EVALUATION OF ALTERNATIVE PEDESTRIAN CONTROL DEVICES

Final Report

SPR 721

Oregon Department of Transportation

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by

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16. Abstract

A literature review, field study of Rectangular Rapid Flashing Beacon (RRFB) installations in Oregon, and a static survey on the sequencing of the Pedestrian Hybrid Beacon (PHB) were completed.

The field study conducted in this project was designed to compare side and overhead-mounted beacons and RRFBs. The field study results indicated that the environment surrounding the crossing has an impact on compliance and that the presence of a median can increase compliance.

The PHB study verified that drivers are confused about what these devices are and how they operate. For the first deployment of a PHB in an area, a public education program is recommended during the early deployment of the PHB.

The Guidelines that have been developed as part of this project were based on the literature review and the Oregon field study. The major recommendation is that RRFBs be installed on medians when side-mounted devices are considered and at locations with posted speeds of 40 mph or less unless additional features such as stripping, signing , and advance warning RRFBs are used. To reinforce the guidelines, a decision matrix was developed.

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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
		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

NOTE: Volumes greater than 1000 L shall be shown in m^3.

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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DISCLAIMER

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1.0 INTRODUCTION

In Oregon in 2008 there were 610 motor vehicle crashes in which 52 pedestrians were killed and 616 pedestrians were injured. More than half of the pedestrians killed or injured were crossing at an intersection or in a crosswalk and an additional 137 were killed or injured while crossing the street, but not at an intersection. Of the drivers with errors reported, "failure to yield to pedestrians" was identified in 69% of the cases.

In 2008 the Federal Highway Administration (FHWA) issued Interim Approval for Optional Use of Rectangular Rapid Flashing Beacons (RRFB) (IA-11) as a supplement to standard pedestrian crossing or school crossing signs at crosswalks at uncontrolled approaches. Evaluations performed in several Florida cities show compliance rates over 80 percent compared to rates in the 15 to 20 percent range for standard beacons. Since the RRFB is often installed as a solar operated device, it can be installed at locations without electric power at a cost considerably less than a traffic signal. Because of this, the potential for the RRFB to significantly improve pedestrian crossing safety is significant. It is important that various alternative designs be evaluated to support the development of specific guidelines for their installation in Oregon.

The Pedestrian Hybrid Beacon (PHB), also known as the HAWK (High intensity Activated crossWalK signal system), is included in the 2009 Manual of Uniform Traffic Control Devices (MUTCD). Previous research identified significant improvements in driver yielding rates when a PHB system was installed. Of the five installations in Oregon, two PHB installations in Portland vary from the MUTCD guidelines for the signal sequence of the device whereas the installations in Klamath Falls and Springfield conform to the guidelines in the MUTCD.

The Oregon Traffic Control Devices Committee (OTCDC) and ODOT Traffic Operations Leadership Team (TOLT) are interested in having the effectiveness of RRFB devices evaluated to determine whether the devices improve driver compliance rates at pedestrian crossings, to compare their performance to pedestrian-activated beacons, and to examine their use with pedestrian medians.

Research was also needed to investigate drivers' understand of the PHB and its operational sequence to determine if more education is needed for new installations of the devices. The unique aspects of Portland's installations (phasing, use of two crosswalks) were investigated through observation at the two crosswalks.

A key outcome of the project is a framework for practitioners that provides guidance for selecting pedestrian traffic control devices that are safe, navigable and can be installed for a reasonable cost. Providing guidance to state and local traffic engineers faced with making decisions about improving the safety of pedestrian crossings has become increasingly important. In both 2009 and 2010, the years during which the research was being conducted, Oregon experienced a significant increase in motor vehicle crashes involving pedestrians. In 2010 there were a total of 792 pedestrian-involved motor vehicle crashes in which 62 pedestrians were killed and 772 were injured. The number of motor vehicle crashes involving a bicycle also increased during the last three years. In 2008 there were 785 bicycle-involved crashes injuring or killing 767 bicyclists and in 2010 there were 910 bicycle-involved crashes injuring or killing 884 bicyclists.

The report includes a literature review, a description of the methodology used for field work investigations, the results of those investigations, and the results of static surveys conducted to determine driver understanding of PHB indications. Based on the literature review and the findings of the research conducted, guidelines are developed and presented as a decision matrix. The report ends with conclusions and recommendations.

2.0 LITERATURE REVIEW

This literature review provides an overview of roadway characteristics that affect driver yielding rates and pedestrian crashes; the studies performed on Pedestrian Hybrid Beacons (PHB) and Rectangular Rapid Flashing Beacons (RRFB) systems; and the methodologies that the studies used to determine test sites and evaluate the devices. The goal of this literature review is to learn more about the effectiveness of these devices, to gain a better understanding of the factors to consider when selecting devices for a specific location, and to gain insight regarding the methodology to follow for the field work to be performed on Oregon. Gaps in the research are identified.

2.1 CROSSING CHARACTERISTICS

To better understand the impact of roadway characteristics and pedestrian crossing safety research has been done to identify characteristics of roadways that have an impact on crash rates. Since the 1970s there has been conflicting research results about the benefits of a marked crosswalk. Recent research with data from over 1000 marked crosswalks and 1000 unmarked crosswalks concluded that no meaningful differences in crash risk exists between marked and unmarked crosswalks (*Zeeger et al. 2005*). Another study at six crossings of varying lane width and speed limits between 25 and 30 mph found that marked crosswalks improved driver yielding rates (*Mitman et al. 2008*).

Roadway characteristics such as average daily traffic volumes, speed limit, number of lanes, and land use patterns around the crossing have been shown to have an impact on pedestrian crash rates. Below is a summary of some research results regarding roadway, land use and driver behavior characteristics and their impact on pedestrian crash rates:

- Longer crossing distances and crossings with more lanes can be more dangerous than narrower crossings *(Baltes and Chu 2002; Petritsch et al. 2005; Zeeger et al. 2005; Zeeger et al. 2006; Harwood et al. 2008*)

- Right-turn only lanes are positively associated with an increase in crash rates *(Petritsch et al. 2005; Schneider et al. 2010*)

- Crash rates increase with higher speed limits at uncontrolled crossings (*Zeeger et al. 2006*)

- Sidewalks tend to decrease crash rates *(McMahon et al. 1999; Berhanu 2004*)

- Median islands and Danish offsets (a pedestrian island in the shape of a “Z” which causes the pedestrian to look in the direction of oncoming traffic before crossing) have been shown to mitigate pedestrian crash rates at mid-block, uncontrolled, and signalized

- Urban areas have higher crash rates than rural areas.(*Zeeger et al. 2006*)

- Transit stops, neighborhoods with median annual income of less than $25,000, and proximity to alcohol sales establishments tend to be positively associated with crash rates *(Harwood et al. 2008*)

- Higher crash rates occur around malls, schools and parks *(Wedagama et al. 2006; Clifton and Kreamer-Fults 2007*)

- Drivers are less likely to yield to pedestrians when approaching non-signalized crossings at higher speeds (*Gårder 2004*)

- Higher traffic volumes are associated with more pedestrian crashes at intersections and uncontrolled crossings on arterial and collector roadways (*Zeeger et al. 2006; Harwood et al. 2008*)

- The number of non-residential driveways within 50 feet of an intersection is positively associated with pedestrian crashes (*Schneider et al. 2010*)

- The number of commercial retail properties within 0.1 miles of the intersection is positively associated with pedestrian crashes (*Schneider et al. 2010*)

- The percentage of residents living within 0.25 miles of the intersection that are younger than 18 is positively associated with pedestrian crashes (*Schneider et al. 2010*)

These characteristics help identify crossings that may experience higher pedestrian crash rates and may be appropriate for some kind of crossing treatment. Previously completed research provides insight into selecting the most effective crossing treatment for a particular type of crossing. The literature review focuses on two new crossing technologies, the Pedestrian Hybrid Beacon (PHB) and Rectangular Rapid Flashing Beacons (RRFB), which have been shown to be effective.

2.2 MEASURES OF EFFECTIVENESS

Several measures are commonly used in studies to assess the effectiveness of pedestrian traffic control devices. The measures are described below and the methodology used to assess them is given.

Driver compliance

This is the percentage of drivers that yielded at the crossing. It is calculated by dividing the total number of vehicles that stopped by the total number of vehicles that could have safely stopped for the pedestrian. Vehicles that are not within the safe stopping distance are not included. The safe stopping distance is calculated using standard ITE equations. This can be evaluated through video analysis or in-person observation.

Evasive conflict

This is when a driver or pedestrian needed to change his course to avoid a crash. A vehicle stopping suddenly or swerving and a pedestrian jumping, running or suddenly stepping backward are examples. An on-sight observer or video analysis can be used to evaluate this.

Trapped pedestrian

This is when a pedestrian must stop at the centerline and cannot complete a crossing for a given amount of time because a vehicle traveling in the other direction did not yield. This can be evaluated through in-person observation or video analysis.

Distance the drivers yielded in advance of the crosswalks

This is the distance at which a driver yielded to the pedestrian. One study used colored flags to identify different distances so that an observer could record the distance for each yielding vehicle (*Shurbutt et al. 2009*).

Sudden Stops

When a vehicle suddenly stops to avoid a pedestrian or a vehicle that is yielding or stopped for a pedestrian. This can be evaluated through video analysis or in-person observations.

Driver and pedestrian knowledge of the systems and signal

The PHB uses a unique phase progression and studies have shown that there is driver confusion with the system. Godavarthy and Russell (*2010*) distributed surveys to drivers at a traffic signal and PHB crossing to evaluate their knowledge of the PHB signal phases, but there were a low percentage of surveys returned which did not make this a robust study. Static surveys and computer based questionnaires may be used to evaluate a person's response to a traffic control device. This approach has been shown effective and a good precursor for a larger driving simulator study(*Knodler et al. 2006; Hurwitz and Knodler 2009*).

2.3 PEDESTRIAN HYBRID BEACONS (PHB)

The PHB, also referred to as the HAWK (High intensity Activated crossWalK) pedestrian treatment, is one of the newest crossing systems and has been included in the 2009 MUTCD (*FHWA 2009*). Chapter 4F, Pedestrian Hybrid Beacons, which is included as Appendix A, provides guidelines on determining whether a PHB is warranted based on pedestrian crossings, vehicle volumes, and posted speed. Standards are given on design and operation. The PHB, which is based on a European railroad signal design and is similar to a school bus warning flasher system or lights on an emergency vehicle, is intended to attract attention. The device consists of two red beacons centered on top of a single yellow beacon to make a triangle formation. The MUTCD does not allow a single red beacon over a single yellow beacon because this design may cause confusion with a standard traffic signal. Figure 2.1 is a photo of a PHB installation in Portland, Oregon.

The MUTCD states that a PHB should be considered for installation at a location that does not meet a traffic signal warrant, or meets warrants under section 4C.05 (Pedestrian Volume) and/or 4C.06 (School Crossing) and it was decided that a signal would not to be implemented. If a warrant for a signal is not met, a PHB should be considered if an engineering study that "considers major-street volumes, speeds, widths, and gaps in conjunction with pedestrian volumes, walking speeds, and delay" finds inadequate gaps in traffic, vehicle speeds too high for pedestrians to cross, or excessive pedestrian delay (*Section 4F.01.05*).

Figure 2.1: PHB installation at NE 41st Ave and E Burnside St in Portland, Oregon

2.3.1 PHB Operation

The system was designed to be highly effective and minimize delay at unsignalized intersections and mid-block crossings. The following sequence is recognized by the MUTCD:

1. The PHB system remains in a dark state until a pedestrian activates it.

2. Upon activation by a pedestrian, the PHB will display a flashing yellow signal indication.

3. This is followed by steady yellow.

4. This is followed by the WALK interval. Drivers are given a steady red indication and pedestrians are given a WALK signal.

5. The clearance interval follows and the steady red indication turns into an alternating flashing red to allow vehicle traffic to pass through the crosswalk if it is clear. Pedestrians have a flashing DON'T WALK display during this phase.

6. After the clearance interval, pedestrians are given a steady DON'T WALK signal indication and the PHB display returns to a dark state.

The phase sequence is shown graphically below in Figure 2.2.

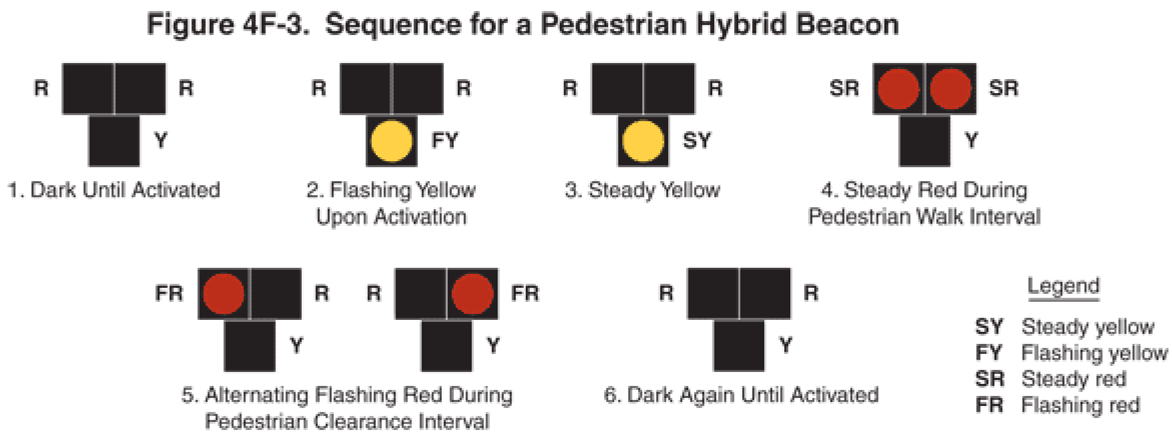


Figure 2.2: MUTCD sequence for a PHB (Section 4F.02) (U.S. Department of Transportation 2009)

Portland, Oregon has two PHB installations and currently uses a phase sequence that deviates from the MUTCD guidelines (*City of Portland Bureau of Transportation 2010*). The city has experimented with different modifications of the phase sequence and currently uses one that maintains a solid red indication for the clearance interval. This is followed by a short (three to four second) phase of simultaneously flashing the two red signal indications .and the pedestrians are given a DON'T WALK indication. Below are the phases of the PHB installations in Portland:

1. The PHB system remains in a dark state until a pedestrian activates it. DON'T WALK is displayed for the pedestrians.

2. At activation, the yellow indication begins flashing and pedestrians continue to have a DON'T WALK indication.

3. This is followed by steady yellow. Pedestrians still have a DON'T WALK indication.

4. This is followed by a steady red indication. Two seconds after drivers are given a steady red indication, pedestrians are given a WALK indication.

