benson & 12th	2	5	--	--	3	7	0	5
NW Laidlaw Rd	2	5	1	4	2	5	2	4
NE Science Park Drive	2	5	--	--	2	5	--	--
US 20 & Samaritan Hospital	2	6	1	6	2	7	--	--
Glisan & 65th	3	9	2	9	3	10	--	--
Kaiser Rd	2	9	3	10	2	9	--	--
60th & Willow St	2	6	1	6	2	7	--	--
Barrows & Walnut	2	6	1	5	2	5	--	--
Olympic St & Winco	2	10	2	10	2	10	2	5
Sandy Blvd.	3	13	--	--	3	12	--	--
West Union & Rock Creek Trail	2	5	0	11	2	6	--	--
Cottage Grove	2	4	--	--	2	4	--	--
Lincoln City US 101	3	16	1	13	3	16	--	--
Waverly Dr	2	7	--	--	2	7	--	--
US 101 between 33rd & 34th St	3	15	3	14	4	14	--	--
Dalles California Hwy	3	15	--	--	4	16	--	--
Geary & Heritage	2	7	--	--	2	7	--	--

4.3 STATISTICAL ANALYSIS

Statistical tests were conducted to statistically compare the proportions of yielding rates between near and far-side drivers within each volume category between the no median and with median beacon conditions. A series of z-test of proportions are conducted. The test is conducted between near and far-side drivers within each group to determine if proportions are statistically different.

The z-test of proportions is based on the following null and alternative hypotheses:

$$\boldsymbol{H_0}: \boldsymbol{P_1} = \boldsymbol{P_2} \tag{4-1}$$

$$\boldsymbol{H_A}: \boldsymbol{P_1} \neq \boldsymbol{P_2} \tag{4-2}$$

Where:

P_1 and P_2 are the proportions of sample one and sample two, respectively. With these hypotheses in mind, a z-statistic is calculated to determine if the null hypothesis is rejected:

$$\boldsymbol{Z} = \frac{(\widehat{\boldsymbol{P}}_1 - \widehat{\boldsymbol{P}}_2)}{\sqrt{\widehat{\boldsymbol{P}}(1 - \widehat{\boldsymbol{P}})\left(\frac{1}{\boldsymbol{N}_1} + \frac{1}{\boldsymbol{N}_2}\right)}} \tag{4-3}$$

With:

$$\widehat{\boldsymbol{P}}_1 = \frac{\boldsymbol{S}_1}{\boldsymbol{N}_1} \quad \textbf{and} \quad \widehat{\boldsymbol{P}}_2 = \frac{\boldsymbol{S}_2}{\boldsymbol{N}_2} \tag{4-4}$$

$$\widehat{\boldsymbol{P}} = \frac{\boldsymbol{S}_1 + \boldsymbol{S}_2}{\boldsymbol{N}_1 + \boldsymbol{N}_2} \tag{4-5}$$

S_1 is the number of yielding drivers in the no median category on the near-side , S_2 is the number of yielding drivers at locations with a median beacon on the near-side, N_1 is the total number of drivers on the near or far-side at locations with no median (yielding and non-yielding), and N_2 is the total number of drivers on the near or far-side at locations with a median beacon. For the proportions test, a statistical significance threshold of p-value ≤ 0.05 is chosen. In Table 4.10, statistical significance is denoted by an asterisk. The only proportion that was statistically significantly different are the yielding rates on the far-side at locations where ADT is less than 9,000 vehicles per day.. Overall, the statistical tests show no difference in yielding rates between the no median and median beacon sites within the same volume ranges.

Table 4.4 shows the difference in percent yielding rates due to the addition of a median and median beacon compared to the base case of no median. In general, the addition of a median and median beacon has improved the yielding rates compared to the no median yielding rates. The only exceptions are observed in the near-side yielding rates for ADT less than 9,000 and ADT between 9,000 and 12,000. For the higher ADT's the trend holds. These results suggest that although the increases are not significant, the addition of a median and median beacon improves yielding rates.

Table 4.10: Statistical Tests of Average Yielding Rates

ADT	Near-side					Far-side				
	1-NMR-OO		3-MR-IO			1-NMR-OO		3-MR-IO		
	Yielding (n)	Not Yielding (n)	Yielding (n)	Not Yielding (n)	p-value	Yielding(n)	Not Yielding (n)	Yielding (n)	Not Yielding (n)	p-value
<9,000	196	4	185	9	0.93	75	4	119	1	0.03*
9,000-12,000	187	3	128	11	0.99	112	2	120	0	0.07
12,000-15,000	20	1	169	5	0.32	18	0	140	1	0.64
>15,000	173	3	86	0	0.11	155	0	84	0	NA

*statistically significant at the 95% confidence level.

4.4 SUMMARY

The high yielding rates observed provide evidence that the RRFB is a useful tool alerting drivers to the presence of pedestrians at crosswalks. The observed yielding rates in Oregon continue to reflect some of the highest reported in the literature. The high yielding rates, however, make answering the primary research question of the effect or need for the median-mounted beacons challenging. The data and analysis do generally indicate that the yielding rates increase with the addition of the median beacons. However, the difference is not a large increase (<5%) and is also not statistically significant. The data are more consistent for the > 12,000 ADT groups, and the addition of the median refuge increases yielding, but, again, the RRFBs on the median island do not make a significant difference in the observed yielding rates.

There are some limitations of the sample. All yielding samples were during daylight hours and good weather. The crossings were mostly during non-peak hours. The majority of crossings were staged, and the pedestrian followed the same protocol for each sample, which included waiting to activate the beacon until there was a gap in traffic, approaching and waiting in a consistent location, and wearing the same clothing. All of these variables would not be as consistent with non-staged crossings (Fitzpatrick et al., 2015).

There are other reasons, primarily for pedestrian comfort and safety to add a median refuge that should be considered. Median islands reduce pedestrian exposure while crossing and have been proven to reduce pedestrian crashes (Lindley, 2008, Schneider et al. 2017). They also reduce the complexity of crossing (by dividing the crossing into two-stages), provide space to install lighting which also reduces pedestrian crashes, and lower the delay incurred by pedestrians waiting for a gap in the traffic to cross which leads to fewer pedestrians engaging in risky behaviors (FHWA, n.d.).

5.0 ANALYSIS: PEDESTRIAN VOLUMES

This chapter presents the analysis of the 48-hour pedestrian counts at the midblock locations. A descriptive summary is presented, followed by factor development and grouping of the locations as either commute or multipurpose. A direct demand model is then estimated from the data, so that daily pedestrian volume could be estimated at other mid-block locations where no pedestrian count was available.

5.1 VOLUME SUMMARY

To generate the pedestrian volume demand model, pedestrian volumes were obtained at RRFB locations found to have pedestrian-related crashes. This resulted in a total of 25 RRFB locations in which pedestrian volumes were collected. This was accomplished by recording a 48-hour video (for three locations, a 36-hour video was recorded due to equipment malfunction) and manually counting pedestrian volumes for every 15-minute interval. The 15-minute interval counts were then aggregated to create daily volumes. For the demand model, the average of the two days of collected data was used.

