ASSESSMENT OF DRIVER YIELD RATES PRE- AND POST-RRFB INSTALLATION, BEND, OREGON

Oregon Department of Transportation

ASSESSMENT OF DRIVER YIELDING RATES PRE- AND POST-RRFB INSTALLATION, BEND, OREGON

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16. Abstract

The Oregon Department of Transportation improved two crosswalks on US 97 (Bend Parkway) near Bend, Oregon by installing Rectangular Rapid Flashing Beacons (RRFB), replacing signs, and enhancing pavement markings. At the location of the intersections where the RRFBs were installed the highway is a four-lane facility with a center median, bike lanes, and sidewalks. The posted speed is 45 miles per hour. At about the same time that the improvements were made at the two crosswalks on the Bend Parkway, RRFBs were installed at another nearby location in the City of Bend. As the use of RRFBs is considered experimental, particularly at locations with posted speeds in excess of 35 mph , an evaluation of driver compliance rates and conflicts at the three intersections was undertaken.

Driver yielding rates increased significantly at all three intersections where RRFBs were installed. Prior to the installation of RRFBs, data was collected on a total of 159 crossings at the three intersections; following RRFB installation data was collected on a total of 211 crossings. The average yielding rate was 17.8%; following installation the average yielding rate more than tripled to 79.9%.

The conclusion of the study was that RRFBs should be considered for installation on high-speed facilities where there are posted speeds greater than 35 miles per hour if there are pedestrians and bicyclists using the facility and a history of crashes or the potential for them. The design of an RRFB installation needs to include features to improve the visibility of the crossing.

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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	(F-32)/1.8	Celsius	°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
m^2	meters squared	1.196	square yards	yd^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	1.8C+32	Fahrenheit	°F

*SI is the symbol for the International System of Measurement

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1.0 INTRODUCTION

Oregon Department of Transportation Region 4 improved two crosswalks on US 97 (The Dalles-California Highway), by installing Rectangular Rapid Flashing Beacons (RRFB), replacing signs, and enhancing pavement markings. At the location of the intersections where the RRFBs were installed on US 97, the highway is a four-lane facility with a center median, bike lanes, and sidewalks. The posted speed is 45 miles per hour. As the use of RRFBs is considered experimental, particularly at locations where posted speeds are greater than 35 mph, an evaluation of driver compliance rates and conflicts was undertaken. The two locations on US 97, also known as the Bend Parkway, are Reed Lane (MP 139.68) and Badger Road (MP 140.30).

At about the same time that the improvements were made at the two crosswalks on the Bend Parkway, RRFBs were installed at 12th and US 20 (Central Oregon Highway) also known as Greenwood Avenue in the City of Bend. An evaluation of driver compliance was also conducted at this location.

Section 2.0 of this report provides a description of the locations where the improvements were implemented, descriptions of the improvements themselves, as well as the methodology utilized to collect the data.

Section 3.0 presents a summary of the data collected before and after the installation of the RRFBs and associated improvements. It includes an analysis of pre- and post-installation yielding rates and conflicts.

Section 4.0 provides a summary of results and discusses project conclusions.

2.0 STUDY LOCATIONS AND METHODOLOGY

2.1 BEND PARKWAY LOCATIONS

At the location of the intersections where the RRFBs were installed on the Bend Parkway, the highway is a four-lane facility with a center median, bike lanes, and sidewalks. The posted speed is 45 miles per hour; the 85th percentile speed on November 17, 2010 (before RRFBs were installed) at Reed Lane was 54 mph and at Badger Road on March 31, 2011 it was 52 mph. The 2010 Average Annual Daily Traffic (AADT) was 22,600 at 0.17 miles north of Powers Road Interchange near Reed Lane and 0.08 miles north of Badger Road the AADT was 18,300.

The Bend Parkway, was constructed in 2001 as a bypass with limited access, well-spaced signals, and two marked crosswalks at uncontrolled intersections to accommodate pedestrians. The crosswalks were indicated with continental markings. At the two crosswalks a bike/pedestrian warning sign as shown in Figure 2.1 was accompanied by a diagonal downward pointing arrow. Signs in advance of the intersection were accompanied by a supplemental plaque containing the legend "AHEAD."

Figure 2.1 Bike/Pedestrian Warning sign displayed at Reed Lane and Badger Road crosswalks

Due to the relatively long crossing distances and relatively high speeds, the number of pedestrians crossing at these locations was low, but increasing. Crash reports indicated there had been three crashes involving pedestrians at Reed Lane since 2001 as well as one fatal bicycle crash that occurred in 2010. This fatal crash involved a bicyclist traveling west across the highway at the Reed Lane crosswalk. When the vehicle in the 'B' lane stopped the bicyclist proceeded to cross and was struck by a second vehicle in the 'A' lane. During the same time period, there was one pedestrian involved crash at Badger Road as well as a fatal pedestrian crash. In the fatal crash, a pedestrian was struck by a vehicle while crossing outside of the marked crosswalk at night.

The intersection of the Bend Parkway and Reed Lane was listed as a top 10% Safety Priority Index System (SPIS) site for 2011 based on 2008 – 2010 crash data. The Safety Priority Index System (SPIS) was developed in 1986 by ODOT as a method for identifying potential safety problems on state highways. The SPIS identifies locations based on three years of crash data and considers crash frequency, crash rate, and crash severity. A roadway segment becomes a SPIS site if the location has three or more crashes or a least one fatal crash over the three-year period.

The crosswalk design and signing at the Reed Lane intersection prior to installation of the RRFBs is shown in Figure 2.2.

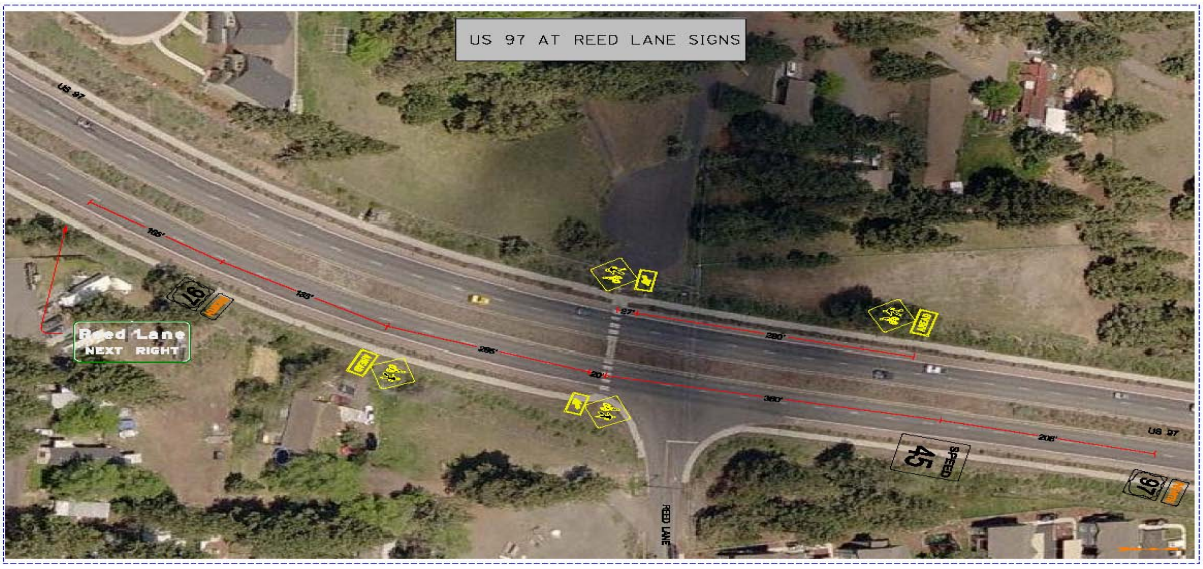

Figure 2.2: Pre-RRFB crosswalk and signing at the Reed Lane and Bend Parkway intersection

At Badger Road, the crosswalk configuration is such that the pedestrian crossing the median is facing toward traffic. The pre-RRFB crosswalk configuration and signs at Badger Road are shown in Figure 2.3.