5. The clearance interval follows and pedestrians are given a flashing DON'T WALK indication. The steady red indication remains for drivers.

6. Drivers are given a flashing red and pedestrians are given a steady DON'T WALK indication.

7. After the clearance interval, pedestrians are given a steady DON'T WALK signal indication and the PHB display returns to a dark state.

Figure 2.3 graphically compares the Portland PHB sequence to the MUTCD sequence.

Interval	Vehicle	Pedestrian
1	Dark	DW
2	FY	DW
3	SY	DW
4	SR	DW
5	SR	W
6	SR	FDW
7	FR	DW
8	Dark	DW

Portland PHB Sequence

Interval	Vehicle	Pedestrian
1	Dark	DW
2	FY	DW
3	SY	DW
4	SR	W
5	AR	FDW
6	Dark	DW

MUTCD PHB Sequence

Figure 2.3: Comparison of Portland PHB and MUTCD PHB sequences

Portland utilizes a simultaneously flashing red instead of an alternating red so that the beacon is not confused with a railroad crossing. The sequence was modified in response to driver and pedestrian behavior observed when the PHB displayed an alternating red during the clearance phase. When an alternating red indication was used during the clearance interval, queued vehicles followed the lead vehicle through the intersection instead of stopping at the crossing to ensure the crosswalk was clear. Pedestrian confusion was also observed when vehicles traveled through the crosswalk when they had a FLASHING DON'T WALK. There was concern that pedestrians assume protection as long as the pedestrian countdown signal is not at zero, and that they may suddenly enter the intersection during the FLASHING DON'T WALK phase if the countdown signal indicates there is sufficient time to cross. In response to these safety concerns, a steady red signal is displayed (*City of Portland Bureau of Transportation 2010*). As more experience is gained with various PHB installations in Oregon and elsewhere modifications to the design and operation guidance given in the MUTCD may be made.

2.3.2 PHB Placement of Devices

If a PHB is to be installed, the MUTCD states that it should only be installed at a marked crosswalk (*Section 4F.01.03*). Section 4F.02.04 further states:

- It should be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs.
- Parking and other sight obstructions should be prohibited for at least 100 feet in advance of and at least 20 feet beyond the marked crosswalk, or site accommodations should be made through curb extensions or other techniques to provide adequate sight distance.
- It should include suitable standard signs and permanent markings.
- If it is installed within a signal system, the PHB should be coordinated.

PHB systems can be installed with side-mounted displays or with an optional overhead display that should be installed at locations with speed limits above 35 mph, obscured sight lines, or other factors.

The ODOT Traffic Manual (*Oregon Department of Transportation 2009*) gives further guidance for identifying locations where safety improvements could result from the installation of pedestrian activated warning beacons which include PHBs as well as warning beacons, RRFBs, and in-roadway lights, Section 6.6.7.4 identifies the following situations where installation of additional safety devices should be considered:

"Engineering Considerations

- Pedestrian Activated Warning Lights typically work best at locations where special emphasis is required such as mid-block crossings, crossings with a high percentage of vulnerable pedestrians (predominately young, elderly or disabled), or a history of pedestrian crashes.
- Proven pedestrian safety measures such as median refuge islands and/or curb bulb-outs should be (or will be) in place prior to the installation of Pedestrian Activated Warning Lights.
- The crosswalk crosses a multi-lane roadway (more than one lane in each direction) with more than 8,000 Average Daily Traffic (ADT) volume, 6,000 ADT if high percentage of vulnerable pedestrians.
- The crosswalk is not controlled by traffic signal, stop sign or yield sign. There should be no other crosswalks, traffic signals or stop signs within 250 feet of the crosswalk.
- Posted speeds should be 35 mph or less, but may not exceed 45 mph.

- The crosswalk has an average of 25 pedestrians per hour (10 pedestrians per hour with high percentages of vulnerable pedestrians) for any four hours of the day. The crosswalk has nighttime pedestrian activity (at least half the volumes above for any two hours during the nighttime)."

Other factors to consider include the extent of local support, the willingness of the local jurisdiction to pay for installation, power, and maintenance and to provide education on the meaning and use of the devices to drivers and pedestrians in the community.

The ODOT Traffic Manual provides additional guidance:

"Considerations:

- "Consideration should be given to installing a Pedestrian Hybrid Beacon if the location meets an applicable traffic signal warrant.
- It is recommended that drivers have sufficient decision sight distance to the Pedestrian Activated Warning Lights to be able to respond and stop for pedestrians if required.
- Either automatic (passive detection) or push-button activation is allowed. If push-button activated the proper signing should be attached next to the push-button, such as the "PUSH BUTTON TO TURN ON WARNING LIGHTS" R10-25 sign in the 2009 Edition of the Manual on Uniform Traffic Control Devices."

2.3.3 Completed Research

PHBs have been studied and shown to be effective at locations with speed limits up to 40 mph at unsignalized intersections with a four-leg, T, or offset T layout as well as at mid-block crossings. Several different lane layouts were investigated with use of a PHB and it was found that the number of lanes did not have an effect on the effectiveness of the devices; there was not a noticeable difference in the performance of the devices at installations where there were two, four or six lanes (*Turner et al. 2006*).

Previous studies on PHBs have focused on the effectiveness and safety of the devices installed at a single crosswalk. There was no information found discussing the impacts of installing the devices at intersections with more than one crosswalk.

The studies discussed in this section do not give information on the reasons why a PHB was selected over other treatments. Some of the studies provide characteristics of the roadway where PHBs were installed (number of lanes, posted speed limit, etc.), but none of the studies explained why a PHB was selected as the appropriate treatment.

The literature review has shown that certain jurisdictions tend to prefer one device over another. For example, PHBs were installed in Tucson, Arizona, but RRFBs were the devices of choice in Florida. Table 2.1 summarizes information on 85 PHB installations in Tucson, Arizona and one site in Lawrence, Kansas.

PHBs have been installed at crossings of two lanes up to nine lanes; over half have been installed at crossings with five lanes. Over 60% of the installations do not feature a median and over 95% are located at an intersection.

Table 2.1: Summary of PHB installations

Roadway Characteristic	Value	Crossings	Percentage
Lanes	2	3	3.5%
	3	11	12.9%
	4	9	10.6%
	5	43	50.6%
	6	4	4.7%
	7	13	15.3%
	8	1	1.2%
	9	1	1.2%
Median	Yes	31	36.5%
	No	54	63.5%
Intersection	Mid-block	4	4.7%
	Four Let	46	54.1%
	Offset T	4	4.7%
	T	31	36.5%
Speed	30	13	16.1%
	35	35	43.2%
	40	32	39.5%
	45	1	1.2%

All of PHB installations in Tucson feature one marked crosswalk, no matter where they are installed. Figure 2.4 is an aerial photo of a PHB installation at an intersection in Tucson and Figure 2.5 shows the driver's perspective at the same intersection.

Figure 2.4: Aerial view of PHB installation at E 29th St & S Irving Ave in Tucson, AZ

Figure 2.5: Driver perspective at PHB installation in Tucson, AZ

2.3.3.1 PHBs and Bicycles

The city of Tucson investigated the use of PHBs for pedestrians and bicyclists; however they were not satisfied with the results. The city was concerned that if bicyclists entered the crossing suddenly during the flashing red phase of the PHB it would be difficult for a vehicle to see them and this could lead to a crash. For this reason, the city of Tucson uses TOUCAN, or "Two Can Cross" signals at intersections with heavy bicycle traffic (*City of Tucson Department of Transportation 2009*). The TOUCAN system was designed to provide a safe crossing for both pedestrians and bicyclists. The system features a standard traffic signal on the major road and a bicycle and pedestrian signal on the crossing street. TOUCAN systems are placed at locations of heavy bicycle and pedestrian crossing activity and along roadways that are prioritized for non-motorized uses, sometimes known as "Bike Boulevards." An added benefit of the TOUCAN signal system is that motorized traffic is not allowed to proceed through these signals, decreasing the number of cars on neighborhood streets, and enhancing the neighborhood's quality of life. A TOUCAN can be activated only by bicyclists or pedestrians. (*City of Tucson 2009*)

The City of Portland has made changes to a PHB to accommodate bicyclists. Portland uses signal phasing for their PHBs that varies from the phasing given in the MUTCD. By not using the flashing red phase, Portland is able to safely use a PHB for heavy bicycle traffic. Portland also uses special advance warning signs showing a bicycle and a pedestrian (Figure 2.6) and a bicycle signal along with a pedestrian signal at the crossing (Figure 2.7).

Figure 2.6: Advance warning sign for a bike and pedestrian crossing at Portland PHB

Figure 2.7: Bicycle signal and pedestrian countdown signal at a Portland PHB

As shown in Figure 2.8, a special bicycle signal activation button is located close to the roadway to make it convenient for bicyclists. As a result, a high percentage (74%) of bicyclists activate the system (*City of Portland Bureau of Transportation 2010)*. This differs from a study in Florida regarding a popular bike crossing that did not make accommodations for bicyclists to activate an RRFB system. In the Florida study, the bicyclists made up 32% of all trail users, and pedestrians were noted as more likely to activate the system compared to bicyclists. (*Hunter et al 2009*).

Figure 2.8: Activation button to accommodate bicyclists at a Portland PHB

2.3.3.2 PHB Driver Compliance

A study was performed to evaluate nine different pedestrian crossing treatments against varying conditions such as number of lanes and speed limit (*Turner et al. 2006*). Driver compliance was measured by observing driver and pedestrian behavior at selected crossings and by performing staged crossings. Staged crossings were performed for consistency and to ensure a large enough sample size. The PHB system achieved a 98% driver compliance rate at five test sites (*Turner et al. 2006*). A half signal and full signal were the other devices featuring a red beacon in the study. They were found to be as effective as the PHB, leading the authors to recommend that "red signal or beacon devices need to be added to the engineer's toolbox for pedestrian crossings." It should be noted that half signals have been essentially prohibited by the MUTCD since 1971 (*Sections 4C.05 and 4C.06*).

2.3.3.3 PHB Safety

A study of PHB installations in Tucson was performed to compare the safety of PHBs to similar intersections that are either signalized or unsignalized in the city. In the study, 21

PHB sites were compared to 71 reference sites using an empirical Bayes method. Statistical evidence supports that the treatments correspond to a 28% reduction in all crashes and 58% reduction in pedestrian crashes (*Fitzpatrick and Park 2009*). This study and others did not state if PHBs were installed specifically in locations due to characteristics that are correlated to pedestrian crashes.

The Alaska Department of Transportation cites that a PHB system implemented at mid-block crossing should use a Crash Cost Reduction Factor (CCRF) of 12%, which was determined from the findings of Elvik and Vaa on pedestrian injury reduction (*Kinney 2009*).

The pedestrian perception of the safety effectiveness of the PHB system was measured by distributing surveys to pedestrians at PHB crossings in Tucson, Arizona. Even though the PHB

system demonstrated impressive driver compliance rates, the system received a score of 3 (1-very safe and 5-not safe) from pedestrians that have used the system (*Fitzpatrick and Park 2006*).

The 2009 MUTCD requires countdown pedestrian signal heads be installed at crosswalks where the pedestrian change interval is more than 7 seconds (*Section 4E.07*). This requirement applies to PHB crossings. The countdown signal occurs during the alternating flashing red signal when vehicles are permitted to stop and proceed through the crosswalk if it is clear, but a driver may not see a pedestrian suddenly enter the crosswalk which may lead to the pedestrian being struck by the vehicle.

2.3.3.4 PHB Driver Confusion and Understanding

The literature on installations of PHB devices shows that very high driver compliance rates and drastic crash reductions have been achieved. However, there are some potential drawbacks to the installation of the devices.

It is thought that drivers may be confused and may assume there is a power outage when the device is in a dark state; however a study of driver behavior in Tucson investigated this and did not find evidence of confusion (*Nassiand Barton 2008*). It is important to note that the study was performed in a city that has over 60 systems that have been installed for several years; driver confusion may occur in a city where there have been no previous installations.

A study was performed in Kansas to investigate driver perception of PHBs and more specifically their knowledge of each phase of the device. Surveys were distributed to drivers in stopped vehicles at a mid-block PHB crossing and a nearby signalized intersection. The results of the survey show that drivers understood the dark signal and steady red signal (93.9% and 90.9% understood respectively) (*Godavarthy and Russell 2010*). The flashing and steady yellow signals were less well understood (75.8% and 66.7% respectively); only 57.6 % responded that they understood the flashing red signal. This was verified in the field by observing several vehicles that did not proceed through the crossing during the clearance interval even though the crossing was clear. The authors of the Kansas study suggested that handouts explaining the PHB signal phases be distributed in the vicinity of new installations of PHBs (*Godavarthy and Russell 2010*).