A summary of RRFB locations and pedestrian volumes is presented in Table 5.1. The table is arranged in ascending order by average daily volume. The highest volumes were observed at the 12th Street location in Salem, followed by the Siskiyou Blvd. near Bridge St location in Ashland (near Ashland high school). Figure 5.1 shows the time series of all data collected. Each location is a line in the figure. The figure shows the variation in hourly counts.

Table 5.1: RRFB Locations and Pedestrian Volumes in 2018

Location	Day 1 Volume	Day 2 Volume	Average
NE Sandy Blvd. & 131st St	32	9	21
SE Powell Blvd & 141st St	23	26	25
SE Foster Rd East	32	28	30
Bend Pkwy & Badger Road	55	45	50
Main St West	59	54	57
NE 12th St & NE Greenwood Ave	83	45	64
SE Stark St	58	83	71
US 199	104	81	93
SW Kelly Ave	105	107	106
Beaverton Hillsdale Hwy	119	97	108
NE Jackson School Rd	189	79	134
Hillsboro Silverton Hwy	149	174	162
Main St East	160	201	181
SE Foster Rd	201	160	181
SE 122nd Ave	214	152	183
NE 33rd Ave & NE Klickitat St	211	161	186
NE 122nd Ave	191	183	187
SE Division St	256	222	239
Commercial St SE	289	321	305
SE 82nd Ave & SE Center St	399	352	376
Siskiyou Blvd between Avery & Garfield St	403	--	403
Siskiyou Blvd between Beach St & Mountain Ave	451	--	451
NE 60th Ave	642	632	637
Siskiyou Blvd near Bridge St	804	--	804
12th Street	910	881	896

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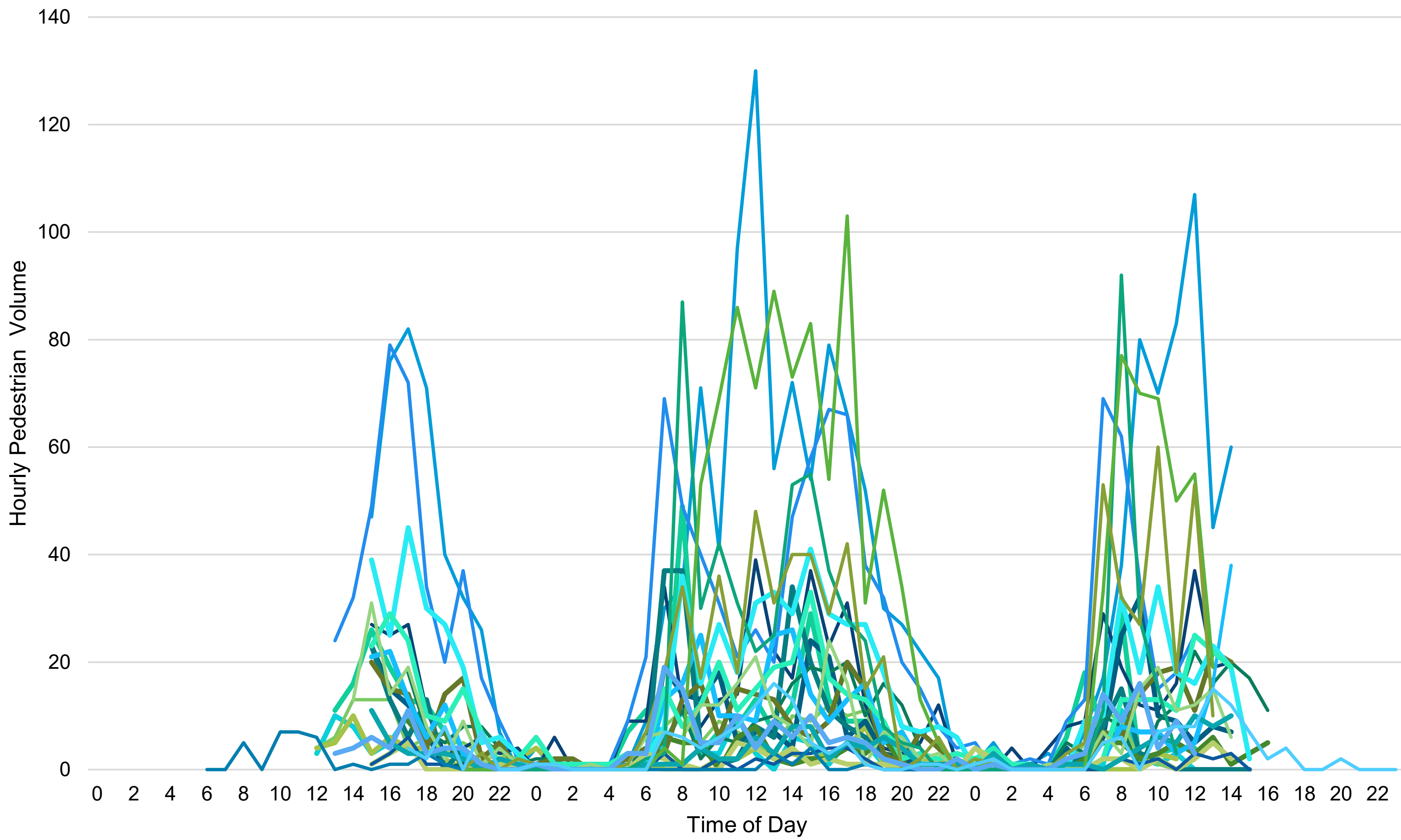

Figure 5.1: Timeseries of hourly pedestrian volumes at all locations

5.2 PATTERNS AND TRENDS

Pedestrian volume is typically higher during the day and declines during the early morning and late evening hours. The time series chart of hourly pedestrian volumes at the different locations is shown in Figure 5.1. One way to express the variability in pedestrian hourly counts is to calculate the hourly factor using the following formula:

$$\boldsymbol{Hourly\ factor} = \frac{\boldsymbol{Daily\ volume}}{\boldsymbol{Hourly\ volume}}$$

(5-1)

The factor expresses the relationship between the hour count and the total 24-hour count. In expanding short-duration counts, the daily volume can then be estimated by multiplying the hourly count with the hourly factor.

In the literature, it is suggested that sites should be classified based on the observed traffic pattern. To do this, the sites were then grouped into two factor groups based on these hourly patterns and a traffic distribution index proposed by Miranda-Moreno et al., the Average Morning/Midday Index (AMI) (Miranda Moreno et al., 2013). The AMI is a ratio of the morning to midday traffic. Average AMI is calculated using the following equation:

$$\boldsymbol{AMI} = \frac{\sum_{7}^{8} \boldsymbol{v_h}}{\sum_{11}^{12} \boldsymbol{v_h}}$$

(5-2)

Where:

AMI = Average Morning/Midday Index, and

v_h = Weekday average hourly count for hour, h.

The calculated AMI values were grouped using the following criteria: hourly multipurpose (0.0 < AMI <= 1.0), hourly commute (AMI > 1.0). Sites classified as multipurpose have peak counts between the morning and evening peak hours. Sites categorized as commute show morning and evening peak hour counts higher than the noon hour count. A summary of this grouping is provided in Table 5.2.Within each of the factor groups, hourly factors were developed and averaged across the sites. The hourly factors between 7 AM – 7 PM for the multipurpose and commute sites and the resulting average factors are shown in Table 5.3 and Table 5.4.