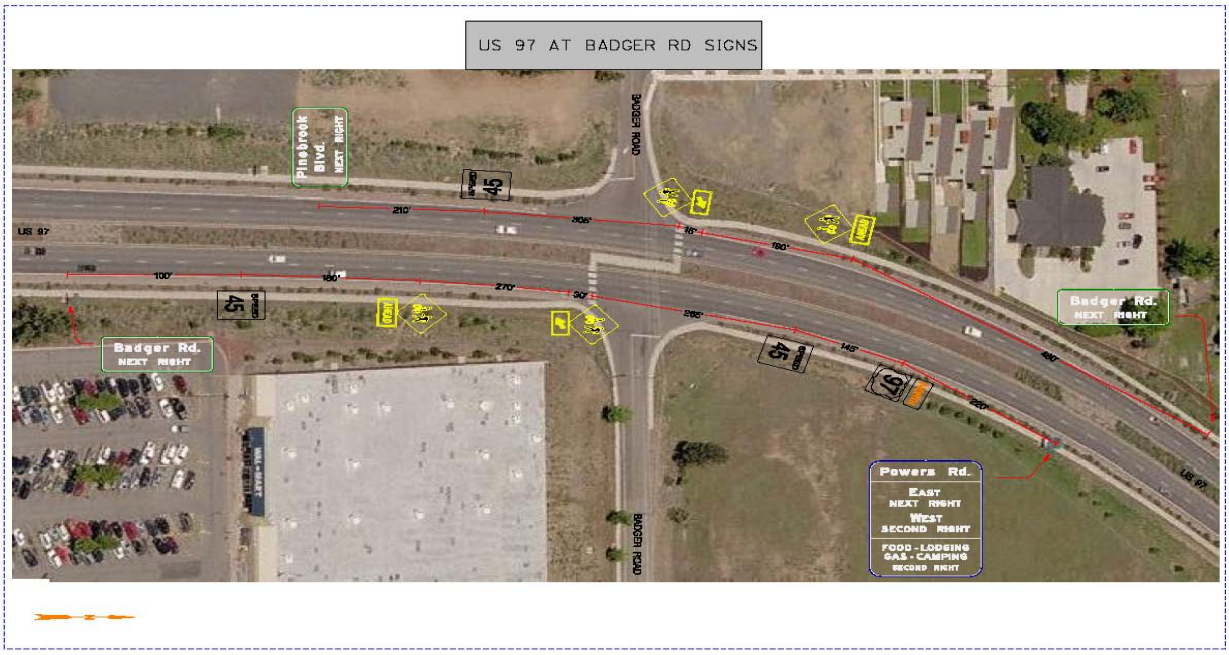

Figure 2.3: Pre-RRFB crosswalk and signing at the Badger Road and Bend Parkway intersection

Rapid Rectangular Flashing Beacons (RRFBs) were installed at both intersections in May 2011. Figure 2.4 is a picture of a typical RRFB device.

Figure 2.4: Rectangular Flashing Beacon Device (*FHWA 2011*)

The RRFBs at both locations were installed in accordance with conditions given in the Federal Highway Administration (FHWA) memorandum regarding Interim Approval for Optional Use of Rectangular Flashing Beacons (IA-11) dated July 16, 2008 as well as conditions noted in an approval letter from the State Traffic Engineer dated December 10, 2010. These include the following:

- Four pedestrian beacons meeting FHWA specifications shall be installed for each approach, for each direction. Two RRFB assemblies will be installed at the crosswalk (one on shoulder and one in median) and two will be installed approximately 500' in advance of the crosswalk (one in shoulder and one in median). (Previously the advance signs were on the right side of the road only and were placed about 350 feet from the crosswalk.) Beacons will be combined with combined Bicycle/Pedestrian signs that are fluorescent yellow in color. Forty-eight inch signs will replace 36 inch signs that were not fluorescent yellow. The RRFB assemblies at the crosswalk and those in advance of the crosswalk are activated simultaneously when a pedestrian or bicyclist pushes the button. When the pushbutton is activated the following message is heard: "Lights are on to cross the Parkway. Traffic may not stop."

- Ladder bars will be added to the continental crosswalks and the side streets, which currently do not have marked crosswalks, will have longitudinal crossings installed.

- A stop line shall be installed for each travel lane 50' in advance of the crosswalk.

- "Stop Here for Pedestrians" signs shall be installed in advance of the marked crosswalks.

- Double white solid no lane change lines will be installed approximately 150' in advance of the crosswalk to deter vehicles from passing a stopping vehicle (multiple threat crash).

Determining the timing at the two Bend Parkway intersections, as well as at the Greenwood Avenue location, was the responsibility of ODOT Region 4 Traffic staff. After testing various time periods for the three intersections, the timing in effect was calculated by using the crossing distance / 3.5 feet/second plus 7 seconds of delay. This formula was based on the MUTCD procedures for timing of pedestrian clearance times for pedestrian signals plus a delay for drivers' response time. If the crossing time is too long drivers comment that the lights are flashing but no pedestrians are in the vicinity.

A pedestrian push button (similar to the photo in Figure 2.6 which shows the push button at 12th and Greenwood) was used at the two locations on the Bend Parkway. When the push button was activated on the Parkway the following message was heard: "Warning lights are on to cross Bend Parkway. Traffic may not stop."

2.2 GREENWOOD AVENUE LOCATION

RRFBs were installed on Greenwood Avenue (US 20) at NE 12th Street in the City of Bend which is a transition point between urban and suburban design components. This is a four-lane facility with a center median. The posted speed is 35 miles per hour; the 85th percentile speed as measured in March 13, 2009 during a speed zone investigation was 44 mph.

To the west of NE 12th Street, Greenwood Avenue is five lanes with a two-way center left turn lane. The roadway in this section is bordered by small scale commercial businesses and crosses through the heart of the mid-town residential neighborhoods. Both Pilot Butte Middle School and Bend Senior High School have jurisdictional attendance boundaries spanning both sides of the roadway, requiring students to cross Greenwood Avenue on their trip between home and school. There is short block spacing and frequent driveways. There are pedestrians and bicyclists crossing the roadway at multiple locations.