A study by the city of Portland found driver confusion with the flashing red phase of the PHB (*City of Portland Bureau of Transportation 2010*). The study found that motorists queued up during the solid red phase and entered the crossing in platoons when the steady red phase changed to the flashing red and some did without regard of pedestrians. It also found that pedestrians and bicyclists were confused during the FLASHIING DON'T WALK phase because they expected to have the right-of-way and were confused when vehicles entered the crossing because they had a flashing red phase.

2.3.3.5 PHB Efficiency

Godavarthy and Russell (*2010*) conducted research to determine if there was a statistically significant improvement in delay for a PHB signal at a mid-block crossing compared to a signalized mid-block crossing. The researchers used video analysis to determine motorist delay at a mid-block PHB and compared it to motorist delay at a mid-block signal that was located on a roadway with similar characteristics as the PHB installation. Since the researchers only used data from cases where the driver appeared to understand the alternating red phase and cases where the driver did not respond within three seconds were not included in the analysis, the results are not very useful.

The signal sequence that the City of Portland currently uses does not take advantage of the potential efficiency gains of a flashing signal during the pedestrian clearance phase that allows the first queued vehicles to proceed through the crossing if it is clear.

2.3.4 PHB Cost

The hardware for an overhead PHB installation is estimated to cost approximately $100,000 and about $60,000 for a side-mounted PHB installation (Obery *2010*). This compares favorably with the cost for the hardware of a full signal. The cost, including labor, is about $30,000 for the hardware for an RRFB where four devices are installed and $60,000 where advance heads are included (*Serpico 2011*). Overhead installations of either the PHB or the RRFB involve considerably more costs associated with temporary traffic control, excavation and construction of the mast pole foundations, and specialized lift equipment.

2.4 RECTANGULAR RAPID FLASHING BEACONS (RRFB)

The Rectangular Rapid Flashing Beacon (RRFB) is another alternative pedestrian device that has shown impressive results in improving driver yielding rates and is less expensive to implement than a PHB system. RRFBs have not been included in the 2009 MUTCD, but they were given interim approval by the FHWA in July 2008 (*FHWA 2008*). See Appendix B for a copy of the interim approval memorandum.

2.4.1 RRFB Operation

The RRFB consists of two rectangular yellow indications (roughly six inches wide by two inches tall) placed about seven inches apart below a pedestrian or school crossing sign. The FHWA interim approval requires two W11-2 or S1-1 crossing warning signs to be installed at the crosswalk, one on the right-hand side and one on the left-hand side of the roadway. A median-mounted device may be included. An installation with a median-mounted device in this report refers to a treatment that has a side-mounted sign and device and a sign and device mounted on a median island for each direction. An installation without a median-mounted device refers to one that has a side-mounted crossing sign and device on each side of the roadway. Many of the studies referenced in this report consider an installation with a median-mounted RRFB to be a “four-device treatment” since it usually requires four separate mounting posts and an installation without a median-mounted RRFB to be a “two-device treatment” since the devices can be installed back-to-back on the same post. In this report we distinguish between the types of installations by identifying whether or not there is a median.

The devices are activated by a push button unit or passive pedestrian detection. The devices are usually designed to be activated simultaneously. Solar panels are often attached to power the systems or they can be connected to the existing power infrastructure. The length of time the RRFB is activated is determined by the signal technician with consideration given to the length of the crossing, number of pedestrians, and characteristics of the pedestrians. On the Bend Parkway, the pedestrian interval was set by measuring the length of the crossing and dividing this by 3.5 feet to determine the number of seconds needed to cross the street and then adding seven additional seconds for delay (*Ross et al. 2010*)

2.4.2 RRFB Placement of Devices

The ODOT Traffic Manual (*Oregon Department of Transportation 2009*) requires that RRFB installations comply with the terms and conditions of the FHWA interim approval of RRFBs. The FHWA requires that RRFBs be installed at crosswalks located along roadways that are not controlled by YIELD signs, STOP signs, or traffic control signals. Section 2.3.2 of this report provides the guidance provided by the ODOT Traffic Manual for the installation of pedestrian activated warning lights that can be utilized if an RRFB installation is being considered. Guidance regarding specific roadway characteristics or situations where an RRFB should be installed, such as the number of lanes or characteristics of the surrounding environment, is not provided in the ODOT Traffic Manual or in FHWA documents.

The City of Boulder Colorado draft guidelines for Pedestrian Crossing Treatments recommend an ADT threshold of 1, 500 for any crossing treatment, such as high visibility signage. An ADT of 5,500 for crossings with no medians, and 9,000 for crossing with a median should be considered for an advance treatment such as an RRFB. This corresponds to an expected wait time in excess of 45 seconds (LOS F) for a pedestrian waiting for a 15 second gap in traffic during the peak hour (60/40 directional split in peak hour, 40 foot crossing), [equation 19-75, HCM 2010]. Part of the draft guidelines from the City of Boulder is included in this report as Appendix C because the draft guidelines address the needs of small urban areas. (*City of Boulder, Colorado 2011*).

2.4.3 Completed Research

RRFBs have been tested to be effective at mid-block and unsignalized intersection crossings on roadways with posted speed limits up to 45 mph (*Van Houten and Malenfant 2009; Hunter et al. 2009; Shurbutt et al. 2009; Ross et al. 2011*). RRFBs have also been tested on roadways with varying characteristics and implemented safety technologies. The majority of the installations that have been tested were at unsignalized intersections, featuring one or two crosswalks. Figures 2.9 and 2.10 below show a single and a double crosswalk at two unsignalized intersections with RRFBs.

Figure 2.9: RRFBs at an intersection with two crosswalks in St. Petersburg, Florida (Google Maps)

Figure 2.10: RRFBs at an intersection with one crosswalk in St. Petersburg, Florida (Google Maps)

Table 2.2 compiles the roadway characteristics at 25 RRFB installations that were studied by various researchers (*Shurbutt et al. 2009*; *Van Houten and Malenfant 2009; Hunter et al. 2009*).

Table 2.2: RRFB literature review sites

State	City	Configuration	Lanes	Median	Traffic	ADT	Speed
FL	St. Petersburg	Mid-block	4	Yes	2 way	9600	35
FL	St. Petersburg	Intersection	4	Yes	2 way	17657	35
FL	St. Petersburg	Intersection	4	Yes	2 way	13524	35
FL	St. Petersburg	Intersection	4	No	2 way	12723	35
FL	St. Petersburg	Intersection	4	Yes	2 way	18367	35
FL	St. Petersburg	Intersection	5	Yes	2 way	12025	35
FL	St. Petersburg	Intersection	5	No	2 way	14336	35
FL	St. Petersburg	Mid-block	3	No	1 way	9715	30
FL	St. Petersburg	Intersection	4	No	2 way	12723	35
FL	St. Petersburg	Mid-block	4	Yes	2 way	6216	35
FL	St. Petersburg	Intersection	4	Yes	2 way	13826	35
FL	St. Petersburg	Intersection	4	No	2 way	12742	40
FL	St. Petersburg	Intersection	3	No	1 way	12742	35
FL	St. Petersburg	Intersection	4	No	1 way	9128	35
FL	St. Petersburg	Intersection	2	No	2 way	4774	35
FL	St. Petersburg	Intersection	4	No	2 way	9343	35
FL	St. Petersburg	Mid-block	4	No	2 way	9343	35
FL	St. Petersburg	Intersection	3	No	2 way	5008	35
FL	St. Petersburg	Intersection	4	No	2 way	11982	35
IL	Mundelein	Intersection	2	No	2 way	-	35
IL	Mundelein	Intersection	4	No	2 way	-	35
DC	Washington DC	Intersection	4	No	2 way	30000	30
FL	Miami Lakes	Intersection	5	No	2 way	25125	40
FL	Miami	Intersection	4	Yes	2 way	38996	35
FL	St. Petersburg	Mid-block	4	Yes	2 way	15000	40

Table 2.2 shows that the devices have been installed at crossings with between two and five lanes. The average daily traffic (ADT) varies from less than 5,000 to almost 40,000 vehicles.

Three of the twenty-five locations (12%) in Table 2.2 had an ADT below 8,000, which is the threshold ADT suggested in the Oregon Department of Transportation Traffic Manual for the installation of pedestrian activated warning lights. The majority of the installations were at locations with posted speed limits of 35 mph, but three were at locations with 40 mph and two were at locations with 30 mph.

2.4.3.1 RRFB Driver Compliance

Studies have shown that RRFBs are an effective way of producing high driver compliance rates that previously had only been obtained by full signals or systems that utilize a red beacon to stop traffic at crosswalks, such as a PHB. Shurbutt et al. (2009) performed a three-part study to assess the effectiveness of the RRFBs at multilane uncontrolled crosswalk locations, the effectiveness of RRFBs compared to overhead and side-mounted beacons, and the effectiveness of the devices over time.

The devices were tested through observation and staged crossings at 19 crossings in St. Petersburg, Florida where driver compliance rates ranged from single digits up to 30% before the RRFB devices were installed (*Shurbutt et al. 2009*). After the RRFB devices were installed, driver compliance rates at most crossings were between 80 and 90 percent.

Another aspect of the study examined the effectiveness of including an RRFB device on an advance warning sign in conjunction with RRFBs at the crossing. Results showed there was a slight decrease (-0.1%) in the driver compliance rate and a slight increase in yielding distance when there is an advance warning sign compared to RRFBs installed only at the crossing (Shurbutt et al. 2009). The researchers suggest that including advance yielding markings can improve safety at crossings with high ADT.

The researchers examined the effectiveness of applications with and without a median. Applications with a median showed higher compliance rates than applications without a median as shown in Table 2.3 below.

Table 2.3: Compliance of two and four RRFB device applications

Condition	Compliance
Baseline (No Devices)	18.2%
No Median	81.2%
Median	87.8%

The study also compared driver yield rates for a traditional side-mounted yellow beacon treatment, an overhead treatment that consisted of two yellow beacons and a pedestrian crosswalk sign, and RRFB treatments. All systems were pedestrian activated. Two 12-inch diameter yellow beacons that flashed at a rate of 55 times per minute and an illumination period of 50% were utilized for the overhead and side-mounted beacon treatments. The side-mounted beacon treatment had a driver compliance rate of 11.5%, the overhead treatment had a compliance rate of 15.5%, whereas the compliance rate for RRFB installations with or without a median were more than five times greater. The RRFB driver compliance rate was 76.2% without a median and the RRFB rate was 86.5% with a median.

The authors followed up on the study two years after installation of the RRFB devices to test if the compliance rates changed over time. The mean driver compliance rate at the intersections was 85% during the day and over 90% at night, confirming that the impressive compliance rates achieved from RRFBs can be sustained.

As part of the two-year follow-up study, RRFBs were tested at two locations in Illinois and one in Washington D.C. to determine if there were regional differences. Applications of RRFBs were tested against no treatment (base condition) and overhead and side-mounted yellow beacons. The two sites in Illinois demonstrated compliance rates of 71.2 % and 62.2% and the site in Washington D.C., a compliance rate of 80% (*Shurbutt et al. 2009*). The authors note that the Illinois percentages are lower than the Florida average, but the testing was done only seven days after implementation; at the Washington D.C. location testing was done after 180 days.

Three other studies looked at driver compliance at various locations in Florida. One study in Miami Lakes, Florida, and another on South Bayshore Drive in Coconut Grove, Florida tested RRFBs against a baseline (no devices) to compare driver compliance. The results at the two sites showed yielding rates improved from single digit compliance before installation, to an average of 63% after the devices were installed (*Van Houten et al. 2008; Van Houten and Malenfant 2009*). A third study in St. Petersburg, Florida used video and observational analysis to test the results of installing a sign and an RRFB at a mid-block crossing of a high traffic multi-use bike and pedestrian trail intersecting a four-lane road with an ADT of 15,000. The study found that the devices increased driver compliance from 2% with no devices, to 35% with a sign only, and to 54% with the RRFB activated (*Hunter et al. 2009*).

Driver yielding rates were assessed in a research study conducted on RRFB installations at two crossings on the Bend Parkway in Bend,Oregon. This is a four lane expressway with bike lanes and median and has a posted speed of 45 mph. The RRFB installation included advance devices in addition to those at the intersection and enhanced signing and pavement markings. Before the RRFBs were installed 23% of the drivers yielded at one intersection and 25% yielded at the other. After RRFBs were installed, the yield rates were 83% at both intersections (*Ross et al. 2011*).Figure 2.11 shows the installation of RRFBs at the Reed Lane intersection on the Bend Parkway.

2.4.3.2 RRFB Evasive Conflicts

A study performed to evaluate the effectiveness of RRFBs in decreasing evasive conflicts found they dropped from 11% to 2.5% at one site and 5.5% to zero at a second evaluation site when RRFBs were installed (*Van Houten et al. 2008; Van Houten and Malenfant 2009*). An evasive conflict is when a driver suddenly stops or swerves to avoid a pedestrian. A pedestrian jumping, running, or suddenly stepping backward to avoid a crash is also considered an evasive conflict.

Figure 2.11: RRFB installation at the Reed Lane intersection on the Bend Parkway

Conflicts were recorded in the study of RRFB installations on the Bend Parkway. Prior to the installation of the RRFBs conflicts occurred in 9.8% of the crossings at one intersection and in 5.8% of the crossings at the other. After the RRFBs were installed there was one conflict recorded at one intersection (this was .6% of the crossings) and no conflicts observed at the other intersection (*Ross et al. 2011*).

2.4.3.3 RRFB Trapped Pedestrians

It is more comfortable and safer for a pedestrian to be able to clear a crosswalk without stopping or becoming trapped in the roadway. At a site in Miami Lakes, Florida and one on South Bayshore Drive in Coconut Grove, Florida the percentage of trapped pedestrians decreased from 44% before RRFBs were installed to 0.5% after RRFBs were installed (*Van Houten et al. 2008; Van Houten and Malenfant 2009*). A pedestrian was considered trapped if he waited at the centerline for five seconds or more while attempting to cross.