Table 5.2: Factor Groups

Location	AM Count	Noon Count	AMI	Grouping
12th Street	34	97	0.35	Multipurpose
NE 12th St & Greenwood Ave	11	10	1.1	Commute
NE 33rd & Klickitat St	49	8	6.13	Commute
B-H Hwy	11	7	1.57	Commute
Bend Pkwy & Badger Rd	0	2	0	Multipurpose
Commercial St & Bellevue St	12	14	0.86	Multipurpose
OR 214 & Park Ave	14	5	2.80	Commute
NE Jackson School Rd & NE Estate Dr	37	2	18.50	Commute
Main St East	11	5	2.20	Commute
Main St West	5	6	0.83	Multipurpose
NE 122nd Ave & NE Oregon St	13	15	0.87	Multipurpose
NE 60th St & Willow St	49	21	2.33	Commute
SE 122nd Ave & SE Morrison St	16	10	1.60	Commute
SE 82nd Ave & SE Center St	36	18	2.00	Commute
SE Division St & SE 129th Ave	8	11	0.73	Multipurpose
SE Foster Rd	6	16	0.38	Multipurpose
SE Foster Rd & SE 121st St	1	5	0.20	Multipurpose
US 26 & 141st St	0	0	NA	NA
NE Sandy Blvd & 131 Pl	0	0	NA	NA
SE Stark St	1	2	0.50	Multipurpose
Siskiyou Blvd & Beach St	87	31	2.81	Commute
Siskiyou Blvd & Bridge St	1	86	0.01	Multipurpose
Siskiyou Blvd & Garfield St	34	18	1.89	Commute
SW Kelly Ave	15	10	1.50	Commute
US 199 between Lister St & Watkins St	6	8	0.75	Multipurpose

Table 5.3: Hourly Factors for the Multipurpose Factor Group

Hour	12th St	Bend Pkwy & Badger Rd	Commercial St & Bellevue St	Main St West	NE 122nd Ave & NE Oregon St	SE Division St & SE 129th Ave	SE Foster Rd	SE Foster Rd & SE 121st St	SE Stark St	Siskiyou Blvd & Bridge St	US 199 between Lister St & Watkins St	Average Factor
7	29.77	--	9.15	8.67	55.00	15.47	23.43	14.00	60.00	205.50	12.86	25.37*
8	26.26	--	25.92	10.40	12.69	29.00	27.33	28.00	60.00	822.00	15.00	26.07*
9	12.58	--	38.88	10.40	10.31	19.33	13.67	--	15.00	15.51	22.50	17.57
10	21.78	23.00	23.92	--	27.50	11.60	13.67	--	30.00	11.91	15.00	19.82
11	9.21	23.00	22.21	8.67	11.00	21.09	10.25	5.60	30.00	9.56	11.25	14.71
12	6.87	11.50	7.97	6.50	11.79	15.47	7.81	7.00	10.00	11.58	7.50	9.45
13	15.95	23.00	14.14	26.00	12.69	12.21	16.40	14.00	20.00	9.24	5.63	15.39
14	12.40	15.33	18.29	52.00	20.63	11.60	20.50	7.00	7.50	11.26	6.92	16.68
15	16.54	23.00	8.41	26.00	27.50	7.03	41.00	28.00	7.50	9.90	18.00	19.35
16	11.30	15.33	13.52	26.00	18.33	13.65	6.83	14.00	30.00	15.22	30.00	17.65
17	13.53	11.50	10.03	13.00	8.25	16.57	10.25	28.00	12.00	7.98	18.00	13.56
18	17.17	5.75	25.92	17.33	11.00	17.85	164.00	28.00	15.00	26.52	90.00	38.05

* Removed Siskiyou Blvd. and Bridge St count from average factor computation

Table 5.4: Hourly Factors for the Commute Factor Group

Hour	NE 12th St & Greenwood Ave	NE 33rd & Klickitat St	B-H Hwy	OR 214 & Park Ave	NE Jackson School Rd & NE Estate Dr	Main St East	NE 60th St & Willow St	SE 122nd Ave & SE Morrison St	SE 82nd Ave & SE Center St	Siskiyou Blvd & Beach St	Siskiyou Blvd & Garfield St	SW Kelly Ave	Average Factor
7	12.20	31.83	13.88	8.26	4.81	34.20	9.33	15.46	46.38	152.00	22.56	5.84	18.61*
8	5.55	3.90	10.09	11.21	4.81	15.55	13.14	12.56	10.31	5.24	11.94	7.40	9.31
9	20.33	63.67	22.20	12.08	44.50	85.50	16.10	8.04	23.19	15.20	23.88	22.20	29.74
10	20.33	27.29	12.33	8.72	178.00	28.50	20.77	20.10	13.74	10.86	11.28	22.20	31.18
11	6.10	23.88	15.86	31.40	89.00	34.20	30.67	20.10	20.61	14.71	22.56	11.10	26.68
12	20.33	14.69	22.20	22.43	22.25	19.00	24.77	22.33	11.97	20.73	8.46	27.75	19.74
13	--	27.29	55.50	22.43	29.67	17.10	32.20	8.04	11.24	18.24	13.10	12.33	22.47
14	10.17	15.92	11.10	39.25	5.24	10.69	13.70	7.73	12.79	8.60	10.15	18.50	13.65
15	12.20	6.59	12.33	6.54	8.90	9.00	11.10	14.36	9.05	8.29	10.15	11.10	9.97
16	61.00	14.69	9.25	7.48	16.18	9.50	9.61	22.33	12.79	12.32	14.00	22.20	17.61
17	12.20	21.22	11.10	26.17	22.25	8.55	9.76	15.46	13.74	16.29	9.67	18.50	15.41
18	12.20	21.22	10.09	17.44	29.67	17.10	16.95	12.56	13.74	19.00	27.07	22.20	18.27

* Removed Siskiyou Blvd. and Beach St count from average factor computation

5.3 DIRECT DEMAND ESTIMATION MODEL

The Environmental Protection Agency (EPA) Smart Location Database (SLD) was used to create variables in an attempt to predict pedestrian volumes. The SLD provides various characteristics on land-use and demographics at the census block level. Therefore, characteristics of a given census block in which an RRFB is located was associated with that RRFB. The number of potential predictors is vast; therefore, refer to Ramsay and Bell (2014a) and Ramsay and Bell (2014b) for a full list and corresponding definitions. Although the number of potential predictors is vast, the number of observations for the demand model is limited to the number of RRFB locations with pedestrian volumes: 25. As such, careful consideration of model overfitting was taken into account when arriving at final model specifications.