To the east of NE 12th Street, the roadway carries an expressway designation and is designed to provide a limited access four-lane facility separated by a median. The median has no landscaping at this time and there are no street trees. This section primarily has curb-tight sidewalks, although there are some portions where the sidewalk is buffered with rock mulch. There are limited accesses for the next two miles to Bend's eastern Urban Growth Boundary. There are large box commercial enterprises or auto dominant commercial centers. There is limited housing in the area and, this, combined with the auto dominant retail, leads to fewer pedestrian and bicyclist crossings. Crossings are mainly focused at the signalized intersections or the main pedestrian undercrossing tunnel located east of NE 15th Street. All of these attributes lead to higher travel speeds, coincident with the higher posted speed of 45 mph.

Drivers traveling from the eastern expressway section approaching the NE 12th Street intersection westbound do not expect, and are not prepared to react to, the greater pedestrian and bicyclist activity that begins at NE 12th Street. Drivers traveling from the western urban facility with its many pedestrians and bicyclists and relatively lower speeds and greater congestion are anticipating the reduced conflicts that exist in the expressway section and are therefore accelerating as they approach NE 12th Street. The roadway eastbound has a large, right-handed, sweeping horizontal curve pulling pedestrians standing on the south curb line out of driver's line of sight. The 2010 AADT at 0.06 mile east of Summit Drive (Pilot Butte State Park entrance) which is just east of the 12th Street installation was 21,700.

This intersection of Greenwood Avenue and NE 12th Street has been identified as a high crash location due to pedestrian and bicyclist crashes with motor vehicles.

Prior to the installation of the RRFBs there was no marked crosswalk at this location. In 2009 ODOT Region 4 submitted an engineering study requesting approval of the marked crosswalk which was approved in August of that year. The new crosswalk design and signing at the Greenwood Avenue and NE 12th Street intersection is shown in Figure 2.5.

Figure 2.5 represents the current signing and crosswalk configuration at the Greenwood Avenue and NE 12th Street intersection.

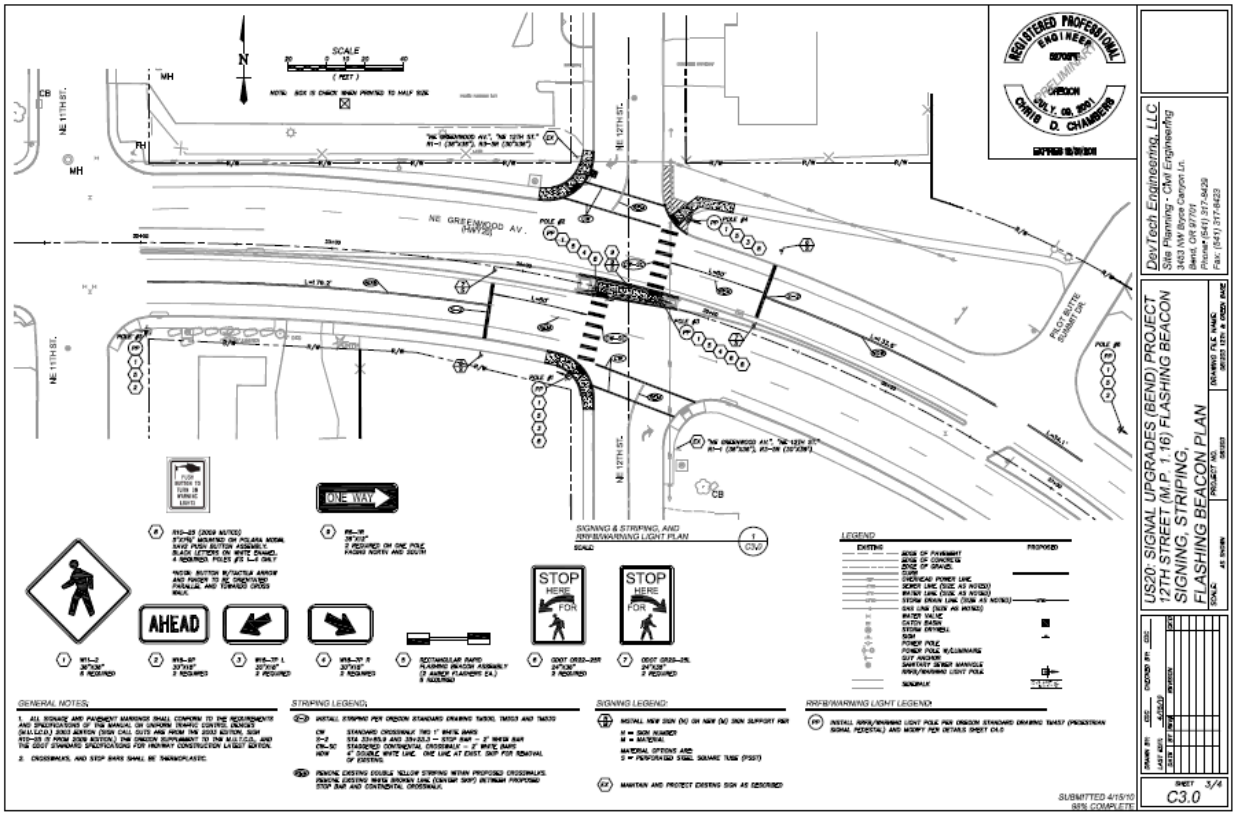

Figure 2.5 represents the current signing and crosswalk configuration at Greenwood Avenue and NE 12th Street.

As on the Bend Parkway, RRFBs were installed according to guidance from FHWA. There were a few exceptions. At this location there is only one advance sign with an RRFB which is located on the right side of the roadway. There was insufficient space on the median to accommodate an advance sign on the left side of the roadway. Signs at this location are 36 inches rather than the larger 48 inch signs used at the higher speed Bend Parkway locations. The continental crosswalks do not have ladders added.

Figure 2.6 shows the pushbutton at Greenwood Avenue and NE 12th Street. The same pushbutton and warning light is used at the two locations on the Bend Parkway. When the pushbutton is activated the following message is heard: "Warning lights are on to cross Greenwood Avenue. Traffic may not stop."

Figure 2.6: Pushbutton at Greenwood Avenue and NE 12th Street RRFB location

2.3 METHODOLOGY

2.3.1 Pre-Installation Data Collection

Data was collected at the three locations between March 31, 2011 and April 8, 2011. Prior to the data collection, basic descriptive information about the characteristics of the intersections was recorded and pictures of the existing signs and crosswalk markings were taken. The methodology used for collecting data at the Bend Parkway locations and the 12th and Greenwood location varied slightly.

2.3.1.1 Bend Parkway at Badger Road and Reed Lane

On the Bend Parkway, data was collected for approximately one hour at each crosswalk by staging individual pedestrian crossings in both the east and west directions at each of the locations. The person recording the entries stood well away from the crosswalk to not distract drivers or to give drivers any indication that data was being collected for the study. The form, which is included in the report as Appendix B, was utilized to collect the following for each crossing:

- direction of travel,
- whether the pedestrian was crossing from the sidewalk or median,
- if a bicyclist was riding or walking his/her bike,

- whether it was a staged crossing or a crossing by the general population,
- how many people crossed at the same time,
- number of vehicles yielding and not yielding by lane, and
- conflicts and observations.