A study done in St. Petersburg, Florida evaluated RRFB devices at a mid-block crossing of a high traffic multi-use bike and pedestrian trail and a four-lane road with an ADT of 15,000. The study found that the RRFB devices decreased the percentage of trapped pedestrians in the intersection from 18% before they were installed to 6% after the RRFBs were activated (*Hunter et al. 2009*).

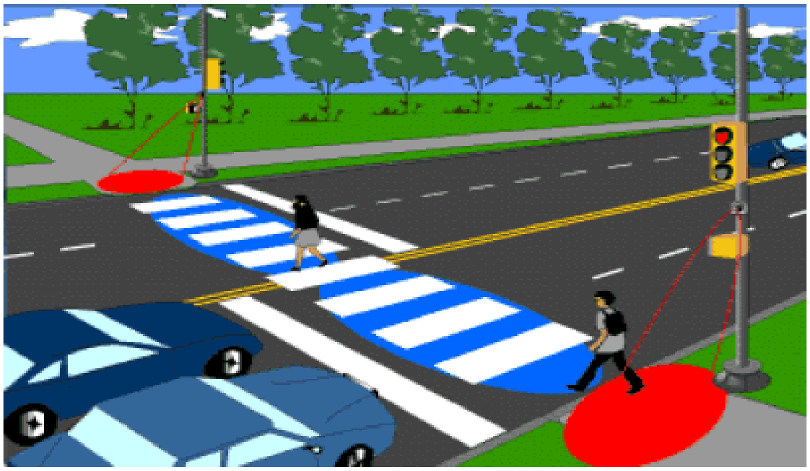
2.4.3.4 RRFB Sudden Stops

The Miami Lakes and Coconut Grove RRFB sites in Florida were used to determine if there was a decrease in the number of sudden stops that occur at crosswalks when the devices are installed. Sudden stops are defined as drivers who begin to yield (stop or begin to slow) less than 30 feet from the crossing. The percentage of sudden stops decreased from 25% before the RRFBs were installed to 7% after RRFBs were installed at the crossings (*Van Houten et al 2008; Van Houten and Malenfant 2009*).

2.5 PEDESTRIAN DETECTION

The RRFB systems that have been studied to date have all used pedestrian activation. The study of the trail crossing site found that 32% of trail users activated the system, 19% were at the crossing when it was already activated, and 49% of users did not activate the system *(Hunter et al. 2009*). It was observed that bicyclists were less likely to activate the system than pedestrians. In contrast, a study in Portland, Oregon showed that bicyclists activated the PHB at a higher rate than pedestrians (City of Portland Bureau of Transportation 2010). To achieve the highest driver compliance rates, the system needs to be activated, but only 51% of users activate the system. A study on active versus passive warning devices for unsignalized and mid-block crosswalks concluded that systems will not achieve their full potential as effective warning systems if pedestrians are required to play an active role in actuating the warning (*Smith et al. 2009*). Smith et al. recommended that passive pedestrian detection technology be further investigated as a way to increase safety at crosswalks.

There are two zones where it is desirable to detect pedestrians as shown in Figure 2.12.The zone located adjacent to the street on the sidewalk is the pedestrian waiting zone. Detection in this zone can be used to trigger a crosswalk signal or vehicle warning system and monitor if waiting pedestrians leave the zone indicating that they no longer need to cross the street. RRFB systems that feature this type of pedestrian detection are under development.



http://www.walkinginfo.org/pedsmart/infred.htm

Figure 2.12: Pedestrian detection zones

The second detection zone monitors the crosswalk. This is useful in crossings to ensure that pedestrians safely clear the street before vehicles are allowed to flow again. The MUTCD recommends that pedestrian crosswalks be timed according to a person walking at 3.5 feet/second. This timing may represent 85% of the population, but it may not give adequate time for the entire population, such as the elderly, to clear in time. A pedestrian detection device is able to monitor the crosswalk and change the signal for traffic to flow when the crosswalk is clear. This allows for faster signal timings when the intersection is cleared quickly and ensures adequate time for slower walkers.

Radar, magnetic, piezoelectric, inductive loop, infrared (IR), microwave, and camera-based systems are commonly used to detect pedestrians. Microwave and infrared sensors have been the most widely used, but camera technology is rapidly improving and the costs are decreasing making it a competitive option (*Gibson et al. 2009*).

The City of Tucson, Arizona is experimenting with modified PHB treatments that detect pedestrian crossing speeds and adjust the WALK and clearance intervals to allow for safe crossings (*Nassi and Barton 2008*).

2.6 MEDIAN ISLANDS

Pedestrian refuge islands have several benefits including simplifying pedestrian crossings by having pedestrians cross one direction of traffic at a time and creating room for additional lighting, crossing treatments, and landscaping. They are required for RRFB installations using four devices.

On a four-lane roadway with 5000 ADT, medians can reduce pedestrian delay by up to 79 percent (*Dowling et al. 2008*), which translates into fewer pedestrians taking risks with short gaps in traffic. Medians at marked pedestrian crossings have been shown to reduce crashes by 46 percent and, at unmarked crossings, by 39 percent (*Lindley 2008*) as well as reduce vehicle speeds on the roadway (*King et al. 2003*). A Danish offset, also known as a "Z" crossing, in a refuge island provides more space for pedestrians and directs them to face oncoming traffic, giving them more visibility to drivers. This is a desirable feature for crossings with low or obstructed visibility.

The FHWA "*strongly encourages the use of raised medians (or refuge areas) in curbed sections of multi-lane roadways in urban and suburban areas, particularly in areas where there are mixtures of a significant number of pedestrians, high volumes of traffic (more than 12,000 vehicles per day) and intermediate or high travel speeds*" (*FHWA 2009*).

The 2011 Oregon Bicycle and Pedestrian Design Guide developed by ODOT states:

"These [raised medians] should be considered the first option on multi-lane, two way roads.. A median allows a pedestrian to cross only one direction of traffic at a time, making it much easier to find and correctly identify acceptable gaps. Where it is not possible to provide a continuous raised median, refuge islands can be provided across from high pedestrian generators such as schools, park entrances, libraries, parking lots, transit stops, etc.

The preferred location for a raised island, based on pedestrian demand, may conflict with vehicular turning movements if driveway accesses are present at that location. Careful negotiation with property owners may be required to ensure placement of island meets the intended goal of improved pedestrian crossings, while taking into account vehicular movements. Moving an island away from the desired crossing location may be a solution, but can be counter-productive if it's too far, as pedestrians will not use it and cross at the desired location with no island. Another option is to keep the island where needed for pedestrians, and move the driveways to allow turns to occur. On streets with diffuse crossing generators, judicious placement of high quality pedestrian crossings along the corridor can help to concentrate pedestrian crossings at the improved locations, improving roadway operations and safety. Paring improved pedestrian crossings with transit stops is a natural choice." (ODOT 2011)

A median island is needed for four treatment installations of RRFBs as described earlier. The installation of a median is highly recommended if roadway geometry allows.

2.7 SUMMARY OF FINDINGS

Pedestrian Hybrid Beacons (PHBs) have been shown to be highly effective in increasing driver compliance to near 100% and improving the safety of crosswalks by reducing pedestrian crashes by 58%. A review of current installations shows that they are installed on roads with from two to nine lanes and with varying roadway features and characteristics. A PHB is costly to install compared to other treatments. The literature review did not reveal information on why a PHB was selected over other treatments.

Guidance on the installation of PHBs was included in the 2009 MUTCD. Some PHBs that were installed before publication of the MUTCD have different features than those installed more recently. PHBs in Tucson follow MUTCD guidance and feature one crossing, whereas in Portland there are two crossings. Portland PHBs also feature a different signal sequence to increase safety for bicyclists and pedestrians.

Rectangular Rapid Flashing Beacons (RRFBs) have also been shown to have high driver compliance rates, decrease sudden stops, decrease the number of trapped pedestrians, and reduce evasive conflicts between pedestrians and vehicles. Current installations of RRFBs show that they have been installed at crossings with varying roadway characteristics, such as the number of lanes and posted speed limits up to 45 mph. They have yet to be included in the MUTCD, but the FHWA provides guidance on their installation.

More specific guidance is needed on when the additional cost of a PHB installation is merited and when a RRFB or a more conventional treatment is sufficient. The literature review found that studies on RRFBs and PHBs had information on the roadway characteristics, but they did not always include the characteristics of the surrounding environment. This information might be of use when deciding the appropriate treatment for a crosswalk.

RRFBs were found to be more effective than side-mounted and overhead-mounted yellow beacons. The compliance rates of RRFBs in Oregon are of interest to verify the high compliance rates achieved in other parts of the country and to compare to more traditional crosswalk treatments such as overhead and side-mounted yellow beacons.

3.0 REVIEW OF OREGON PEDESTRIAN CRASH DATA AND CURRENT PRACTICES

In Oregon in 2008 there were 610 motor vehicle crashes in which 52 pedestrians were killed and 616 pedestrians were injured. The majority (350) of the pedestrians killed or injured were crossing at an intersection or in a crosswalk and an additional 137 were killed or injured while crossing the street, but not at an intersection. Failure to yield to pedestrians was identified as a factor in the majority of the cases.

The availability of new traffic control devices to improve the safety of crosswalks has given Oregon an opportunity to respond more actively to address pedestrian safety. This chapter includes a summary of the characteristics of pedestrian-involved crashes occurring in Oregon between 2002 and 2008, information about the RRFB and PHB installations in Oregon, and observations about the installations in Portland. This information is used to identify locations to be visited and evaluated more closely and to provide guidance in determining the methodology to use for the evaluation.

To guide the research plan it was necessary to identify the proposed and existing installations of PHBs and RRFBs in Oregon and review their roadway characteristics to select evaluation sites. Since additional RRFBs were installed during the study period, the tables below may not include all sites.

3.1 OREGON CRASH HISTORY DATABASE

Analysis of Oregon crash data from 2002 to 2008 compared the characteristics of pedestrian-involved crashes with the characteristics of all crashes. Table 3.3 is a summary of the findings and is shown to identify roadway and pedestrian characteristics that correlate to crash rates.

Table 3.3 shows that almost 90% of pedestrian crashes occurred in urban areas and almost 30% occurred at crosswalks. Almost 50% occur at an intersection, and two-thirds occurred due to the driver not yielding. Weather appears to have an effect in one out of five crashes occurring during rainy conditions and 27.5% occurring during wet road conditions.

In Oregon, the state highways 26, 29 63, 68 and 81 had proportionately more pedestrian-involved crashes than would be expected based on analysis of the locations of all crashes. It was found that the presence of a raised median was a factor in 6% of all crashes but in less than 2% of pedestrian-involved crashes,

Table 3.3: Characteristics over-represented in pedestrian crashes compared to all crashes

Crash Characteristics	Pedestrian Crashes %	All Crashes %	Difference %
Crash cause is not yielding	66.6	20.5	46.1
Traffic control device is traffic signal	25.5	16.5	9
Traffic control device is “None”	23	11.9	11.1
Light condition is dark	12.5	9.1	3.4
Light condition is dark with street lights	25.2	12.0	13.2
Weather condition is cloudy	15.6	8.5	7.1
Weather condition is rainy	20.5	17.0	3.5
Road surface condition is wet	27.5	21.9	5.6
Crash severity is fatal	7.9	0.8	7.1
Road character is intersection	49.2	37.3	11.9
Intersection type is Crosswalk	29.1	20.4	8.7
Road is Urban	89.0	74.7	14.3
Posted speed is 20	2.4	0.4	2
Posted speed is 25	9.7	2.9	6.8
Posted speed is 30	4.2	1.4	2.8
Posted speed is 35	9.4	3.8	5.6
Posted speed is 40	2.6	1.1	1.5
School Zone	2.3	0.5	1.8
Alcohol involved	9.1	2.5	6.6
Drug involved	1.8	0.3	1.5

3.2 PHB AND RRFB INSTALLATIONS

Oregon has numerous installed and planned installations of RRFB and PHB systems. The RRFB sites have been summarized in Table 3.1 and PHB sites in Table 3.2. This information was current as of December 2011. Information for the tables was collected from the installation site or using Google Earth.

For each installation, details on the location, design of the device, lane configuration and characteristics, and posted speed are given. The number of lanes a treatment spans is shown and only lanes that a pedestrian is exposed to at the crossing are counted (a median in a turn lane or TWLTL are not counted). The RRFB installation at some locations shows two values for the posted speed limit because the speed changes at the crossing. The RRFB installation at Martin Luther King Jr. Parkway has a value of “Yes/No” for bike lane because some approaches to the roundabout have bike lanes and others do not. The RRFB table identifies if the treatment is planned or currently installed. All of the PHB treatments listed are installed.