Using the EPA SLD data, a linear regression model was developed to identify the relationship between various land-use and demographic characteristics on pedestrian volume. Through a forward stepwise procedure, six variables from the SLD were found to have a statistically significant relationship with the observed pedestrian volumes. The six variables include the percentage of low wage workers, both for census blocks that is their home location and census blocks that is their work location. These variables represent the percent of the total number of works. As it pertains to home and work locations, one refers to which the census block of the RRFB is the home location of the worker and the other refers to the census block of the RRFB as the work location. Other variables found to be significant include intersection density per square mile; specifically, the density of multi-modal intersection of four or more legs and the density of auto-oriented intersections. These were determined based on facility type and facility miles per total land area in the respective census block. For multi-modal intersection density, the following facilities are considered (Ramsay and Bell, 2014a):

- Arterial or local street with speed between 41 mi/hr and 54 mi/hr where car travel is permitted in both directions.
- Arterial or local street with speed between 31 mi/hr and 40 mi/hr.
- Arterial or local street with speed between 21 mi/hr and 30 mi/hr where car travel is restricted to one-way traffic.
- For all of the above, vehicles and pedestrians must be permitted.
- For all of the above, controlled-access highways, tollways, highway ramps, ferries, parking lot roads, tunnels, and facilities having four or more lanes of travel in a single direction are excluded.

For auto-oriented intersections, the following facilities are considered (Ramsay and Bell, 2014a):

- Any controlled-access highway, tollway, highway ramp, or other facility on which vehicles are allowed but pedestrians are restricted.
- Arterial street with speeds of 55 mi/hr or higher.

- Arterial street with speed between 41 mi/hr and 54 mi/hr where car travel is restricted to one-way traffic.

- Arterial street having four or more lanes of travel in a single direction (implied eight lanes bi-directional, where turn lanes and other auxiliary lanes are not counted).

- For all of the above, ferries and parking lot roads are excluded.

Of the final two variables found to be significant, one represents the gross population in terms of people per acre. This is a variable derived from other SLD variables, in which the total population for a census block is divided by the acreage of the census block. The last variable represents the proportion of the census block group employment that is located within one-quarter mile of a fixed-guideway transit stop (e.g., rail, streetcars, ferries, trolleys, and some bust rap transit systems).

Table 5.5: Summary Statistics of Significant Variables in Pedestrian Demand Model

Variable	Mean	Std. Dev.	Minimum	Maximum
2018 Observed Pedestrian Volume	237.80	237.85	20.50	895.50
Percent of Low Wage Workers of Total Number of Workers (Home Location)	26.88	6.87	14.24	39.95
Percent of Low Wage Workers of Total Number of Workers (Work Location)	27.44	11.35	12.00	62.00
Intersection Density in Terms of Multi-Model Intersections Having Four or More Legs Per Square Mile	7.89	8.67	0.00	35.45
Intersection Density in Terms of Auto-Oriented Intersections Per Square Mile	4.56	9.93	0.00	38.16
Gross Population Density (People/Acre) on Unprotected Land	9.05	4.32	1.19	16.76
Proportion of CBG Employment Within 1/4 Mile of Fixed-Guideway Transit Stop	9.89	20.18	0.00	62.84

Final model specifications for the pedestrian volume demand model are shown in Table 5.6. Being that no variable transformations (i.e., log-transformed variables) were made, the estimated coefficients in Table 5.6 can be inferred tantamount to marginal effects. That is, the estimated coefficient provides the estimated change in pedestrian volumes due to a one-unit increase in its corresponding variable. Of the variables found to be significant in predicting pedestrian volume, one has substantially larger effects: the percent of low wage workers (home location). Regression estimates indicate that a one-unit increase in the percentage of low wage workers (in this case, a percentage point), results in an expected increase in the pedestrian volume of approximately 25.

Of the remaining five variables, three have positive effects (i.e., increases) on expected pedestrian volumes. The first of these is the intersection density of multi-modal intersections having four or more legs per square mile. Based on the regression estimates, a one-unit increase in this density is expected to increase pedestrian volume by roughly 9. Also, increasing the expected pedestrian volume is the gross population density (people/acre). In particular, a one-unit increase in the gross population density is expected to increase pedestrian volume by approximately 9, the same increase as the density of multi-modal intersections. The final variable with positive effects is the proportion of census block group (CBG) employment within one-quarter mile of a fixed-guideway transit stop. According to the regression estimates, an increase in the proportion of CBG employment within one-quarter mile of a fixed-guideway transit stop increases the expected pedestrian volume by approximately 6.

Regarding variables with negative effects on expected pedestrian volume, two were found to be significant. The first of these variables is the percent of low wage workers in the census block, in which the census block is their work location, not home location. A one-unit increase, or percentage point increase in this case, in low wage workers in their work location, is expected to decrease pedestrian volume by approximately 7. The final variable with effects, and also negative, on expected pedestrian volume is the intersection density of auto-oriented intersections per square mile. According to model estimations, an increase in auto-oriented intersection density is expected to decrease pedestrian volume by roughly 4. Figure 5.7 shows the plot of actual versus predicted pedestrian volumes. Additionally, if the factors presented in Table 5.6 are know, Eq. (5-3) can be used to estimate pedestrian volumes:

$$\mathbf{Ped\ Volume} = \mathbf{-449.62 + 25.39(PCTLWK) - 6.89(PCTLHM) + 9.30(INTDEN4) - 3.55(INTDENA) + 8.97(POP) + 5.63(TRANSIT)} \qquad \textbf{(5-3)}$$

Where:

variable abbreviations are given in Table 5.6.

Table 5.6: Final Model Specifications for Pedestrian Volume Demand Model

Variable	Coefficient	Robust Std. Error	*t*-statistic
Constant	-449.62[a]	130.00	-3.46
Percent of Low Wage Workers of Total Number of Workers (Home Location) [PCTLWK]	25.39[a]	5.00	5.08
Percent of Low Wage Workers of Total Number of Workers (Work Location) [PCTLHM]	-6.89[a]	1.86	-3.70
Intersection Density in Terms of Multi-Model Intersections Having Four or More Legs Per Square Mile [INTDEN4]	9.30[a]	2.33	3.99
Intersection Density in Terms of Auto-Oriented Intersections Per Square Mile [INTDENA]	-3.55[c]	1.89	-1.88
Gross Population Density (People/Acre) on Unprotected Land [POP]	8.97[b]	3.12	2.87
Proportion of CBG Employment Within 1/4 Mile of Fixed-Guideway Transit Stop [TRANSIT]	5.63[a]	1.01	5.56

Model Summary

Number of Observations	25
R-Squared	0.82
Adjusted R-Squared	0.76

[a] Significant at 99% Level of Confidence
[b] Significant at 95% Level of Confidence
[c] Significant at 90% Level of Confidence