For staged crossings, which most of the crossings were, the person assuming the role of pedestrian approached the crosswalk before a vehicle entered the "safe stopping zone" and stood on the tactile surface in close proximity to the roadway and waited for vehicles to stop before proceeding to cross. Once the vehicles yielded in the "B" (curb) lane, the person entered the crosswalk and waited for the "A" (fast) lane to stop. Once the vehicle in the "A" lane stopped the person crossing proceeded across to the other side (median or sidewalk from median). This method was used for crossing from the sidewalk or from the median. For each crossing the number of vehicles in the "A" lane that yielded and the number that did not yield was noted. The same information was recorded for vehicles traveling in the "B" lane. Conflicts were noted and described. Other observations were noted. Data was collected for 52 crossings at Badger Road and 41 crossings at Reed Lane.

2.3.1.2 Greenwood Avenue at NE 12th Street

At the Greenwood Avenue and NE 12th street location in Bend, data was collected for an hour and a quarter by staging individual pedestrian crossings in both the north and south directions. A form very similar to that used for collecting data at the Bend Parkway locations was used. The city staff either stepped into the crosswalk or held one foot in the crosswalk thus triggering the state law requiring a motorist to yield. Additionally city staff was able to collect data on motorists yielding in the opposing direction.

2.3.2 Post-Installation Data Collection

RRFBs were installed in all three locations in spring 2011. The devices installed at Badger Road were activated on May 3, 2011. The devices installed at Reed Lane were activated on May 20, 2011. Minor changes were made to enhance striping at these locations after the activation dates. The RRFBs were activated at the Greenwood Avenue location in the city of Bend on June 15, 2011. Post installation data was collected approximately two months later using the same methodology as prior to RRFB installation.

Revisions to change this installation from a two stage to one stage crossing were completed in October 20, 2011. Field work was completed again to collect data after the revision.

3.0 RESULTS

3.1 PRE-INSTALLATION RESULTS

3.1.1 Bend Parkway

3.1.1.1 Reed Lane

Data were collected at the intersection of the Bend Parkway and Reed Lane on April 1, 2011 from 9:45 AM to 10:45 AM by two ODOT staff following the methodology given in the previous section. The weather was clear and warm.

At this location the distance from curb to curb is 78 feet. This includes four travel lanes, a 16 foot median, and six foot bike lanes. There is a five foot sidewalk on each side. There is no transit stop and there is one traffic signal 0.29 miles to the south of Reed Lane at Powers Road.

Table 3.1 presents the data collected for the east and west crossing directions with separate data for the crossings from the sidewalk and median. When considering all 41 crossings together the overall yield rate was 22.8%. Yield rates for vehicles traveling southbound and stopping for a pedestrian waiting on the median were higher than for the other travel directions.

Table 3.1: Pre-RRFB installation driver yield summary, Reed Lane crosswalk

Direction of Travel	Number of Crossings	Vehicles Yielding	Vehicles Not Yielding	Percent Yielding	Number of Conflicts
Pedestrian traveling East*					
from Sidewalk (crossing SB lanes)	17	11	30	26.8%	1
from Median (crossing NB lanes)	5	6	17	26.1%	0
Pedestrian traveling West					
from Sidewalk (crossing NB lanes)	12	15	52	22.4%	3
from Median (crossing SB lanes)	7	10	1	90.9%	0
TOTAL	41	42	142	22.8%	4

*Two of the "crossings" were a person riding a bike.

As shown in Table 3.1 there were a total of four conflicts recorded. Two conflicts were due to a car in the “B” lane switching to the “A” lane to go around a vehicle yielding to the pedestrian. One conflict occurred when a vehicle skidded into the bike lane to avoid rear-ending a stopped vehicle and another occurred when a vehicle in the A lane made an avoiding maneuver to avoid rear-ending a stopped vehicle by skidding between the stopped vehicles in the “A” and “B” lanes.

3.1.1.2 Badger Road

Data were collected at the intersection of the Bend Parkway and Badger Road on March 31, 2011 from 9:45 AM to 11:10 AM by two ODOT staff following the methodology given in the previous section. The weather was clear and warm.

At this location the distance from curb to curb is 78 feet. This includes four travel lanes, a 16 foot median, and six foot bike lanes. There is a five foot sidewalk on each side. There is no transit stop and the Badger Road crosswalk is located between two signals at Pinebrook Blvd. and Powers Road.

Table 3.2 presents the data collected for the east and west crossing directions with separate data for the crossings from the sidewalk and median. When considering all 52 crossings together the overall yield rate was just under twenty-five percent (24.7%). Yield rates (50% for southbound and 42% for northbound) for vehicles stopping for a pedestrian waiting on the median were a good deal higher than for vehicles stopping for a pedestrian waiting on the sidewalk on the side of the Parkway. This may be because the pedestrians are more visible or that a pedestrian waiting on the median is a clearer indication that he/she is waiting to cross than if waiting on the sidewalk.

Table 3.2: Pre-RRFB installation driver yield summary, Badger Road crosswalk

Direction of Travel	Number of Crossings	Vehicles Yielding	Vehicles Not Yielding	Percent Yielding	Number of Conflicts
Pedestrian traveling East					
from Sidewalk (crossing SB lanes)	14	11	59	15.7%	0
from Median (crossing NB lanes)	14	15	21	41.7%	3
Pedestrian traveling West					
from Sidewalk (crossing NB lanes)	14	11	55	16.7%	0
from Median (crossing SB lanes)	10	11	11	50.0%	0
TOTAL	52	48	146	24.7%	3

Three conflicts occurred at the Badger Road crosswalk. In one case, a driver passing from the "A" to "B" lane had to make an abrupt stop to avoid hitting the car in front. In another case, a vehicle stopped in the crosswalk. In the third case, the pedestrian had to run across the street to avoid being hit. At this intersection two law enforcement officers were identified as not yielding for the waiting pedestrian.

3.1.2 Greenwood Avenue at NE 12th Street

Data were collected at the intersection of Greenwood Avenue and NE 12th Street on April 8, 2011 from 10:45 AM to noon by City of Bend staff following the methodology given in the previous section. The weather was sunny and cold.

At this location, the distance from curb to curb is 92 feet on the west leg of the intersection and 99 feet on the east leg of the intersection. This was measured between the ADA ramp curbs. These distances include six foot bike lanes and two 12 foot travel lanes in each direction as well as a nine foot wide median on the west leg and a seven foot wide median on the east leg. The distances are large due to large curb radii and the large horizontal curvature of the roadway through the intersection.

Table 3.3 presents the data collected for the north and south crossing directions with separate data for the crossings from the sidewalk and median. When considering all 66 crossings together the overall yield rate was 5.8%. Yield rates for vehicles traveling eastbound and stopping for a pedestrian waiting on the median were higher than for the other travel directions. The lowest yield rate (0.9%) was associated with pedestrians leaving the sidewalk in the southbound direction. One reason for this may be that there is a traffic signal east of this location and drivers may think that once getting a "green" they should be free to travel without stopping.