Table 3.1: Proposed and Installed RRFB installations in Oregon as of December 2011

Location	City	Status	Configuration	Lanes	Bike Lane	Median	Traffic	Posted Speed
TV Hwy and 178th	Aloha	Installed	T-Intersection	4	Yes	Yes	2 way	35
Siskiyou Blvd and Bridge St	Ashland	Installed	Intersection	4	Yes	Yes	2 way	25
Siskiyou Blvd and Avery St	Ashland	Installed	Intersection	4	Yes	Yes	2 way	25
Siskiyou Blvd and Garfield St	Ashland	Installed	Intersection	4	Yes	Yes	2 way	25
Siskiyou Blvd and Palm Ave	Ashland	Installed	Intersection	4	Yes	Yes	2 way	25
Hwy 30 and 37th St	Astoria	Installed	Intersection	3	No	No	2 way	35
US Hwy 20 and 12th St	Bend	Installed	Intersection	4	Yes	Yes	2 way	35
US 97 and Reed Lane	Bend	Installed	Mid-block	4	Yes	Yes	2 way	45
US 97 and Badger Road	Bend	Installed	Intersection	4	Yes	Yes	2 way	45
Hamrick and New Haven	Central Point	Installed	Intersection	3/4	Yes	No	2 way	30
Bailey Hill Road near Westleigh St	Eugene	Installed	Mid-block	2	Yes	Yes	2 way	20/School
River Rd and Knoop St	Eugene	Installed	Mid-block	4	Yes	Yes	2 way	40
River Rd and Owosso Dr	Eugene	Installed	Mid-block	4	Yes	Yes	2 way	40
US Hwy 101 and 30th St	Florence	Installed	Intersection	4	Yes	Yes	2 way	35
US Hwy 101 north of 7th St	Florence	Installed	Mid-block	4	No	Yes	2 way	30
US Hwy 20 and Barnes Ave	Hines	Installed	Intersection	3	Yes	No	2 way	35/School
US Hwy 20 north of Twin Oaks Dr	Lebanon	Installed	Mid-block	2	Yes	Yes	2 way	30
Hwy 213 and Passmore Rd	Mulino	Installed	NA	2	No	NA	2 way	35/School
SE Foster Road and SE 80th Ave	Portland	Installed	Mid-block	4	No	Yes	2 way	35
SE Francis St and SE 82nd Ave	Portland	Installed	Mid-block	4	No	Yes	2 way	35
OR 99W south of SW Hamilton St	Portland	Installed	Mid-block	5	Yes	Yes	2 way	35/45
NE Klickitat St and NE 33rd Ave	Portland	Proposed	NA	NA	NA	NA	2 way	30
NE Going St and NE 33rd Ave	Portland	Proposed	NA	NA	NA	NA	2 way	30
NE Holman St and NE 33rd Ave	Portland	Proposed	NA	NA	NA	NA	2 way	30
Martin Luther King Jr. Pkwy	Springfield	Installed	Roundabout	4-5	Yes/No	Yes	2 way	35/45[1]
OR 126 Business near 51st St	Springfield	Installed	Mid-block	4	Yes	Yes	2 way	40
International Way West Station	Springfield	Installed	Intersection	4	Yes	Yes	2 way	35
International Way Center Station	Springfield	Installed	Mid-block	4	Yes	Yes	2 way	35
International Way East Station	Springfield	Installed	Mid-block	4	Yes	Yes	2 way	35
Hall Blvd and Wall St	Tigard	Installed	Mid-block	NA	Yes	NA	2 way	40
Bethany Blvd and St. Andrews Dr	Wash County	Installed	Intersection	2	Yes	Yes	2 way	35
Oregon 214 and Park Ave	Woodburn	Installed	Intersection	3	Yes	Yes	2 way	35

NA= Not available

[1] Geometric constraints cause operating speeds at the crossings of 15 to 20mph.

Table 3.2: PHB installations in Oregon

Location	City	Configuration	Mount	Crossings	Lanes	Bike Lane	Median	Traffic	Posted Speed
NE Sandy Blvd and NE 18th Ave	Portland	Intersection	Overhead	2	4	No	No	2 way	30
E Burnside St and NE 41st Ave	Portland	Intersection	Overhead	2	4	No	No	2 way	35
Gateway Street near Postal Way	Springfield	Mid-block	Overhead	1	4	Yes	Yes	2 way	35
Harlow Road at Pheasant St	Springfield	Mid-block	Overhead	1	4	Yes	Yes	2 way	35
Oregon 39 and Portland Ave	Klamath Falls	Intersection	Side	1	4	No	Yes	2 way	35

3.3 PORTLAND SITE OBSERVATIONS

The researchers visited the four sites where RRFBs or PHBs had been installed in Portland to observe the devices and to provide guidance for the development of methodology to be used for the field study to be conducted.

The two RRFB installations in Portland are located on streets adjacent to neighborhoods and connect them to shopping and restaurant areas. They are located on Foster Road and 82ndAvenue which are both busy arterial streets and had heavy traffic late on a Sunday afternoon when the observations were made.

On Foster Road there are several businesses with signs and several road signs that create a lot of visual clutter for drivers. There are several marked pedestrian crossings that use various technologies such as pedestrian crossing signs, overhead pedestrian signs and pedestrian-activated flashing beacons to notify drivers of the crosswalks. Despite the visual clutter, it was observed that drivers exhibited a high compliance rate at the RRFB. When pedestrians were aware of the vehicles and gave the drivers ample time to stop, there were no instances of non-compliance. If vehicles are close to the crossing when the devices are activated, they do not have enough time to safely stop and pedestrians should be aware of these situations by checking the crossing before entering the roadway. An audible message from the RRFBs alerts pedestrians to wait for vehicles to stop before crossing, but some pedestrians entered the crossing immediately after activating the devices. In some cases when this occurred, vehicles did not have enough distance to safely stop, resulting in pedestrians swerving and sudden stop conflicts.

The 82nd Avenue RRFB installation also had a high vehicle volume late on a Sunday afternoon. This location had several instances of driver non-compliance. In one situation a pedestrian activated the RRFB devices and waited for cars to slow down. It appeared the vehicles were going to stop so the pedestrian stepped into the crosswalk but a vehicle sped in front of her as she was entering the intersection. Three vehicles followed this car forcing the pedestrian to wait on the curb until two vehicles stopped and allowed her to cross.

Overall, the RRFB installations appeared to be more efficient for vehicular traffic than the PHB installations because they allowed the vehicles to travel through the crosswalk when there were no pedestrians present, whereas the PHBs hold vehicles until the signal is dark. If the phasing used were consistent with the guidance given in the MUTCD, which allows vehicles to proceed on a flashing red if there are no pedestrians present, delay could be reduced.

The two PHB installations appeared to have very high compliance rates. The Sandy Boulevard installation is in an industrial/urban area and there is significant visual clutter in the area, but warning signs and the PHB heads were easily visible. Traffic volumes were not very high when this site was observed early on a Sunday afternoon.

The East Burnside Street PHB installation is at an intersection of a residential street designated as a bikeway and a four-lane urban street. It is located in a residential area and there are many trees which may affect the visibility of the devices. This location was heavily used by bicyclists and appeared to work smoothly for them.

4.0 RESEARCH PLAN

To answer questions that emerged from the literature review, the research team completed additional field and static computer-based research. This section identifies the questions to be answered, the methodology that was used, and the locations selected for field visits. The key measure of effectiveness that can be compared is the relative rates of driver compliance.

4.1 PHB RESEARCH QUESTIONS

The use of the PHB is prescribed in the MUTCD. The literature review has indicated that in many regions drivers do not understand the use of these new devices. Only one research question was proposed for the PHB, and one observational case study was suggested.

1. **How well do drivers understand steady and flashing red and yellow signal indications as well as a "dark" signal?** There is evidence to suggest that young and old drivers may have more knowledge gaps about the rules of the road that result in poor driving behaviors associated with flashing red and yellow lights. The research assessed the driver's understanding of the MUTCD-recommended signal design and the driver's understanding of flashing lights.

   Methodology: A static computer based study, using methodology similar to that used at the University of Massachusetts to assess driver understanding of flashing yellow lights was used to assess drivers' understanding of the MUTCD recommended signal design for the PHB. Over 100 subjects participated in the study (*Knodler et al. 2006*).

   Study locations: Laboratory study with participants selected from the Corvallis community.

2. **Can more than one crosswalk be installed at an intersection with a PHB?** The literature review was inconclusive on the use of PHBs at more than one crosswalk at an intersection since the majority of installations were at sites that included only one crosswalk. Field observations of driver compliance and stop locations were done at a site in Portland that has two marked crosswalks.

   Methodology: Field observations of driver compliance and stop location using staged and general pedestrian crossings were completed. The results are compared with other PHB sites located at intersections with only one crosswalk. This was an observational study.

   Study location: Portland site: NE Sandy Blvd and NE 18th Avenue.

4.2 RRFB RESEARCH QUESTIONS

The study of RRFBs involved gathering data at field locations and computing driver compliance as measured by yield rate.

1. **Would overhead installations of RRFBs increase driver response?** Currently, there are no overhead installations of RRFBs but it is thought that overhead placement of devices might increase compliance above that achieved with side-mounted beacons.

   Methodology: To study this question, an overhead flashing yellow installation and side-mounted flashing beacon installation were studied. The installations were both pedestrian-activated and were located within 10 miles of one another. This provided limited control for local driver behavior that might have been an issue if the locations were further apart. Field observations of driver compliance using random and planted pedestrians with a minimum of 40 completed crossings were recorded.

   Study Locations: Overhead flashing yellow beacon located on Hwy.34 (Main Street) between 16th and 17th Streets in Philomath and side-mounted flashing yellow beacons on Hwy. 99 W (3rd Avenue near Mayberry Avnue in Corvallis.

2. **Is the RRFB more effective when used in conjunction with a raised median?**

   Methodology: Field evaluation of driver compliance using random and planted pedestrians. The measure of effectiveness was whether there was a significant difference in driver compliance between sites in Springfield which have medians and Astoria locations which do not have medians.

   Study Locations: Springfield site: RRFB at OR126 (Main Street) near 51st Street; Astoria site: US 30 (Leif Erickson Drive) at 37th Street.

3. **How does driver response to side-mounted RRFBs compare to driver response to side-mounted flashing yellow beacons?** The literature review identified that RRFBs were found to be more effective than side-mounted beacons, but the study only examined a single beacon design. For this study, sites with the higher intensity RRFBs were studied. It should be noted that most of the lower intensity RRFBs are in the process of being replaced with the higher intensity beacons.

   Methodology: Field Evaluation of driver compliance using random and planted pedestrians. By studying two locations in Astoria and two in Springfield, there was control for local driver behavior. The Astoria sites did not have medians; both Springfield sites had medians.

   Study Locations: Astoria sites: RRFB at US 30 (at 37th Street and a yellow flashing beacon at US 30 (West Marine Drive) and Bay Street which is east of the Astoria-Megler Bridge turn-off in the Union Town section of Astoria. Springfield sites: RRFB at US 126 (Main Street) near 51st Street, and a yellow flasher at Olympic Street near 21st Street which are both mid-block crossings.

4.3 PROTOCAL FOR DATA COLLECTION

The data collection protocol that was developed included documentation of site characteristics as well as recording compliance rates and conflicts. (See Appendix D.)

To determine compliance rates, the point at which a vehicle could be expected to stop safely was determined by calculating the safe stopping distance using the posted speed limit. This was used to determine if a vehicle was capable of safely stopping. If a vehicle that was between this location and the crosswalk where the pedestrian was crossing stopped for the pedestrian it was considered compliant. A vehicle that was able to safely stop for the pedestrian and did not was considered non-compliant.

Conflicts were recorded for situations where vehicles or pedestrians had to change their behavior (stop, swerve, jump, run, or lunge) because of interactions with other vehicles or pedestrians. Some examples of conflicts included dart/dash (driver does not initially see the pedestrian and the driver does an avoidance maneuver), multiple threat (pedestrian enters in front of a stopped vehicle but conflicts with a vehicle heading in the same direction in another lane), near rear end collision, and pedestrians stopping and waiting for vehicles while in the crossing.

Staged crossings performed by the researchers were done to provide consistency and provide a large enough sample size. General population crossings were documented as well. The field data collection at each intersection consisted of a minimum of 40 staged crossings by a member of the research team while the other team member observed and recorded data. Research teams consisted of a male and female, each dressed in a plain colored jacket and blue jeans. Each researcher completed at least 20 of the staged crossings. Data was collected during daylight hours when there was no precipitation and at time durations that ranged between two to four hours.

Staged crossings were performed by walking up to the crossing when a vehicle or group of vehicles was in sight and activating the signal. Upon activation, the pedestrian stood on the curb within one foot of the edge and faced oncoming traffic showing intent to cross. Once vehicles in the oncoming direction were stopped or showing signs of stopping, the pedestrian began the crossing while being cautious of traffic in each lane. If a median was present, the pedestrian stopped on the median, faced oncoming traffic from the median, and waited for vehicles to stop before completing the crossing.

The following information was recorded for each crossing: the direction of the crossing, the number of pedestrians crossing, if it was staged, the compliance for each direction of traffic, and any conflicts that occurred.

5.0 RRFB FIELD WORK

This section describes the field work completed to address the research questions related to the deployment of Rectangular Rapid Flashing Beacons (RRFB). The field study approach focuses on documenting data from the driver perspective and specifically examines driver compliance and conflicts at each crossing. Each site is documented to examine possible characteristics that may impact the compliance rate. The field study findings and how they address the research questions are discussed.

5.1 DESCRIPTION OF BEACON TREATMENTS

This project identified beacon treatments that varied in the number of beacons used and their placement. A single beacon is shown in Figure 5.1, variations of two beacon systems is shown in Figure 5.2 and an overhead beacon is shown in Figure 5.3. The single beacon site was used for pilot data collection activities, but the results were not included in the study.

Figure 5.1: Single yellow beacon at 53rd Street, Corvallis, Oregon

Figure 5.2: Variations of a double yellow beacon (Left: Corvallis, OR; Right: Astoria, OR)

Figure 5.3: Overhead beacon installation in Philomath, Oregon

The overhead beacon treatment in the study is similar to Figure 5.3 and the side-mounted treatment is similar to Figure 5.1. The side-mounted treatments in this study are similar to the treatments shown in Figure 5.2. These treatments are similar to those studied by Shurbutt which showed compliance rates of about 15% for beacons and from 65 to 89% for RRFBs (*Shurbutt 2009*).