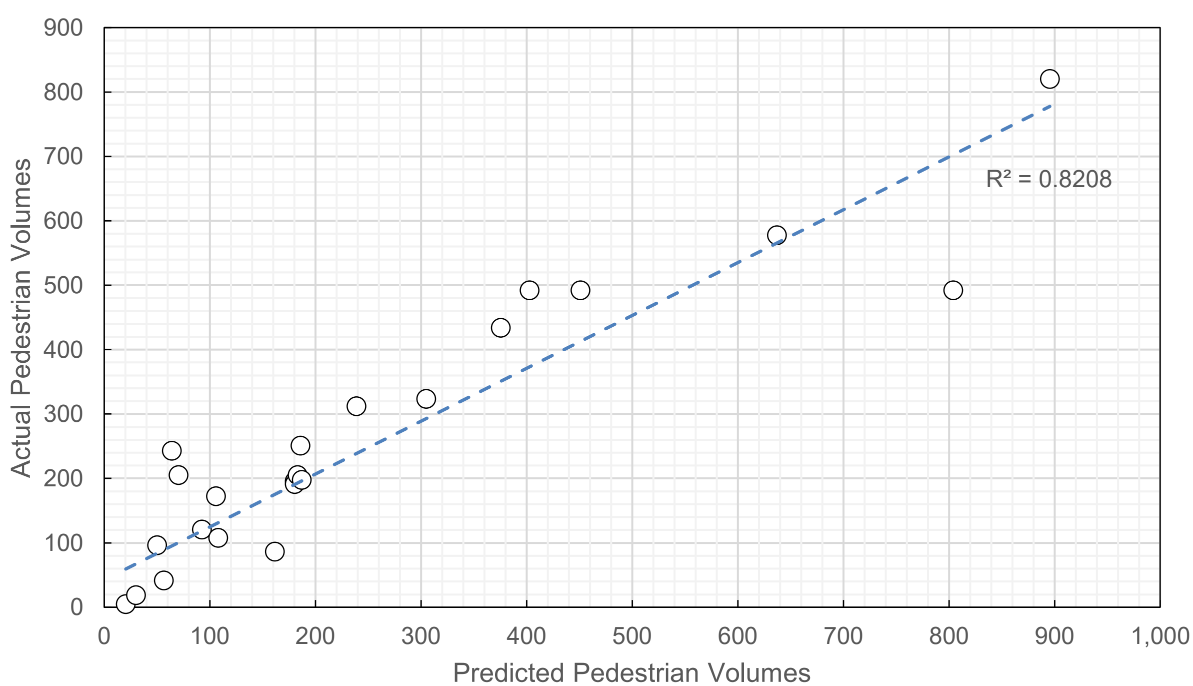

Figure 5.7: Actual pedestrian volumes vs. predicted pedestrian volumes

5.4 SUMMARY

This chapter presented the analysis of the 48-hour pedestrian counts at the midblock locations. While not central to this research, the analysis produced hourly factors for two groups of mid-block crossing patterns (commute and multipurpose). These factors could be used by those who undertake a short duration count to obtain an estimate of daily pedestrian volume, knowing the type of pedestrian traffic at that site. A direct demand model is then estimated from the data so that daily pedestrian volume could be estimated at mid-block locations where no pedestrian count was available.

6.0 ANALYSIS: SAFETY EFFECTIVENESS UPDATE

With additional years of ODOT crash data available, CMFs that were calculated in SPR 778 for RRFBs at select locations can be re-estimated. This is accomplished using a simple before-after analysis and an updated safety performance function (SPF) that utilizes both average annual daily traffic (AADT) and pedestrian volume count. In addition, the pedestrian volume demand model that was created in the previous chapter was used to estimate pedestrian volumes at RRFB locations in which pedestrian volumes were not available.

6.1 SIMPLE BEFORE-AFTER ANALYSIS

6.1.1 Pedestrian Crashes

For the updated CMF for pedestrian-related crashes, the analysis was conducted considering only RRFBs along with any enhancements such as median islands that are often included, that were present at each location. With the additional years of crash data, there were now pedestrian crash records spanning from 2007 to 2017. During this time period, at the RRFB locations with known install years, a total of 46 crashes occurred. Of these 46 crashes, 26 occurred before RRFB installation and 20 occurred after installation. Table 6.1 shows the results of the simple before-after analysis for pedestrian-related crashes. As observed in Table 6.1, an updated CMF of 0.84 was estimated with a standard deviation of 0.25. An estimate of the 95% confidence interval includes the value 1.0.

Although additional years of crash data have been included, the sample is still limited due to the low number of RRFB locations in which there are known install dates. In the case of the current work, just 28 locations have been included. A few of the locations had an increase in the number of crashes in the after period. With the small sample, the CMFs being sensitive to changes, albeit small, in crash counts in after years.

Table 6.1: Simple Before-After Analysis for Pedestrian Crashes

Parameter	RRFB (2007 to 2017)
Number of Locations/Crosswalks	28
Total Number of Crashes in the After Period $(\boldsymbol{\lambda})$	20
Total Number of Crashes in the Before Period $(\boldsymbol{\pi})$	22.83
Estimated Change in the Total Number of Crashes $(\boldsymbol{\delta})$	2.83
CMF = Index of Effectiveness $(\boldsymbol{\theta})$	0.84
Standard Deviation of $\boldsymbol{\delta}$	6.61
Standard Deviation of $\boldsymbol{\theta}$	0.25
CMF $(\pm \mathbf{1}\ \mathbf{Std.Dev})$	0.59 to 1.09
CMF $(\mathbf{95\%\ C.I.})$	0.35, 1.32

6.1.2 Rear-End Crashes

For the updated CMF, the analysis was conducted considering only RRFBs. With the additional years of crash data, there were now rear-end crash records spanning from 2007 to 2017. During this time period, at the RRFB locations with known install years, a total of 602 reported rear-end crashes occurred. Of these 602 crashes, 288 occurred before RRFB installation and 314 occurred after installation. Table 6.2 shows the results of the simple before-after analysis for rear-end crashes. As observed in Table 6.2, an updated CMF of 1.42 was estimated with a standard deviation of 0.12. An estimate of the 95% confidence interval does not include the value 1.0.

The addition of RRFBs may increase yielding to pedestrians, and as a result, opportunities for the occurrence of rear-end crashes would increase. Although an increase in crashes is observed at these RRFB locations, it may not necessarily reflect the effectiveness of the installed RRFB. That is, this increasing trend follows the increasing trend experienced by Oregon in recent years (the additional years of crash data that have been used to update the CMF, 2014 to 2017). Specifically, Oregon has experienced a 12.65% increase in the total number of crashes during these years. Comparing that to the RRFB locations with known install dates, the increase in after crashes are less than the statewide increase at 9%.

Table 6.2: Simple Before-After Analysis for Rear-End Crashes

Parameter	RRFB (2007 to 2017)
Number of Locations/Crosswalks	62
Total Number of Crashes in the After Period (λ)	314
Total Number of Crashes in the Before Period (π)	220.76
Estimated Change in the Total Number of Crashes (δ)	-93.24
CMF = Index of Effectiveness (θ)	1.42
Standard Deviation of δ	22.97
Standard Deviation of θ	0.12
CMF ($\pm$1 Std. Dev)	1.29 to 1.54
CMF (95% C.I.)	1.17, 1.66

6.2 EMPIRICAL BAYES BEFORE-AFTER ANALYSIS

6.2.1 Pedestrian Crashes

To conduct the Empirical Bayes (EB) before-after analysis for pedestrian crashes, a safety performance function (SPF) must first be estimated. However, of the 28 RRFB locations with pedestrian crash occurrences, three did not have available pedestrian volumes. As such, the pedestrian demand volume model presented in Table 5.6 was used to predict pedestrian volumes at these locations. Upon prediction of these pedestrian volumes, various SPF models were tested:

- Poisson and Negative Binomial fixed-effects models.
- Poisson and Negative Binomial pooled models.
- Gamma distributed Poisson models.