Table 3.3: Pre-RRFB installation driver yield summary, Greenwood Avenue and NE 12th Street intersection

Direction of Travel	Number of Crossings	Vehicles Yielding	Vehicles Not Yielding	Percent Yielding	Number of Conflicts
Pedestrian traveling North					
From Sidewalk (crossing eastbound lanes)	30	10	177	5.3%	0
From Median (crossing westbound lanes)	11	7	88	7.4%	0
Pedestrian traveling South					
From Sidewalk (crossing westbound lanes)	9	1	109	0.9%	0
From Median (crossing eastbound lanes)	16	11	93	10.6%	0
TOTAL	66	29	467	5.8%	0

3.2 POST-INSTALLATION RESULTS

3.2.1 Bend Parkway

3.2.1.1 Reed Lane

Data were collected at the intersection of the Bend Parkway and Reed Lane on July 28, 2011 from 10:15 AM to 11:50 AM by two ODOT staff following the methodology given in the previous section. The weather was clear and warm. Figures 3.1 and 3.2 show the installation of the RRFB devices at the Reed Lane intersection. Figure 3.1 shows the Reed Lane intersection from the driver's point of view, taken to include the advance RRFBs as well as the RRFBs at the crossing. Figure 3.2 shows the crossing from the pedestrian's point of view.

Figure 3.1 Driver's perspective of RRFB installation at the Bend Parkway and Reed Lane

Figure 3.2 Pedestrian's perspective of RRFB installation at the Bend Parkway and Reed Lane

Each crossing at Reed Lane is a full crossing but yielding and non-yielding for the second stage of the crossing was not considered until the pedestrian had reached the median.

Table 3.1 presents the data collected for the east and west crossing directions with separate data for the crossings from the sidewalk and median. In staged crossings, the researchers always activated the push buttons to give vehicles adequate space to stop. Activating the button when vehicles do not have adequate space to stop may give different results with regards to vehicle conflicts and driver compliancy). When considering all 100 crossings together the overall yield rate was 82.9%. Yield rates for vehicles stopping for a pedestrian waiting on the median were higher than for vehicles stopping for pedestrians crossing from the sidewalk. This may be because the pedestrians are more visible or that a pedestrian waiting on the median is a clearer indication that he/she is waiting to cross than if waiting on the sidewalk.

Table 3.4: Post-RRFB installation driver yield summary, Reed Lane crosswalk

Direction of Travel	Number of Crossings*	Vehicles Yielding	Vehicles Not Yielding	Percent Yielding	Number of Conflicts
Pedestrian traveling East*					
from Sidewalk (crossing SB lanes)	24	31	8	79.5%	0
from Median (crossing NB lanes)	24	27	0	100.0%	0
Pedestrian traveling West					
from Sidewalk (crossing NB lanes)	26	41	18	69.5%	0
from Median (crossing SB lanes)	26	42	3	93.3%	0
TOTAL	100	141	29	82.9%	0

*Six of the "crossings" were a person riding a bike.

It may be that the low driver yield percentage for pedestrians traveling from the sidewalk in the westbound direction is due to the fact that drivers are coming from the nearby signalized intersection at Powers and feel that once they have a “green” they should be able to continue to proceed down the Parkway.

At the time the post-installation data was collected the research team made the following observations:

- Activation of the RRFBs resulted in a quieter and more comfortable environment for the crossing pedestrian. It appeared that vehicles decelerated at a more comfortable rate rather than coming to sudden or abrupt stops.

- Vehicles often stopped or slowed down far from the intersection when activation occurred, giving the pedestrian a safe opportunity to cross.

- Crossers generally did not activate the pushbutton but typically waited for a safe gap and crossed.

Additional follow-up data collection was conducted in September 2011, approximately three months after the RRFBs had been installed. Speed data was collected 400 feet north of Reed Lane on 9/14/2011 and resulted in an 85th percentile speed of 55 mph, pace limits of 44-53 mph with 75% of drivers within in the pace limit. The maximum speed recorded was 64 mph; 94% of drivers were exceeding the posted speed.

The Reed Lane crosswalk was video recorded from 4:00 AM on Friday, September 23, 2011 to 4:00 AM on Sunday September 25th. Pedestrians and bicyclists were observed during this period and it was noted if they activated the RRFBs to cross. There were a total of 78 crossings during the period and majority of the crossers were bicyclists (64%). Half of the bicyclists did not activate the flasher; most pedestrians (75%) activated the flashers. All bicyclists rode their bikes across the highway except one. (See Figure 3.3 which was taken prior to modifying the crosswalk.) Note that the RRFB was not activated and the bicyclist was riding in the crosswalk.

Figure 3.3: Bicycle crossing at the Bend Parkway and Reed Lane

3.2.1.2 Badger Road

Data was collected at the intersection of the Bend Parkway and Badger Road on June 24, 2011 from 10:00 AM to 11:15 AM by two ODOT staff following the methodology given in the previous section. The weather was clear and warm. Figures 3.4 and 3.5 show the installation of the RRFB devices at the Badger Road intersection. Figure 3.4 shows the

crossing from the driver's point of view and Figure 3.4 shows the crossing from the pedestrian's point of view.

Figure 3.4 Driver's perspective of RRFB installation at the Bend Parkway and Badger Road

Figure 3.5 Pedestrian's perspective of RRFB installation at the Bend Parkway and Badger Road

At this intersection the RRFBs are activated for one direction at a time. Table 3.5 presents the data collected for the east and west crossing directions with separate data for the crossings from the sidewalk and median. When considering all 60 crossings together the overall yield rate was 82.6%. Yield rates were similar for all four of the crossings.

Table 3.5: Post-RRFB installation driver yield summary, Badger Road crosswalk

Direction of Travel	Number of Crossings	Vehicles Yielding	Vehicles Not Yielding	Percent Yielding	Number of Conflicts
Pedestrian traveling East					
from Sidewalk (crossing SB lanes)	16	22	5	81.5%	0
from Median (crossing NB lanes)	15	22	6	78.6%	0
Pedestrian traveling West					
from Sidewalk (crossing NB lanes)	15	23	4	85.2%	1
from Median (crossing SB lanes)	14	23	4	85.2%	0
TOTAL	60	90	19	82.6%	1

One conflict occurred at the Badger Road crosswalk. A driver traveling northbound didn't stop at the crosswalk and proceeded through the intersection before the pedestrian was finished crossing.

At the time the post-installation data was collected the research team made the following observations which were similar to those made at Reed Lane:

- Activation of the RRFBs resulted in a quieter and more comfortable environment for the crossing pedestrian.
- Vehicles often stopped or slowed down far from the intersection when activation occurred, giving the pedestrian a safe opportunity to cross.
- Crossers generally did not activate the pushbutton but typically waited for a safe gap and crossed.
- Pedestrians and bicyclists were observed crossing outside of the Z-Crossing. (See Figure 3.6.).

Figure 3.6: Bicyclist traveling across Badger Road not in "Z" crossing (note RRFB is not activated)

Speed data was collected 400' north of Badger Road on September 21, 2011 and resulted in an 85th percentile speed of 52, pace limits of 43-52 mph with 79% of drivers in the pace limit. The maximum speed recorded was 58mph; 67% of drivers were exceeding the posted speed.