5.2 FIELD STUDY LOCATIONS

The research questions required identifying installations with overhead and side-mounted devices, with and without medians. Each site was documented by photos and notable characteristics of the crossing were recorded. Photos were taken of each approach of the crossing showing both the driver's and pedestrian's perspective and of other relevant signage and characteristics of the crossing. Table 5.1 below is a compilation of the field study locations and their characteristics.

Table 5.1: Selected RRFB and beacon sites

	Corvallis: Highway 99W (3rd Avenue) near Mayberry Avenue	Springfield: OR 126 (Main Street) near 51st St.	Springfield: Olympic St. near 21st St.	Astoria: US 30 (W. Marine Dr.) @ Bay St.	Astoria: US 30 (Leif Erickson Dr.) @ 37th St.	Philomath: Main St @ 17th St.
Treatment	Side, 2 Beacon	Side RRFB	Side, 2 Beacon	Side, 2 Beacon	Side, RRFB	Overhead, 2 Beacon
Signage	4	4	2	2	4	2
Activation	Pedestrian	Pedestrian	Pedestrian	Pedestrian	Pedestrian	Pedestrian
Signal Duration	30 seconds	32 seconds	36 seconds	60 seconds	30 seconds	30 seconds
Lanes	4	4	2	4	3	4
Posted Speed	35	40	35	30	35	25
Median	Yes	Yes	Yes	No	No	Yes
Mid-block	Yes	Yes	Yes	No	No	No
Median Width (ft)	9	8	8	No	No	9.75
Curb to Curb (ft)	74	65.4	61	54	48.9	68.7
Parking Lane	No	No	No	Yes	Yes	No
Bicycle Lane	Yes	Yes	Yes	No	No	Yes
Curb Extension	No	No	No	Yes	Yes	No
Sidewalk	Yes	Yes	Yes	Yes	Yes	Yes
Distance to Transit (ft)	57	50	56	~400	~70 (not marked)	~450
Distance to Signal (ft)	~570 South	~1750 West	~260 East	~460 East	~1350 West	765 East
Advance Stop Bar	Yes	Yes	No	Yes	No	On one side

The research questions call for the RRFB installations to be compared to beacon installations with similar characteristics.

5.2.1 Corvallis: Highway 99W (3rd Avenue) near Mayberry Avenue

Roadway and Environment Description

Highway 99W features two lanes in each direction with a two-way-turn lane (TWTL) and is a major road running north to south. A median is installed in the TWTL at the crossing. This crossing is located south of downtown in a business district and connects a strip mall with a neighborhood. Transit stops are located near the crossing. This is one of four mid-block crossings within about three quarters of a mile. All crossings have a similar design.

This installation features four crosswalk signs (two in each direction) with two beacons attached to each sign (one above and one below). The beacons flash in an alternating wig-wag fashion with no stutter. The crossing features both advance stop bars and signage which help improve the visibility of the crosswalk.

Location

Figure 5.4 shows the location of the crosswalk in Corvallis.

Figure 5.4: Location of beacon installation on Highway 99W, Corvallis

Driver and Pedestrian Perspective

Figure 5.5 shows the intersection from a driver's perspectives; Figure 5.6 shows the pedestrian's perspective of the same intersection.

Figure 5.5: Driver view of beacon installation on Highway 99W, Corvallis

Figure 5.6: Pedestrian view of beacon installation on Highway 99W, Corvallis

Compliance and Conflicts

The compliance rate for this crossing was 88.1%. The only conflict recorded was a driver that impeded a pedestrian crossing by making a sudden stop.

Observations

Corvallis is a recognized bicycle and pedestrian friendly community. This seems to produce high motorist compliance rates for pedestrians. It is not uncommon for motorists to yield to pedestrians even before they activate the beacons. Most drivers stopped at the advance stop bars.

5.2.2 Springfield: OR 126 (Main Street) near 51st Street

Roadway and Environment Description

Main Street has a mixture of housing and businesses and is a wide arterial street with few pedestrian crossings and widely spaced signals. The crossing connects a restaurant to a market. There are two lanes in each direction with a TWTL in the middle that has a refuge island at the crossing. There is a far side bus stop on each side of the crossing and there are advance stop bars with signage. This installation features four signs (two in each direction) with RRFBs attached. There is a pedestrian refuge island.

Location

Figure 5.7 shows the location of the crosswalk in Springfield.

Figure 5.7: Location of RRFB installation on Main Street in Springfield

Driver and Pedestrian Perspective

Figure 5.8 shows the intersection from a driver's perspective; Figure 5.9 shows the pedestrian's perspective of the same intersection.

Figure 5.8: Driver perspective of RRFB installation on Main Street in Springfield

Figure 5.9: Pedestrian perspective of RRFB installation on Main Street in Springfield

Compliance and Conflicts

The compliance rate for this crossing was 86.4%. One conflict was recorded at this crossing. A driver began to slow down giving the pedestrian the impression that he could cross. However, the vehicle did not stop and the pedestrian had to stop in the middle of the crosswalk to avoid a collision. The driver did not appear to notice the pedestrian.

Observations

When the RRFB was activated, in most cases it clearly caught the drivers' attention, but many drivers did not know how to respond. Researchers noted a few vehicles that slowed down but continued through the crossing and looked confused by the RRFB. Several drivers waited the entire duration (32 seconds) of the RRFB activation before continuing through the crossing, even if the crossing was clear before the time that the RRFB stopped flashing. .

In some cases, drivers braked suddenly for pedestrians at the advance stop bar. This could result in rear end collisions since drivers do not anticipate a vehicle stopped as far from the actual crosswalk.

Traffic signals and pedestrian crossings are spaced far apart and during data collection several pedestrians were witnessed crossing at segments of the road without a marked crossing and getting trapped in the two-way turn lane.

5.2.3 Springfield: Olympic Street near 21st Street

Roadway and Environment Description

This location is in a shopping district and provides a crossing between a restaurant and stores. Far side transit stops are located at the crossing. Both sides of the roadway have a bicycle lane, but the westbound lane has a large shoulder that becomes a bus lane.

This crossing features two side-mounted installations (one in each direction), each with two beacons. The beacons are located above and below the signs and flash in an alternating or wig-wag fashion when activated. There is advance signage but no advance stop bars.

Location

Figure 5.10 shows the location of the crosswalk in Springfield.

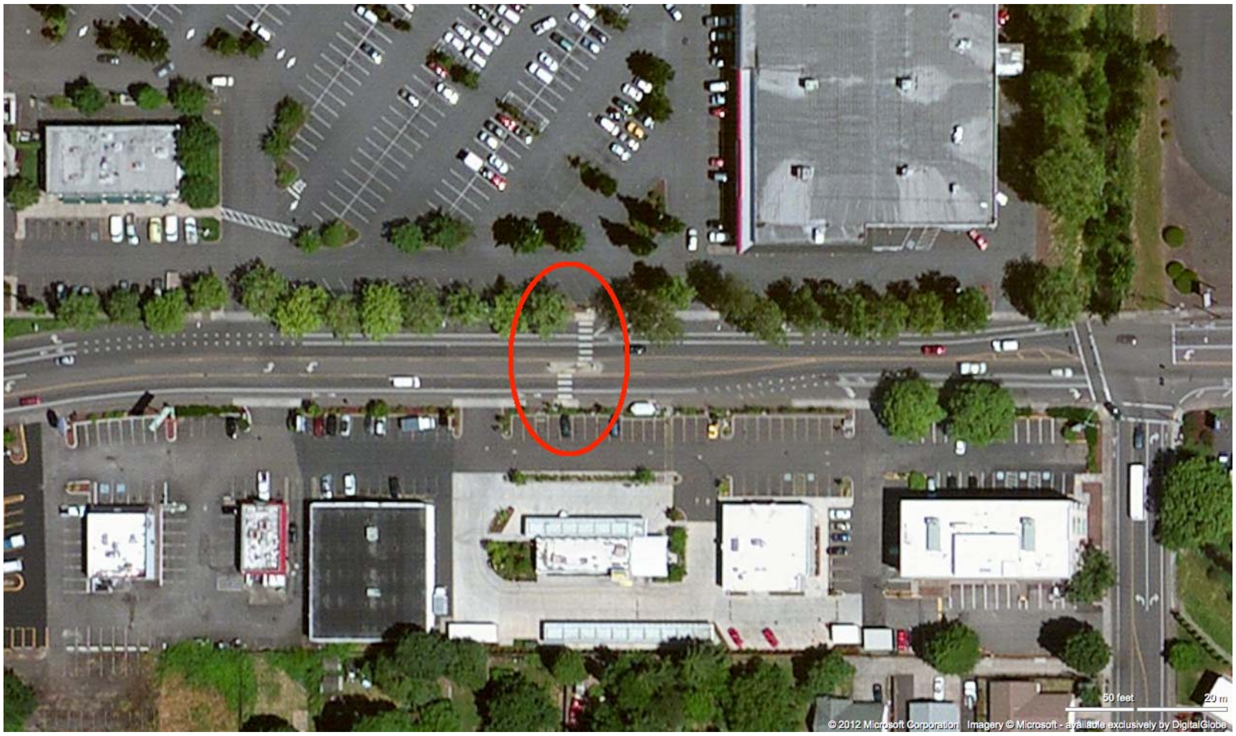


Figure 5.10: Location of beacon installation on Olympic Street in Springfield

Driver and Pedestrian Perspective

Figure 5.11 shows the intersection from a driver's perspective; Figure 5.12 shows the pedestrian's perspective of the same intersection.

Figure 5.11: Driver perspective of beacon installation on Olympic Street in Springfield

Figure 5.12: Pedestrian perspective of beacon installation on Olympic Street in Springfield

Compliance and Conflicts

The compliance rate was 60.8% at this location. Compliance in the westbound direction was observed to be much lower than in the eastbound direction. It was clear that drivers were not seeing the pedestrian or the sign and beacons. There were no conflicts recorded at this location.

Observations

The extra width next to the westbound lane makes it difficult for drivers to see the side-mounted crossing sign and beacon as well as the pedestrians waiting to cross. Drivers appear to stop when they noticed a pedestrian but not necessarily the beacon.

There is a sign on the median alerting drivers to stay to the right of it. This sign disrupts visibility between pedestrians and drivers. As a pedestrian you have to peak around the sign to be able to see vehicles. This negates the advantages of the offset design of the median, which is designed to have pedestrians face oncoming traffic before entering the roadway.

A driveway located about 50 feet to the east of the crossing provides access to the parking lot for a shopping center. Long platoons of vehicles form at a traffic signal further to the east which makes it difficult for vehicles to turn from the parking lot onto Olympic Street. When drivers do have an opportunity to turn onto Olympic Street, they usually focused on the roadway and did not notice the flashing beacon or a pedestrian waiting to cross. It was also noted that if the first vehicle in a platoon did not stop, a vehicle later in the platoon generally did not stop either.

5.2.4 Astoria: US 30 (W. Marine Drive) at Bay Street

Roadway and Environment Description

US 30 (W. Marine Drive) is a busy four lane road providing vehicles access to US 101. The pedestrian crossing provides access between businesses. In the summer, cruise ships dock nearby and large numbers of pedestrians use the crossing. The crossing does not have a median and features one side-mounted device in each direction that has two side-by-side beacons that flash in an alternating or wig-wag fashion. This crossing is at an intersection and features advance stop bars with accompanying signage.

Location

Figure 5.13 shows the location of the crosswalk in Astoria.

Figure 5.13: Location of beacon installation on W. Marine Dr. at Bay Street in Astoria

Driver Perspective

Figure 5.14 shows the intersection from a driver's perspective.

Figure 5.14: Driver perspective of beacon crossing on W. Marine Dr. at Bay St in Astoria

Compliance and Conflicts

The compliance rate was 71.8% at this location. Four conflicts were recorded including three sudden stops by vehicles and one double threat. A double threat is when a driver in the curb lane stops to let a pedestrian cross but the motorist in the adjacent lane doesn't notice the first car has stopped to let a pedestrian cross and continues. The pedestrian doesn't see the other car coming and continues to cross, which can result in a high-speed, fatal or severe injury crash.

Observations

The bulbouts help motorists see the pedestrians and vice-versa, but the beacons did not seem to get the attention of the drivers. This may be due to the way the crossing signs and beacons are installed. The crossing signs and beacons are installed higher than normal to improve visibility since large trucks occupying the curb lane obstruct the view of the beacons. However, placement may need to be reevaluated as many drivers seemed to find them too high.

Several people told the research team that they do not feel safe using the crossing and prefer to walk out of their way to the signalized intersection located 460 feet away.

The duration of the beacon activation is one minute, which is considerably longer than the activation period for the other installations studied. For some crossings it took some time for cars to stop when the beacon was activated; and drivers complied very quickly at others. The beacons remained activated long after the pedestrian crossing was completed. It confused some motorists who slowed down or stopped when there was no pedestrian waiting to cross.

Besides the recorded conflict listed above, double threat situations occurred on other occasions but a pedestrian was not present in the crosswalk.

The sudden stops recorded may be a result of the location of the crossing and the advance stop bars. The crossing is located on one side of the T-intersection and the advance stop bars on the other side are located at the intersection, leaving a large gap between the crossing and stop bars. Several motorists appeared to not anticipate this gap and made sudden stops when they saw the signage.

5.2.5 Astoria: US 30 (Leif Erickson Dr.) at 37th Street

Roadway and Environment Description

This crossing is located on the edge of town on the main street providing an exit to the east. The crossing provides access from a neighborhood to the waterfront. This crossing is at an intersection, does not have a median, and spans three lanes of traffic; one lane in each direction and a left turn lane. The bulbouts at the crossing increase visibility and sight lines for motorists and pedestrians. In each direction, there are two side-mounted crossing signs with RRFBs that share the same post. There are no advance stop bars but there is advance crosswalk signage. Visibility to the east is good, but a curve that begins about 250 feet to the west limits visibility in that direction.