- Zero-inflated Poisson and Negative Binomial fixed-effects models.
- Traditional Poisson and Negative Binomial models based on cross-sectional data.
- Zero-inflated variants of the traditional Poisson and Negative Binomial models based on cross-section data.

After specifying these various models, it was determined that the most reliable estimates were that of the Poisson model for cross-sectional data, indicating the pedestrian RRFB crash data is not over- or underdispersed. Final SPF model specifications for pedestrian crashes are shown in Table 6.3.

Table 6.3: Final Poisson Model Specifications for Estimating Pedestrian Crashes

Variable	Coefficient	Std. Error	*t*-statistic
Constant	0.57	1.22	0.47
Natural Logarithm of AADT	-0.13[a]	0.06	-2.20
Natural Logarithm of Pedestrian Volume	0.11	0.21	0.54
Model Summary			
Number of Observations	28		
Log-Likelihood at Convergence	-30.91		

[a] Significant With 95% Level of Confidence

For diagnostic purposes, Figure 6.4 shows a cumulative residual (CURE) plot. If the line representing the cumulative residuals stays within the fitted bounds and oscillates about zero, the SPF is said to have good fit over the *range* of the model (i.e., all crash values). In the case of the pedestrian SPF, this holds true.

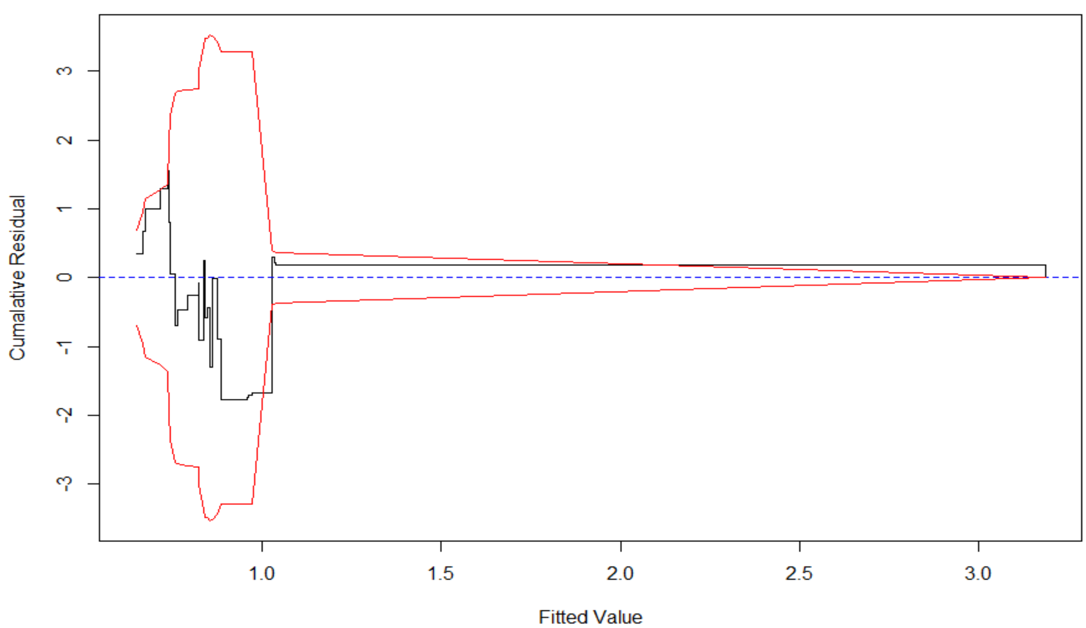

Figure 6.4: CURE plot for pedestrian crash SPF model

Using the estimates obtained in Table 6.3, the pedestrian SPF can be written as follows:

$$\textbf{Expected Crashes}_{\textbf{Pedestrian}} = e^{(\textbf{0.57}-\textbf{LNAADT}(-\textbf{0.13})+\textbf{PVOL}(\textbf{0.11}))}$$

(6-1)

Where:

Expected $\text{Crashes}_{\text{Pedestrian}}$ is the predicted number of pedestrian-related crashes based on model estimates, $AADT$ is average annual daily traffic, and $PVOL$ is pedestrian volume.

Following the method outlined in Monsere et al. (2017), the Empirical Bayes summary is shown in Table 6.5.

Table 6.5: Empirical Bayes Summary for Pedestrian Crashes

Time Period	Observed Crashes	SPF Predicted Crashes
Before	26	25.99
After	20	27.12

The estimated parameters using the EB approach are presented in Table 6.6. The estimated CMF obtained through the EB before-after analysis is 0.71. The standard error of the estimated CMF is 0.20, with a 95% confidence interval of 0.31 to 1.11 that includes the value 1.0. The data was not found to over- or underdispersed; therefore, the SPF weight is equal to one, and all emphasis in the EB estimates is put on the predicted values.

Table 6.6: Parameter Estimates for Empirical Bayes Pedestrian Crash Analysis

Parameter	Estimate
$\boldsymbol{N}_{\textbf{Expected,T,B}}$	25.99
$\boldsymbol{N}_{\textbf{Expected,T,A}}$	27.12
$\textbf{Var}(\boldsymbol{N}_{\textbf{Expected,T,A}})$	28.30
$\textbf{CMF}$	0.71
$\textbf{Var}(\textbf{CMF})$	0.04
$\textbf{SE}(\textbf{CMF})$	0.20
$\textbf{95\% C.I.}$	0.31, 1.11

6.2.2 Rear-End Crashes

As with the pedestrian EB analysis, a safety performance function (SPF) must first be estimated for the EB analysis on rear-end crashes. For the EB rear-end crash analysis, the following SPF models were tested:

- Poisson and Negative Binomial fixed-effects models.
- Poisson and Negative Binomial pooled models.

- Gamma distributed Poisson models.
- Zero-inflated Poisson and Negative Binomial fixed-effects models.
- Traditional Poisson and Negative Binomial models based on cross-sectional data.
- Zero-inflated variants of the traditional Poisson and Negative Binomial models based on cross-section data.

After specifying these various models, it was determined that the most reliable estimates were that of the Negative Binomial model for cross-sectional data, indicating dispersion is present in the rear-end crash data. Final SPF model specifications for rear-end crashes are shown in Table 6.7.

Table 6.7: Final Negative Binomial Model Specifications for Estimating Pedestrian Crashes

Variable	Coefficient	Std. Error	*t*-statistic
Constant	1.06[b]	0.45	2.35
Natural Logarithm of AADT	0.05	0.05	1.07
$\boldsymbol{\theta}$	0.98[a]	0.23	4.53

Model Summary

Number of Observations	62
Log-Likelihood at Convergence	-163.18

[a] Significant With 99% Level of Confidence
[b] Significant With 95% Level of Confidence

For diagnostic purposes, Figure 6.8 shows a cumulative residual (CURE) plot. If the line representing the cumulative residuals stays within the fitted bounds and oscillates about zero, the SPF is said to have good fit over the *range* of the model (i.e., all crash values). In the case of the rear-end crash SPF, Figure 6.8 shows there is room for improvement in the prediction of higher crash values. At some RRFB locations, there were several before years and several crashes in these years, resulting in large residuals. A viable option in addressing the fitted values for higher crash values is the addition of further exposure-based characteristics of the RRFB locations.