3.2.2 Greenwood Avenue at NE 12th Street

Data was collected at the intersection of Greenwood Avenue and NE 12th Street in the City of Bend on August 19, 2011 from 10:00AM to 11:00AM by City of Bend staff following the methodology given in the previous section. The weather was warm and sunny. Figures 3.5 and 3.6 show two views of this intersection. Figure 3.7 is taken from the northeast corner of 12th and Greenwood Avenue and shows the driver's perspective. Figure 3.8 shows the intersection as a pedestrian crossing Greenwood Avenue in the northbound direction would see it. This crossing was designed to be a two-stage crossing with the pedestrian pushing the button to cross from the sidewalk to the median and then pushing a second push button to continue from the median to the other side of the street.

Figure 3.7: Driver's perspective of RRFB crossing at Greenwood Avenue and NE 12th Street

Figure 3.8: Pedestrian's perspective of RRFB crossing at Greenwood Avenue and NE 12th Street

Table 3.6 presents the data collected for the north and south crossing directions with separate data for the crossings from the sidewalk and median. When considering all 51 crossings together the overall yield rate was 87.4%. Yield rates for vehicles traveling westbound and stopping for a pedestrian waiting on the median were higher than for the other travel directions. The low driver yield rate for the northbound crossing of eastbound lanes might be related to sight line visibility. Plants that were blocking the sight lines to the pedestrian were removed after this data was collected.

Table 3.6: Driver yield summary for two-stage crossing at Greenwood Avenue and NE 12th Street intersection

Direction of Travel	Number of Crossings	Vehicles Yielding	Vehicles Not Yielding	Percent Yielding	Number of Conflicts
Pedestrian traveling North					
From Sidewalk (crossing eastbound lanes)	15	23	4	85.2%	3
From Median (crossing westbound lanes)	11	18	0	100.0%	3
Pedestrian traveling South					
From Sidewalk (crossing westbound lanes)	14	21	7	75.0%	2
From Median (crossing eastbound lanes)	11	21	1	95.5%	2
TOTAL	51	83	12	87.4%	10

Ten conflicts were observed. Primarily these conflicts were drivers stopping beyond the stop bar, too close to the pedestrian, and blocking sight lines to the adjacent travel lane which set up serious double jeopardy issues. There were two other conflict types. One driver reacted late to the pedestrian and the warning system and did not stop until downstream of the crossing, traveling past the pedestrian mid-crossing. One rear end conflict occurred. A driver stopped between the stop bar and the crossing prior to the warning light system being activated, when the staged pedestrian was walking in the "Z" portion of the median. There was a semi-tractor trailer following closely to the vehicle that stopped. The semi-truck driver reacted quickly and braked hard and was just able to stop approximately 12 inches from the vehicle in front of it. The pedestrian had not yet pressed the button to activate the flashing warning system so the truck driver did not have much warning of the situation.

Observations were made while compliance data was being collected. There were drivers who were yielding to pedestrians when the pedestrian was on the opposing lane of the median; and drivers that were yielding when pedestrians were in the "Z" portion of the median. The flashing lights were not on for those opposing lanes until the pedestrian has pushed the button to activate that stage of the warning lights. The other drivers following or in the adjacent lane do not know what is going on and why a vehicle is stopping. They are either braking hard and nearly rear-ending the driver who yielded early or changing lanes to avoid the stopped vehicle and zooming past the stopped vehicle. This sets up a serious issue for pedestrians in either case. A rear end at

those high speeds could easily push the vehicles into the pedestrian. This situation led to a decision to revise the operation of the RRFBs at this location from a two-stage crossing to a single stage crossing

On October 20, 2011 the operation of the RRFBs was changed so that all RRFBs in both directions were activated when a crosser pressed any pushbutton. This change was requested by the City of Bend after they collected the post-installation data. The intersection now is operated as a one stage crossing. Data on driver yielding was collected at the Greenwood Avenue and NE 12th Street intersection about a week after the changes.

Table 3.7: Driver yield summary for one-stage crossing at Greenwood Avenue and NE 12th Street intersection

Direction of Travel	Number of Crossings	Vehicles Yielding	Vehicles Not Yielding	Percent Yielding	Number of Conflicts
Pedestrian traveling North					
From Sidewalk (crossing eastbound lanes)	11	19	11	63.3%	0
From Median (crossing westbound lanes)	11	21	1	95.4%	1
Pedestrian traveling South					
From Sidewalk (crossing westbound lanes)	12	20	14	58.8%	1
From Median (crossing eastbound lanes)	13	18	1	94.7%	0
TOTAL	47	78	27	74.3%	2

The average yielding percent of 74.29% is significantly less than the 87.4% when the crossing was set up to be done in two stages. However the percent of vehicles yielding for pedestrians crossing from the median remained very high at about 95%. It should be noted that there was a single crossing northbound and a single crossing southbound that significantly affected the yielding rates for the movement from the sidewalk. Observers stated that it seemed that when one driver does not stop other vehicles follow suit. Eight vehicles for one northbound crossing did not yield; seven did not yield for one southbound crossing.

While the yield rate is lower than when the RRFBs were set up as a two-stage crossing, the research team observed that the change seemed to increase effectiveness. The number of conflicts was reduced from 10 to two for slightly fewer crossings.

Speed data was collected at Summit Drive (just east of 12th Street) on October 14, 2011 which showed an 85th percentile speed of 42 mph, pace limits of 33-42 mph with 84% of drivers in the pace limit. The maximum speed recorded was 48 mph; 72% of drivers were exceeding the posted speed.

3.3 ANALYSIS OF RESULTS

Driver yielding rates increased significantly at all three intersections where RRFBs were installed. Prior to the installation of RRFBs data was collected on a total of 159 crossings at the three intersections; following RRFB installation data was collected on a total of 211 crossings.

The average yielding rate was 17.8%; following installation the average rate more than tripled to 79.9%. Table 3.8 summarizes the yield rates observed before the RRFBs were installed and two to four months later. The data given for the Greenwood Avenue location is from October after the conversion to a one-stage crossing was completed. Figure 3.9 presents the same information as a bar graph.

Table 3.8: Pre- and post-RRFB installation yield rates at three intersections

Location	Pre-RRFB Installation	Post-RRFB Installation
Bend Parkway and Reed Lane	22.8%	82.9%
xBend Parkway and Badger Road	24.7%	82.6%
Greenwood Avenue and NE 12th Street	5.8%	74.3%
AVERAGE	17.8%	79.9%