Location

Figure 5.15 shows the location of the RRFB on US 30 at 37th Street in Astoria.

Figure 5.15: Location of RRFB installation on US 30 at 37th Street in Astoria

Driver and Pedestrian Perspective

Figure 5.16 is a photograph of the intersection showing the driver's perspective; Figure 5.17 shows the pedestrian's perspective.

Figure 5.16: Driver perspective of RRFB crossing on US 30 at 37th Street in Astoria

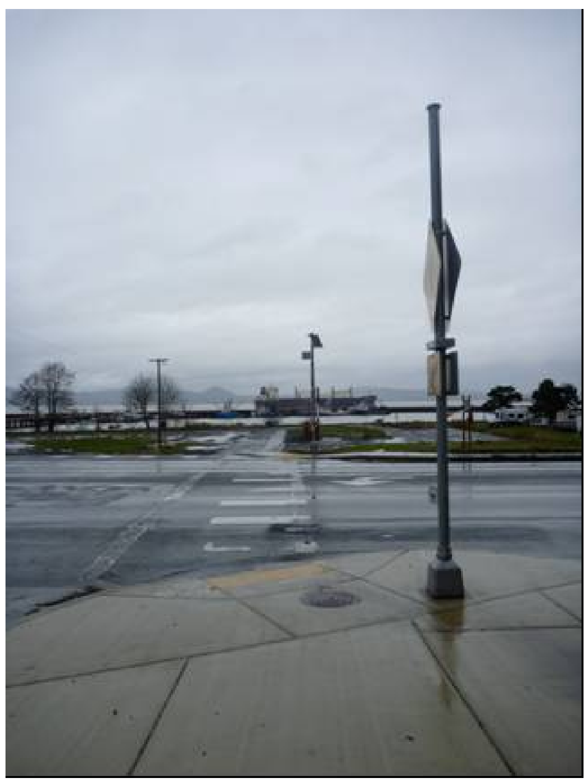


Figure 5.17: Pedestrian perspective of RRFB crossing on US 30 at 37th Street in Astoria

Compliance and Conflicts

The compliance rate was 75.9% at this location. There were no conflicts recorded.

Observations

The RRFBs at this location feature a side facing beacon that alerts the pedestrians when the system was activated. ODOT has taken the position to purposely provide minimal indication to the pedestrian of the flasher status with the intent the pedestrian responds to traffic and not the flasher status. It was noted that other installations in the state feature a voice message about the flasher status.

The RRFBs appear to perform well by getting the attention of drivers and bringing attention to the pedestrian. The researchers noted that the flashing sequence noticeably caught a driver's attention on several occasions and overall compliance at the crossing appeared high. The researchers were provided anecdotal comments by local residents about the treatments and all of them were very positive.

The wet weather conditions at the Astoria sites caused the data collection activities to be disrupted. All crossings were performed when there was no rain.

5.2.6 Philomath: OR 34 (Main Street) at 17th Street

Roadway and Environment Description

This crossing is located on Main Street and is within a school zone. The crossing connects a neighborhood to shopping and a restaurant. The crossing is located at an intersection; all left turns are restricted except for the northbound left turn from 17th Street to Main Street. There are two overhead-mounted beacons facing each direction for a total of four beacons. The beacons are centered over each lane and flash in a wig-wag fashion.

Location

Figure 5.18 shows the location of the beacons in Philomath.

Figure 5.18: Location of beacon installation on OR 34 (Main Street) in Philomath

Driver and Pedestrian Perspective

Figure 5.19 shows the crossing from the driver's perspective; Figure 5.20, from the pedestrian's perspective.

Figure 5.19: Driver perspective of overhead beacon crossing on OR 34 (Main Street) in Philomath

Figure 5.20: Pedestrian perspective of overhead beacon crossing on Main Street in Philomath

Compliance and Conflicts

The compliance rate was 77.1% at this location. Two conflicts were recorded at this crossing. A conflict was recorded when vehicles on Main Street were stopped for a pedestrian and a driver making a right turn from 17th Street saw the stopped traffic and entered Main Street and cut off the pedestrian. The other conflict recorded was a non-compliant vehicle on the far side of a crossing that trapped a pedestrian in the crosswalk.

Observations

Vehicles queued waiting to make a left turn onto Main Street from 17th St south of the crossing were usually focused on looking for traffic and not on the crosswalk. This also happened with vehicles making a right turn onto Main Street from 17th Street.

The overhead beacons did not appear to attract the attention of the drivers as well as other treatments. Compliance appeared to be greater for traffic heading to the east; this may be due to glare from the sun or visibility reasons for traffic heading to the west.

5.3 RESULTS

5.3.1 Summary of Field Data Collection

Tables 5.2 and 5.3 provide a summary of the data collected at each location and the conflicts recorded at each site.

Table 5.2: Summary of crossings

Location	Crossings	Time of Day	Weather
Corvallis – 99W	50	Afternoon	Sunny/clear
Springfield – Main Street	52	Morning	Sunny/clear
Springfield – Olympic Street	42	Afternoon	Overcast/partly cloudy
Astoria – Bay Street	50	Afternoon	Overcast
Astoria – 37th Street	49	Morning/Afternoon	Overcast/light rain
Philomath—Main Street	43	Afternoon	Overcast/sunny

Table 5.3: Conflicts recorded at each site

Location	Conflict
Corvallis – 99W	Sudden stop by vehicle impeded pedestrian crossing
Springfield – Main Street	Non-compliant vehicle cut off pedestrian
Springfield – Olympic Street	None
Astoria – Bay Street	Sudden stop by vehicle impeded pedestrian crossing
Astoria – Bay Street	Double threat
Astoria – Bay Street	Sudden stop by vehicle impeded pedestrian crossing
Astoria – Bay Street	Sudden stop by vehicle impeded pedestrian crossing and near rear end collision
Astoria – 37th Street	None
Philomath -- Main Street	Stranded pedestrian in the crossing
Philomath – Main Street	Sudden stop by vehicle impeded pedestrian crossing

Following established research procedures by others (*Fitzpatrick et al. 2008*), the average compliance rate for each crosswalk was calculated and is shown in Figure 5.21 below.

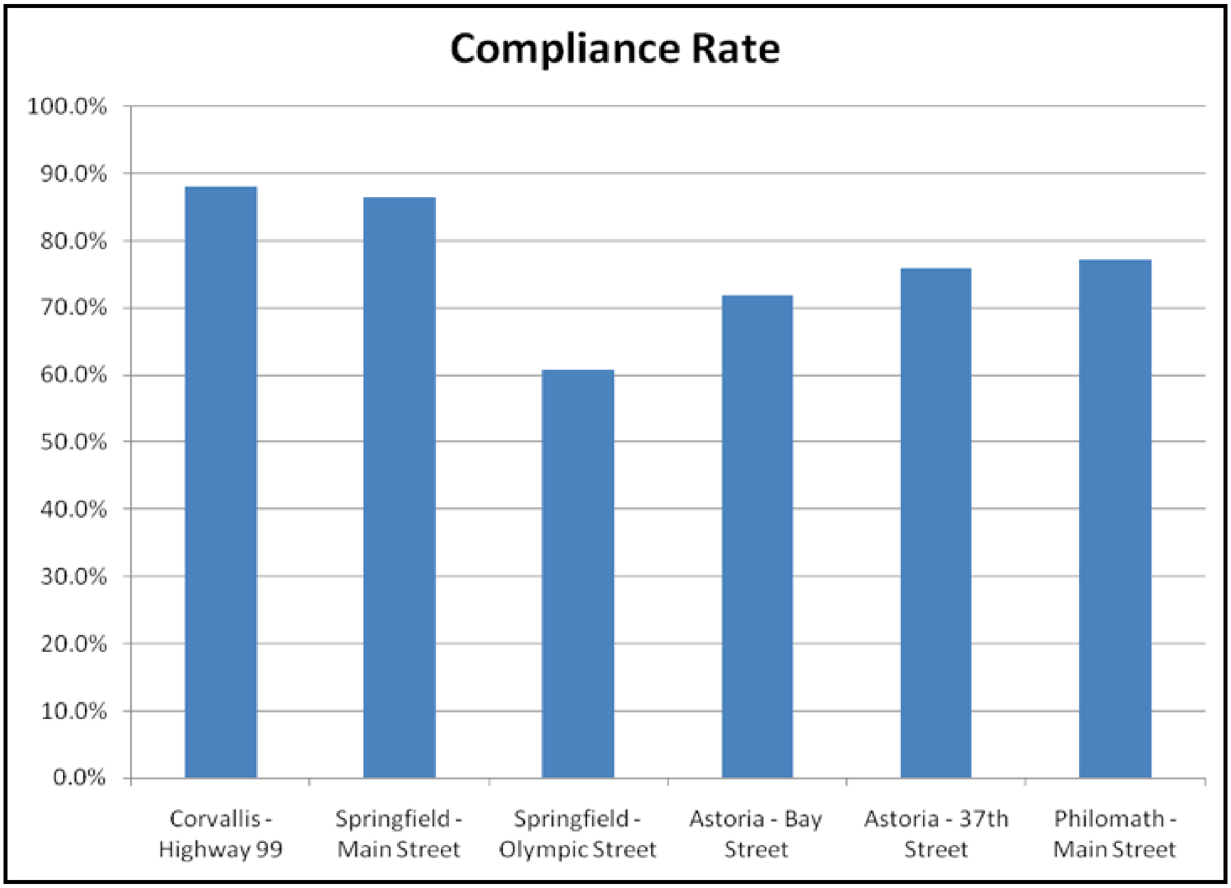


Figure 5.21: Average compliance rates

As shown in the graph, the compliance rates are all fairly high. The Corvallis side beacons had the highest compliance rate at over 88%; the side beacons at Olympic Street in Springfield had a compliance rate of 61%, which was the lowest. The compliance rates are used to provide insight in addressing the research questions.

5.3.2 Research Questions

The limited RRFB sites available at the time of field testing allowed for local driver behavior to be considered, but did not represent a large population from which to randomly select sites. The comparisons made in answering the research questions allow for significance to be determined based on differences in compliance rates for the crossing sites, but the treatment as well as environmental effects and crossing characteristics need to be considered for each crossing comparison.

Question 1: Would overhead installations of RRFBs increase driver response?

The Philomath overhead beacon installation was compared to the side-beacon Corvallis crossing as well as the Olympic Street crossing in Springfield. The Corvallis crossing had the highest compliance rate at 88.1%. The Philomath overhead beacons had a compliance rate of 77.1% and the Olympic Street, Springfield site had a compliance rate of 60.8%, which was the lowest.

Question 2: Is the RRFB more effective when used in conjunction with a raised median?

The three lane RRFB installation with no median in Astoria was compared to the RRFB installation on Main Street in Springfield where there is a median. The Astoria RRFB had a compliance rate of 75.9%; the compliance rate for the Springfield site was 86.4%.

The Springfield installation features four crosswalk signs (two in each direction) with two beacons attached to each sign (one above and one below). The beacons flash in an alternating fashion with no stutter. The driver compliance results for the location in Corvallis where there were side-mounted beacons on the side of the road and on the median and Astoria beacon location where there was no median were compared to assess the effectiveness of a median with beacons. Corvallis had a compliance rate of 88.1% and Astoria a compliance rate of 71.8%.

The results indicate that a median may contribute to higher driver compliance at locations with side-mounted RRFBs or beacons. Other factors need to be considered before the results can be considered conclusive.

Question 3: How does driver response to side-mounted RRFBs compare to driver response to side-mounted yellow beacons?

The Astoria RRFB site was compared to the Astoria beacon site. The RRFB had a compliance rate of 75.9% and the beacon site had a compliance rate of 71.8%.

The RRFB installation in Springfield was compared to the Corvallis side-mounted beacon crossing. This compares sites that have a median and four treatments installed. The compliance rate in Springfield was 86.4% and Corvallis was 88.1%.

The question cannot be answered since the results were not conclusive.

5.4 CONCLUSION

The methodology developed and followed for the field work evaluated the effectiveness of various crosswalk treatments, including overhead and side-mounted beacons, RRFBs, and pedestrian medians. The compliance rate at the crossings were determined, conflicts recorded, and observations made at each crossing. This allowed comparisons to be made among the crossings to determine the factors that influence the compliance rate.

There were a limited number of RRFB installations in Oregon at the time of the field work. This did not allow for a random sample and more in depth statistical comparisons. The RRFB installations in Oregon have greatly increased since the field work was completed and this may allow for a different sampling approach to be used in the future that would allow for more statistical analysis of the information collected for different treatments.

Notable is the installation in Springfield at Olympic Street, which recorded the lowest compliance rate (60.8%). The visibility of the pedestrian and the crossing treatment seem to have a large effect on the driver compliance at a crossing. The large shoulder at the Olympic Street crossing in Springfield put a pedestrian waiting at the curb out of a driver's field of vision.

At the rest of the installations studied in the field work it was found that RRFBs mounted on the median and some side-mounted beacon installations had the highest compliance rates. Both sites also had advance stop bars and signage which may have helped increase visibility and compliance.

The median- and side- mounted beacon and RRFB treatments had higher compliance rates compared to the overhead beacon treatment. The results are inconclusive since only one site with an overhead-mounted beacon was studied. The median-mounted signage and devices may provide more visibility to drivers than an overhead treatment; however the crossing characteristics and local drive behavior may also make a difference in compliance rates. An overhead installation may provide better visibility in a highly cluttered environment or where a bus may limit visibility of side-mounted devices at near side transit stops located at pedestrian crossings. Four treatment installations with a median provide adequate visibility.