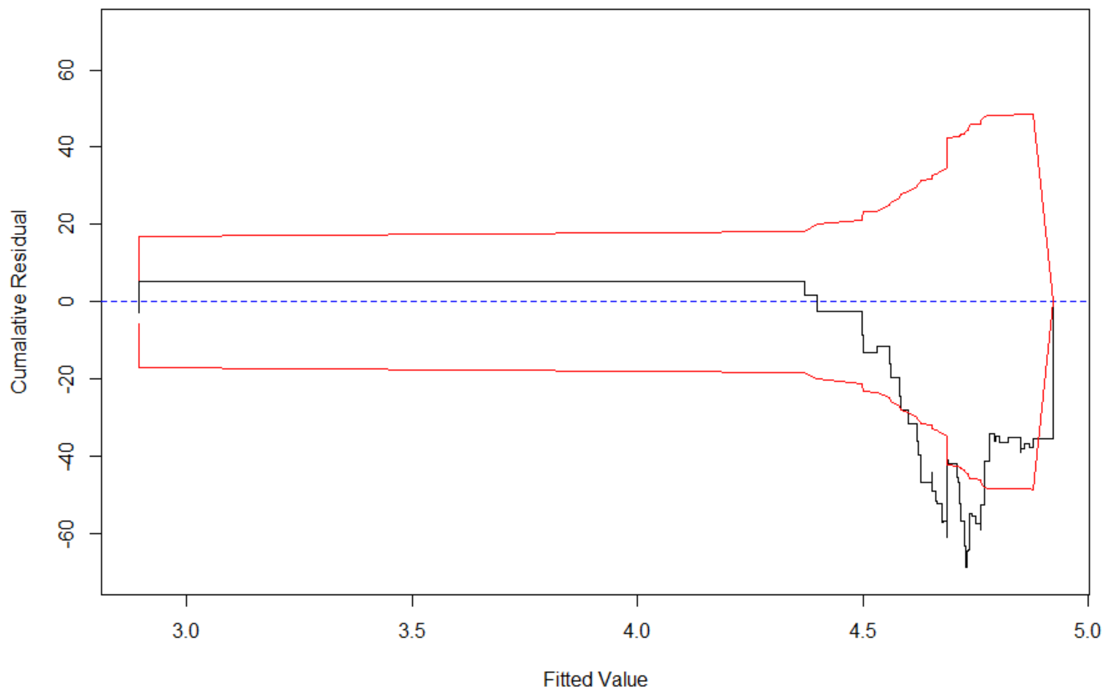

Figure 6.8: CURE plot for rear-end crash SPF model

Nonetheless, using the estimates obtained in Table 6.7, the pedestrian SPF can be written as follows:

$$\textbf{Expected Crashes}_{\textbf{Rear-End}} = e^{(\mathbf{1.06 - LNAADT(-0.05)})} \tag{6-2}$$

Where:

> Expected $\text{Crashes}_{\text{Rear-End}}$ is the predicted number of crashes based on model estimates, and $AADT$ is average annual daily traffic.

The Empirical Bayes summary is shown in Table 6.9.

Table 6.9: Empirical Bayes Summary for Rear-End Crashes

Time Period	Observed Crashes	SPF Predicted Crashes
Before	288	287.36
After	314	282.60

The estimated parameters using the EB approach are presented in Table 6.10. The estimated CMF obtained through the EB before-after analysis is 1.11. This CMF has increased from 0.93 in the previous analysis, see Monsere et al. (2017), yet has decreased from 1.42 obtained in the simple before-after analysis (as expected, since exposure is controlled). Additionally, the standard error of the CMF is estimated to be 0.063, and the 95% confidence interval ranges from 0.98 to 1.24 (includes the value 1.0).

Table 6.10: Parameter Estimates for Empirical Bayes Pedestrian Crash Analysis

Parameter	Estimate
$N_{\text{Expected,T,B}}$	287.37
$N_{\text{Expected,T,A}}$	282.61
$\text{Var}(N_{\text{Expected,T,A}})$	5.56
CMF	1.11
Var(CMF)	0.004
SE(CMF)	0.063
$95\%\ \text{C.I.}$	0.98, 1.24

6.3 SUMMARY

Table 6.11 shows the comparison between this update, the prior research, and NCHRP 841 which also estimated CMFs for RRFBs. Table 6.12 presents the required information for CMFs to be considered for the CMF Clearinghouse.

Table 6.11: Summary of CMFs Across Studies

Crash Type	Analysis Method	SPR 778	SPR 814 Current Research (2019)	NCHRP 841 2017
Pedestrian	Simple Before-After	0.64 (0.26)	0.84 (0.25)	--
	EB Before-After	--	0.71 (0.20)	0.53 (0.38)
Rear-End	Simple Before-After	1.30 (0.19)	1.42 (0.12)	--
	EB Before-After	0.93 (0.22)	1.11 (0.06)	--

Table 6.12: Required Documentation for the Countermeasure Clearinghouse, RRFB

Countermeasure Name and Description	**Install enhanced RRFB pedestrian crossing at mid-block crossing location.**	
Crash Type	Pedestrian	Rear-end
Crash Severity	All (KABCO)	
Time of Day	All hours	
Crash Modification Factor	0.71	1.11
Measures of Precision for the CMF (standard error/deviation)	0.20	0.06
Prior Conditions	Previously unmarked or at a location with prior high-visibility markings. The data set pooled these locations in the estimation of CMFs.	
Roadway Class	Principal arterial, minor arterial, major collector, minor collector	
Road Division Type	Undivided	
State	Oregon	
Area Type	Rural; Urban; Suburban	
Number of Through Lanes	Two to five lanes (includes TWLTL)	
Speed Limit	20 mph to 45 mph	
Traffic Volume Range	Pedestrian: Average = 220; Vehicle: Average = 15,640	
Traffic Control	No control	
Intersection Type	Roadway to pedestrian crossing (i.e., mid-block crossing).	
Years of Data	11	11
Type of Methodology	EB Before-After	EB Before-After
Site Selection Criteria	Sites for inclusion in the study were identified from a list of enhanced crossing locations from state and local inventories. Sites were excluded primarily due to undetermined installation date of treatment.	
Sample Size Used (Crashes)	26 before, 20 after	288 before, 314 after
Sample Size Used (Sites)	28	62
Biases Documentation	Sites likely selected for pedestrian crash experience. Regression-to-the-mean bias present. EB analysis approach adjusted for pedestrian volumes. Year-to-year changes in pedestrian volumes estimated based on population growths.	Sites not likely selected based on rear-end crash history. EB analysis approach includes adjustment for traffic volumes..

7.0 CONCLUSIONS

This research had three objectives. The primary conclusions for each objective are presented in this chapter.