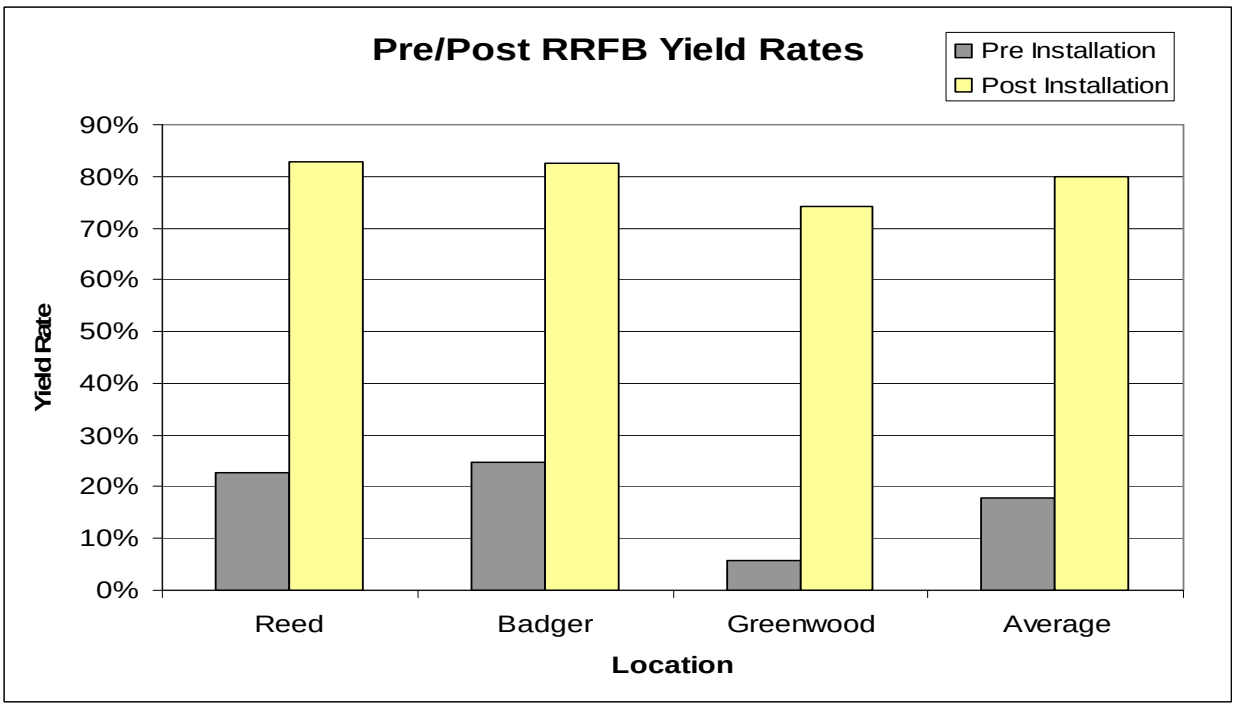

Figure 3.9: Pre- and post-RRFB installation yield rates at three intersections

The number of conflicts went from 4.4 conflicts per 100 crossings to 1.4 conflicts per 100 crossings. Conflicts before the installations were: due to drivers changing lanes and having to stop abruptly to avoid hitting the car in front and a vehicle stopping in the crosswalk. Conflicts after the installations were when a driver proceeded through the intersection at Badger Road before the pedestrian was finished crossing and, at the Greenwood Avenue intersection, the first vehicle to stop, stopped downstream from the advance stop bar close to the crosswalk which could then potentially block the view of a vehicle approaching in the other lane.

Speed data was recorded at the three intersections before and after the RRFBs were installed. At all three intersections the 85th percentile speed was from 15% to 25% greater than the posted speed and 67% to 87% of the vehicles were exceeding the posted speed of 45 mph. The 85th

percentile speed at Badger was 52 mph both before and after the RRFBs were installed. The 85th percentile speed at Reed Lane was 55 mph both before and after the RRFBs were installed. Only on Greenwood Avenue, where the posted speed is 35 mph, did the speed decrease. Here the 85th percentile speed declined by about 5% from 44 mph to 42 mph. The percent of vehicles exceeding the posted speed dropped from 85% to 72%.

4.0 SUMMARY AND RECOMMENDATIONS

Oregon Department of Transportation Region 4 improved two crosswalks on the Bend Parkway, at Reed Lane and Badger Road. RRFBs were also installed at Greenwood Avenue and NE 12th Street in the City of Bend.

Due to the relatively long crossing distances and relatively high speeds on the Bend Parkway, the number of pedestrian and bicycle crossings at the Reed Lane and Badger Road locations was low, but increasing. Crash reports indicated there have been three pedestrian-involved crashes at Reed Lane since 2001 as well as one fatal bicycle crash. During the same time period, at Badger Road there was one pedestrian-involved injury crash and a fatal pedestrian crash in which the pedestrian was struck by a vehicle while crossing outside of the marked crosswalk at night.

ODOT determined that installation of RRFBs could be expected to improve pedestrian safety at the two locations. Since the posted speed of 45 miles per hour was greater than most locations where RRFBs have been installed, the plans for the RRFB installations included additional features to increase the visibility of the crosswalks and the pedestrians and bicyclists using them. These include RRFB assemblies on the side of the road and on the median at the crosswalk and 500 feet in advance of the crosswalk. Pavement markings included ladder bars with a continental crosswalk, a stop line 50 feet in advance of the crosswalk, and a double white solid no lane change lines as well as the legend "PED X-ING" on the road as vehicles approach the intersection. The signs in the RRFB assembly were 48 inches and there was a sign in advance of the crosswalk with the legend "Stop Here for Pedestrians." The installation of RRFBs on Greenwood Avenue where the posted speed is 35 mph included some, but not all of these features.

Driver yielding data and conflicts were recorded at the three locations before and after the RRFBs were installed. It was found that yielding increased from an average of 17% to an average of 79% and conflicts were reduced. The initial design for one of the intersections (Greenwood Avenue) called for a two-stage crossing. It was found that there were conflicts when this design was implemented and the crossing was revised to be a one-stage crossing.

After testing various time periods for the beacons to flash at the three intersections, the pedestrian crossing times now in effect were implemented. The timing was calculated by using the measured crossing distance/3.5 feet/second plus seven seconds of delay. If the crossing time was too long drivers commented that the lights were flashing but no pedestrians or bicyclists were in the vicinity and were no longer visible.

RRFBs should be considered for installation on high-speed facilities where there are posted speeds greater than 35 miles per hour if there are pedestrians and bicyclists using the facility and a history of crashes or the potential for them. The design of the RRFB installation needs to consider measures to improve the visibility of the crossing. The results of the evaluation and observations of the staff involved with the operation of the RRFBs are the basis for

recommending that the following features should be included when RRFBs are installed in an environment similar to that on the Bend Parkway:

- Four pedestrian beacons for each approach for each direction should be installed. Two RRFB assemblies should be installed at the crosswalk (one on the shoulder and one in the median) and two should be installed in advance of the crosswalk (one on the shoulder and one on the median), based on the minimum stopping sight distance for the actual 85th percentile speed. Each assembly should include two beacons, a 36" or 48"inch combined Bicycle/Pedestrian sign that is fluorescent yellow in color. A downward slanting arrow should be added to the assemblies at the crosswalk and an "AHEAD" plaque should be added on the advance assemblies.

- Crosswalks should be enhanced to the greatest extent possible to make drivers aware of the crossing.

- A stop line should be installed for each travel lane 50' in advance of the crosswalk. The stop line should be 24" wide to clearly define where vehicles should stop to avoid blocking a passing vehicle.

- "Stop Here for Pedestrians" signs should be installed in advance of the marked crosswalks.

- Double white solid no lane change lines should be installed at least 150' in advance of the crosswalk to deter vehicles from passing a stopping vehicle.

- A legend on the road reading "PED XING" should be installed at the advance sign locations.