7.1 DRIVER YIELDING ON THREE-LANE ROADS WITH AND WITHOUT REFUGE MEDIANS

The objective of this study was to determine if the RRFB placed in the median refuge island makes a difference to driver yielding rates on 3-lane roadways. RRFB sites on 3- lane roadways were sourced from a previous research project and via outreach to regional cities and agencies. Along with ADT and posted speed limits, these locations were categorized into three categories based on whether a median refuge and median beacon were present. The final sample was 23 locations.

Video data were collected at each site and yielding behavior was studied using a staged pedestrian for consistent presentation. The video data was reduced to a dataset with 1,556 crossings corresponding to 1,621 pedestrians. The data reduction protocol followed the methods suggested by Fitzpatrick et al (2015). Performance measures (delay prior to crossing, delay in the median, crossing time, number of vehicles in the queue, 1-minute vehicle volumes prior to crossing, and near and far-side yielding behaviors) were calculated from the video analysis.

Yielding rates were computed for both near-side and far-side crossings. Yielding was over 90% at all but one of the 23 near-side and one of the 23 far-side crossins locations. A total of seven locations exhibiting 100% yielding rates both on the near-side and far-side. The observed yielding rates in Oregon continue to reflect some of the highest reported in the literature. The high yielding rates observed provide additional evidence that the RRFB is a useful tool alerting drivers to the presence of pedestrians at crosswalks. The high yielding rates, however, make answering the primary research question of the effect or need for the median-mounted beacons challenging. The data generally show that the presence of a median refuge island alone increases yielding. The data and analysis also generally indicate that the yielding rates increase with the addition of the median beacons. However, the difference is not large increase (<5%) and was not statistically significant. Site-specific characteristics are also important as the lowest observed near-side yielding rate was at a site with RRFBs placed in the median refuge (NE Glisan).

The research results suggest that a median refuge could be considered optional on 3-lane roadways with volumes less than or equal to 12,000 ADT. For 3-lane roadways with more than 12,000 ADT, the addition of the median refuge is recommended based on the evidence of increased yielding. The addition of the median beacons were found to generally increase the yielding and should be considered whenever the median refuge is installed based on site specific conditions , especially on roadways with a posted speed limit of 35 mph and higher. Overall, this research is in agreement with the FHWA guidance on improving pedestrian safety at mid-block crossing locations on 3-lane roadways with and without a median refuge (Blackburn et al. 2018).

There are some limitations of the sample. The number of 3-lane crossings identified in each of the ADT and posted speed categories was small (either 1 or 2), so the analysis looked at these dimensions separately. All yielding samples were during daylight hours and good weather. The crossings were mostly during non-peak hours. The majority of crossings were staged and the pedestrian followed the same protocol for each sample, which included waiting to activate the beacon until there was a gap in traffic, approaching and waiting in a consistent location, and wearing the same clothing. All of these variables would not be as consistent with non-staged crossings (Fitzpatrick et al., 2015).

There are other reasons, primarily for pedestrian comfort and safety, to add a median refuge that should be considered. Median islands reduce pedestrian exposure while crossing and have been proven to reduce pedestrian crashes (Lindley, 2008, Schneider et al. 2017). They also reduce the complexity of crossing (by dividing the crossing into two-stages), provide space to install roadway lighting which also reduces pedestrian crashes, and can lower the delay incurred by pedestrians waiting for a gap in the traffic to cross which leads to fewer pedestrians engaging in risky behaviors (FHWA, n.d.). The median also plays an important role relative to motorist behavior. The median physically restricts vehicles in queue from maneuvering around stopped vehicles and would be important when traffic is queued.

7.2 PEDESTRIAN VOLUME ESTIMATION AT MIDBLOCK LOCATIONS

Pedestrian volumes are critical inputs for safety analyses. However, pedestrian volumes are rarely available on a network level. Non-intersection counts are relatively rare in most count databases. Generally, site-specific project level counts are performed which leads to large gaps in pedestrian volume information at many locations. A pedestrian demand model can be used to fill gaps and estimate pedestrian volumes.

Video cameras were set up for 48-hrs at 25 crosswalks equipped with RRFB’s previously identified as part of the safety analysis conducted for SPR 778. Pedestrian volumes were manually extracted in 15-min intervals for the 48-hr time period. These were aggregated into hourly and daily volumes. The volume patterns at these sites were classified using the Afternoon Morning Index (AMI) proposed by Miranda-Moreno. The AMI index is a ratio of the AM peak hour volume to the mid-day volume and reveals whether a site has a commute or recreational/multipurpose travel pattern. Using the AMI values, sites were classified into commute or multipurpose factor groups and hourly factors between 7 AM – 7 PM were estimated at each site within the group. The average factors per pattern were also estimated. These average factors can be used to expand the short-duration counts to daily volumes at other locations.

A direct demand model was estimated using the average 24-hour counts obtained from the video and land use and demographic characteristics for census blocks extracted from the EPA’s Smart Location Database. A linear regression model was estimated. Significant predictors included the percent of low wage workers at the home and work locations, intersection density in terms of multi-modal intersections having four or more legs per square mile, intersection density in terms of auto-oriented intersections per square mile, gross population density, and proportion of census block group employment within ¼ mile of transit stop. The model fit was very good, with R^2 of

0.82. As the EPA database is readily available, this model can be used to predict pedestrian volumes at midblock locations.

7.3 UPDATED SAFETY EFFECTIVENESS OF RRFB

A crash modification factor (CMF) is used to compute the expected number of crashes after implementing a countermeasure. A safety performance function is an equation used to predict the average number of crashes per year at a location as a function of exposure and roadway and intersection characteristics (FHWA). Both CMF's and SPF's are critical pieces of the safety analysis toolbox and are used to assess the effectiveness of a countermeasure.

CMF's for pedestrian and rear-end crashes at crosswalks with RRFB's were estimated as part of a previous project (SPR 778). However, SPF's could not be estimated for pedestrian crashes as pedestrian volumes were not available. Pedestrian volumes were collected as a part of this research to estimate pedestrian SPFs. In addition, more after crash data were available for all locations. In this updated analysis, crash data between 2007 and 2017 was obtained and the methodology used previously was used to extract the pedestrian and rear-end crashes that occurred at RRFB locations.

Two methods – simple before-after and empirical Bayes (EB) were used to determine the safety effectiveness of RRFB's. With the simple-before analysis, CMF's of 0.84 (standard error=0.25) and 1.42 (standard error=0.12) were obtained for pedestrian and rear-end crashes respectively. The EB analysis is considered the state of the practice and more robust than the simple before after-analysis of the previous SPR 778 analysis. The EB method requires an SPF to be estimated first prior to determining an CMF. The SPF equation for pedestrian crashes used motor vehicle AADT and daily pedestrian volume as predictors. A CMF of 0.71 (standard error=0.20) was estimated for pedestrian crashes. For rear-end crashes, a predictor and a CMF of 1.11 (standard error of 0.06) was obtained. These CMF's are applicable for RRFB's with additional enhancements (median island, median island beacon) and can be used in place of the CMFs estimated for SPR 778.

The updated safety analysis confirmed the effectiveness of RRFB's as a countermeasure to reduce pedestrian crashes.

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