- Adequate illumination should be provided at each crosswalk

- Crosswalks designed as "Z" crossings (a marked crossing at opposite corners of the intersection) should be evaluated before the installation of the RRFBs to determine if crossers use the "Z" crossing or cross straight across. If pedestrians and bicyclists cross straight across the options of closing one leg of the intersection and creating one straight crossing or having both crosswalks continue straight across the intersection should be considered.

The evaluation of the three installations and observations of those involved in the operation suggest the following recommendations applicable to all new RRFB installations:

- All new installations of RRFBs should include an evaluation of pre- and post-RRFB installation driver compliance. Not only is it valuable to know whether the installation of the RRFBs has been beneficial in increasing driver compliance, it also provides an opportunity to observe how the intersection is used. By staging crossings and observing how the public uses the intersection, operational concerns can be identified and corrected quickly. Examples include the need to trim vegetation to improve visibility, the

alternatives of having a one- or two-stage crossing, and the need for additional signing or pavement markings.

- Following installation of RRFBs their operation should be observed closely for the first few months after installation. Such things as whether or not pedestrians and bicyclists are using the push button (or whether passive activation would be beneficial) and whether the amount of time given for pedestrians to cross the street is sufficient or too lengthy should be considered and revisions made, as appropriate. Using video to record how pedestrians and bicyclists are using the crosswalks is very beneficial.

- Follow-up field observations and feedback from community, local jurisdiction, police agency and active users should be made periodically and revisions to the RRFB installation completed if indicated.

5.0 REFERENCES

Furst, Anthony T. MUTCD - Interim Approval for Optional Use of Rectangular Flashing Beacons (IA-11). Federal Highway Administration. July 16, 2008.

Pappe, Bob. Request for approval of marked crosswalks & RRFB installation, The Dalles-California Highway (US 97) @ Reed Lane, MP 139.68 & Badger Road, MP 140.30, City of Bend, Deschutes County. December 10, 2010.

APPENDIX A:
DATA COLLECTION PROCEDURE FOR PRE- AND POST-RRFB INSTALLATION

Data Collection Procedure for Pre- and Post-RRFB Installation

Bend Parkway @ Badger Road and Reed Lane Pedestrian Crossings

Site Documentation Form - Complete all information in form

Data Collection Form:
Bike: Did bicyclist walk or ride bike across crosswalk- note any abnormal behavior
Pedestrian: Stgd = Staged crossing by worker or volunteer
Gen = General public crossing
Size: Ind = Individual (1 person crossing)
Grp = Group (less than 5 crossing together as a unit)
Cls = Cluster (5 or more crossing together as a unit) Make note of arrival times

Yield Time = Measure & Record time (sec) between arrival and crossing, how long people have to wait for a yield (measured from arrival at curb to 1st vehicle from stopping sight distance based on 85%).

Lane Compliance Data Collection – A Lane = Fast Lane - B Lane = Slow Lane
"Total Yielded" – "Total Did Not Yield"
Total yielded = number of vehicles stopped for the pedestrian (maximum one per lane) therefore maximum number is 2. The yielding violation is based on when pedestrian arrives at curb in relation to vehicle outside of Stopping Sight Distance. Total did not yield = number of vehicles that passed by the pedestrian without stopping. Example: 2-1 (two yield one did not, so three total vehicles were involved on the approach for the pedestrian crossing). Example: 0-0 (no cars at time of crossing). Example: 1-0 (one yield and only one vehicle on the approach at the time of the crossing).

Opposing Lane Compliance Data Collection - A Lane = Fast Lane - B Lane = Slow Lane
"Total Yielded" – "Total Did Not Yield" (Same as above)
Record behavior of travel lanes across the median until crosser reaches the median, once in the median crossing becomes second data set – continuation

Data Collection Methodology:
Do not put foot out into roadway. Proceed to crosswalk and Stand and Wait on the curb in close proximity to edge roadway. Once driver stops in nearest lane proceed into the roadway but wait for next lane to stop before crossing the rest of the roadway. Once in median proceed as described above noting what happens. This would be considered a second crossing.
Make note of Conflicts – if a crosser had to run or make an evasive maneuver to avoid a vehicle.

Greenwood Avenue at NE 12th Street

Site Documentation Form - Complete all information on form

Data Collection Form:
Bike: Did bicyclist walk or ride bike across crosswalk- note any abnormal behavior
Pedestrian: Stgd = Staged crossing by worker or volunteer
Gen = General public crossing
Size: Ind = Individual (1 person crossing)
Grp = Group (less than 5 crossing together as a unit)
Cls = Cluster (5 or more crossing together as a unit) Make note of arrival times

Lane Compliance Data Collection – A Lane = Fast Lane - B Lane = Slow Lane
Tick mark the number of vehicles that travel past the pedestrian without yielding in all four travel lanes. If someone then yields, the data might look like this:

4-1 (four vehicles passed that should have yielded, the fifth vehicle yielded, and the pedestrian crossed). Motorist yielding compliance = 1/5 or 20%

2-1 (two vehicles passed that should have yielded, the third vehicle yielded, and the pedestrian crossed). Motorist yielding compliance = 1/3 or 33%

12-0 (12 vehicles passed and no one yielded, but a gap allowed the pedestrian to 'cross'). Motorist yielding compliance = 0/12 or 0%

0-0 (no vehicles were present, and the pedestrian crossed). In this case, motorist yielding compliance cannot be calculated as there were no vehicles that should have yielded (0/0).

The staged crossing should be done in such a way that compliance with state law is evaluated. In Oregon, drivers must yield to pedestrians in their lane, and in the adjacent lane. A bike lane is considered part of the adjacent lane. So in this case, whenever a pedestrian is off the curb in the roadway, drivers of both the A lane and B lane on the same side of the median as the pedestrian should yield.

Opposing Lane Compliance – these lanes are on the opposite side of the median from the pedestrian. They are not required to yield, but the number of motorists yielding will be recorded. This may be an indication of a need for education.

Conflict Data

Take careful notes on the nature of the conflict. Conflicts include situations when a vehicle changes course to avoid a stopped vehicle, near rear end collisions.

Data Collection Methodology:
Staff will place a cone at the Safe Stopping Distance from the crosswalk. Vehicles nearer than the cone should not be asked to yield. Do not initiate a step off the curb when vehicles are closer than the cone. While standing and waiting on the curb in close proximity to edge roadway, wait for the Safe Stopping area to be clear. Once a vehicle is just beyond the Safe Stopping line, mock one foot entering the roadway or put one foot down, outside of travel hazard if this is not uncomfortable, but consistently use the same process for indicate intent to cross. Pose there until a driver stops in nearest lane. Proceed into the roadway. Wait for next lane to stop before crossing.

(The form used for data collection was very similar to that used for data collection at the two crossing locations on the Bend Parkway.)

APPENDIX B:
DATA COLLECTION FORM

Time	Ped X-ing Direction		Activation		Bike		Pedestrian		Size			Yield Time	Lane Compliance		Opposing Lane Compliance	
1	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
2	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
3	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
4	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
5	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
6	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
7	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
8	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
9	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																
10	EB	WB	Y	N	Walk	Ride	Stgd	Gen	Ind	Grp	Cls		A_____	B_____	A_____	B_____
Comments:																