The overhead treatment on Main Street in Philomath had a higher compliance rate (77.1%) - compared to the two-side-mounted beacon installation on W. Marine Drive at Bay Street in Astoria. The compliance rate of the overhead treatment is very high compared to other studies reviewed in the literature search of overhead beacons that found some compliance rates of less than 20%. The overhead treatment also featured advance stop bars and signage that may have contributed to the high compliance rate.

Higher compliance rates were found when medians were used in beacon and RRFB installations. They also provide space to install extra signage to increase visibility for the crossing. This is valuable in environments with high visual clutter and near side bus stops. For these reasons a median should be installed at crosswalks when possible.

Beacon and RRFB installations had similar compliance rates and this is in contrast to previous studies that have found the RRFBs to have significantly higher compliance rates compared to beacon treatments (*Shurbutt et al. 2009*). The difference may be attributed to different beacon designs used in this study. The compliance rates of the beacons are much higher than the previous study (11.5% - 17%), whereas the RRFB treatments are similar (63.4% to 84.6% for RRFBs without a median and 88% to 89.3% RRFBs with a median.).

The US 30 crossing at Bay Street in Astoria had more conflicts recorded than other crossing. Three of the four conflicts at the location were a sudden stop by a vehicle that impeded a pedestrian crossing. Due to the large number of large, heavy vehicles using the intersection, the beacons are installed higher than normal. This provides drivers of passenger cars better visibility, but it also places the devices out of the driver's field of vision and makes the crossing and pedestrians less visible. The other conflict at the site was a double threat. Installation of "do not pass" markings and advance stop bars such as used at the Bend RRFB installations may decrease the double threat problem. The researchers noted that advance stop bars give pedestrians a better sense of yielding vehicles and provided a larger distance between stopped vehicles and crossing pedestrians.

6.0 PHB SURVEY AND FIELD OBSERVATIONS

To assess the understanding of the PHB, a static survey of the MUTCD-approved design was given to subjects living in Corvallis. The survey assessed the recognition of a PHB, understanding of the indications, and understanding of the sequence, i.e. what indication comes after the current indication. It should be noted that in the survey the PHB was not given with respect to the context of the signal installation or the sequence of the signal indications.

A section on observations from the Portland PHB installation at NE Sandy Blvd and NE 18th Avenue is included to give insight into the differences between the MUTCD approved operation and the operation in Portland.

6.1 SURVEY METHODOLOGY

The Corvallis community was selected to survey drivers about the PHB because it is desirable to survey persons who are not familiar with the device. There are no installations in the city or surrounding area. The installations in Oregon are in Portland, Klamath Falls and Springfield.

A wide range of ages was represented in the study, but the research question focused particularly on the understanding of older and younger drivers. Three age groups were selected: 26 and under, 27-59, and 60 and older. To reach younger drivers, the survey was administered in one junior and one senior level transportation engineering course at Oregon State University. The Academy for Lifelong Learning provided an audience of older drivers. The survey was conducted in the spring of 2011. As shown in Table 6.1 there were 107 people in three age groups that participated in the survey.

Table 6.1: Survey participants, by age group

Age	26 and under	27-59	60 and over	Total
Total	44	4	59	107

A PowerPoint presentation was used to administer the survey to a group of people who wrote their responses on paper. The survey, which was comprised of 12 questions, is included in Appendix E. The survey questions were analyzed in three different ways. The overall score was calculated using all of the survey responses, scores for young drivers and older drivers were calculated, and comparisons were made between the responses of younger and older drivers.

6.2 SURVEY RESPONSES

The survey focused on three areas: PHB recognition, understanding of PHB indications, and the sequence of indications displayed. Each part is discussed and the responses shown in the following sections.

6.2.1 PHB Recognition

This section of the survey was included to assess the awareness of the PHB. Survey participants were shown a PHB and asked if they had seen the device before. The responses to the first question are shown below in Table 6.2.

Table 6.2: PHB recognition, by age group

	Yes, I have seen this signal	No, I have not seen this signal	I am not sure if I have seen this signal
Overall	18%	61%	21%
26 and under	29%	44%	27%
60 and over	7%	78%	15%

A majority of respondents in the two age groups and the overall results indicated that the respondents had not seen a PHB before. 29% (13 people) of respondents under the age of 26 responded that they had seen a PHB before compared to only 7% (4 people) of respondents over the age of 60. The respondents in the 60 and over age group were overwhelmingly more confident that they had not seen the signal before whereas a higher percentage of the 26 and under age group respondents answered that they were not sure.

To confirm the likelihood that the people who said they had seen a PHB had actually seen a PHB they were asked a follow-up question: "Where have you seen this signal?" The results of the follow-up question about the placement of the PHB are shown below in Table 6.3.

Table 6.3: PHB placement recognition by age cohort

	At an intersection	At a rail crossing	At a pedestrian crossing	At a roundabout
All ages	10%	85%	5%	0%
26 and under	8%	92%	0%	0%
60 and over	25%	75%	0%	0%

The information in Table 6.3 demonstrates that there is a lack of understanding of the placement of the PHB. Of the 13 people in the younger age group that answered they had seen the signal before, 12 of them responded that they had seen it at a rail crossing, where PHBs are not deployed. Only one person responded that they have seen it at an intersection and no one responded that they had seen it at a pedestrian crossing. The only person that did respond "At a pedestrian crossing" was a respondent in the 25-59 age range. Twenty-five percent of the older drivers answered they had seen the device at an intersection. It should be noted that the survey did not present the PHB in the context that the respondents would encounter when driving. In other words it would be unlikely that they would mistake a PHB for a railroad crossing signal if they saw it on the street and there were no railroad tracks, crossing warning signs, or crossing gates.

The results of the first two survey questions indicate that there is a low recognition of the PHB. Hence, the results of the survey questions that test a driver's understanding of the displays can be viewed from the perspective of a driver that is encountering the signal for the first time. The purpose of this is to determine if we can expect satisfactory understanding of the signal and thus satisfactory compliance.

6.2.2 PHB Understanding

The goal of this section of the survey was to determine the respondents' understanding of what are the appropriate actions or responses for each indication of the PHB. No background information was given to the participants and the six indications of the beacon were presented to in a random order. The goal of this section was to determine how people might respond to each option rather than a right or wrong answer because depending on the situation, the correct answer may vary.

Respondents were shown each indication of the PHB and given five options for a possible action or scenario. For this section of the survey, respondents could choose more than one option. The results shown below represent the percentage of the total responses for each answer. Figures 6.1 through 6.5 below are of each of the signal indications and the corresponding results for each option. The signal phase is shown on the left and the percentage for each response is shown on the far right.

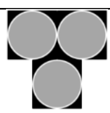
Indication	Options	Overall	26 and younger	60 and over
 **Dark**	1. You have the right of way and can go	59%	67%	49%
	2. The power at the signal is out	34%	28%	40%
	3. You must stop and wait for the appropriate traffic signal	4%	2%	6%
	4. A red light is coming next	2%	2%	1%
	5. A yellow light is coming next	2%	2%	3%

Figure 6.1: Understanding of a dark indication

A critique of the PHB is that drivers may think that the power is out and, in response, stop at the crossing. The results show that a large percentage of responses were that the power is out, but an even higher percentage were that "you have the right of way and can go", which is the correct response. A higher percentage of responses from younger drivers were "you have the right of way and can go" than the responses from older drivers.

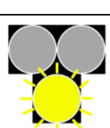
Indication	Options	Overall	26 and younger	60 and over
 **Flashing Yellow**	1. You have the right of way and can go	10%	13%	8%
	2. You are required to yield	52%	72%	37%
	3. You must stop and wait for the appropriate traffic signal	15%	2%	26%
	4. A red light is coming next	19%	9%	28%
	5. A train is coming	3%	4%	2%

Figure 6.2: Understanding of a flashing yellow indication

The majority (72%) of responses from the 26 and under age group were the correct answer “you are required to yield”, whereas only 37% of the responses from the 60 and over age group were for this option. Over a quarter of responses from the 60 and over age group were that “a red light is coming next” and a quarter were that “you must stop and wait for the appropriate traffic signal”. These responses were given much less frequently by the 26 and under age group. This age group gave the response “you have the right of way and can go” more frequently that the rest of the respondents.

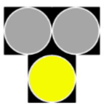
Indication	Options	Overall	26 and younger	60 and over
 **Solid Yellow**	1. You have the right of way and can go	8%	9%	7%
	2. You are required to yield	38%	43%	35%
	3. You must stop and wait for the appropriate traffic signal	16%	9%	24%
	4. A red light is coming next	33%	32%	31%
	5. A train is coming	5%	7%	3%

Figure 6.3: Understanding of a solid yellow indication

Results for this signal indication do not vary as widely as they do for the flashing yellow indication, but there is still some difference. About half the responses given were for the two correct options, “you must stop and wait for the appropriate traffic signal” and “a red light is coming next”. Almost one-fourth of the responses from the 60 and over age group were “you must stop and wait for the appropriate signal”, whereas this response accounted for only 9% of the responses given by younger drivers. One third of the responses overall were “a red light is coming next”.

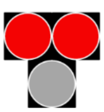
Indication	Options	Overall	26 and younger	60 and over
 **Solid Red**	1. You have the right of way and can go	0%	0%	0%
	2. You must stop, but may proceed if roadway is clear	11%	16%	9%
	3. You must stop and wait for the appropriate traffic signal	71%	66%	75%
	4. A green light is coming next	5%	6%	4%
	5. A train is coming	12%	12%	12%

Figure 6.4: Understanding of a solid red phase

The majority of the responses were “you must stop and wait for the appropriate traffic signal”, the only correct response. There is clearly some confusion since 12% of the responses were that “a train is coming”. That 16% of the responses from younger drivers and 9% of the responses from older drivers were that “you must stop, but may proceed if the roadway is clear” is alarming as this could cause a conflict with pedestrians since this is the pedestrian walk interval.

Indication	Options	Overall	26 and younger	60 and over
 **Alternating Flashing Red**	1. You have the right of way and can go	0%	0%	0%
	2. You must stop, but may proceed if roadway is clear	19%	16%	21%
	3. You must stop and wait for the appropriate traffic signal	25%	27%	24%
	4. A non flashing red light is coming next	8%	7%	6%
	5. A train is coming	49%	49%	48%

Figure 6.5: Understanding of an alternating red phase

These responses clearly show confusion between the PHB and the signal being used at a rail crossing. Almost half of the responses were that a train is coming. Only 16% of the responses from young drivers and 21% of the responses from older drivers were that you can proceed if the roadway is clear after stopping, which is the correct response. The alternating flashing red indication is included to decrease delay to motorists, but it does not work if drivers do not understand the meaning of the indication.

6.2.3 Sequence for a PHB

The survey included questions to examine each respondent's knowledge of what indication follows each of the indications of the PHB. For each indication of the PHB, the survey asked what the following display would be. Each of the six PHB indications was given as an option along with an "I do not know" option. The results are shown below in Figures 6.6 through 6.10. For each of the indication, the correct answer is shown in italics and underlined.

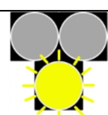
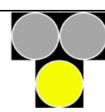
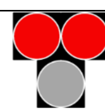
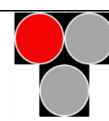
Dark	 **Flashing Yellow**	 **Solid Yellow**	 **Solid Red**	 **Alternating Red**	**I Do Not Know**
Overall	***36%***	18%	2%	7%	37%
26 and under	***41%***	13%	4%	13%	28%
60 and over	***31%***	20%	0%	3%	46%

Figure 6.6: Display following Dark indication

A high percentage of younger and older drivers responded correctly that a flashing yellow display follows a dark display. Almost half of older drivers responded that they did not know and while 28% of younger drivers said they did not know. A notable number of respondents, 13% of younger and 20% of older drivers, thought that a solid yellow display follows the dark phase.

Flashing Yellow	Dark Signal	Solid Yellow	Solid Red	Alternating Red	I Do Not Know
Overall	7%	***20%***	31%	14%	29%
26 and under	9%	***27%***	20%	14%	30%
60 and over	5%	***12%***	39%	15%	29%

Figure 6.7: Display following Flashing Yellow indication

Almost one-third of the respondents said that they did not know what display follows a flashing yellow display. Only 12% of the older drivers and 27% of the younger drivers responded correctly that the solid yellow display follows the flashing yellow display. Nearly 40% of the older drivers thought a solid red display followed the flashing yellow whereas about 20% of the younger drivers chose this option.

Solid Yellow	Dark Signal	Flashing Yellow	Solid Red	Alternating Red	I Do Not Know
Overall	3%	10%	***45%***	19%	23%
26 and under	5%	12%	***30%***	26%	28%
60 and over	2%	8%	***56%***	14%	20%

Figure 6.8: Display following Solid Yellow indication

The majority of older drivers correctly chose the solid red display and only 30% of younger drivers did. A notable percentage of older and younger drivers selected the "I do not know" option.

Solid Red	Dark Signal	Flashing Yellow	Solid Yellow	Alternating Red	I Do Not Know
Overall	32%	9%	5%	***14%***	40%
26 and under	41%	16%	5%	***9%***	30%
60 and over	27%	5%	5%	***15%***	48%

Figure 6.9: Display following Solid Red indication

A high percentage of younger and older drivers selected the "I do not know" option for this display and only a small percentage correctly answered that it was the alternating red display. A high percentage of drivers said a dark display followed the solid red phase.

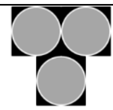
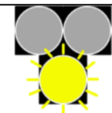
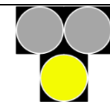
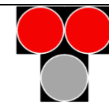
Alternating Flashing Red	 **Dark Signal**	 **Flashing Yellow**	 **Solid Yellow**	 **Solid Red**	**I Do Not Know**
Overall	***30%***	2%	5%	32%	31%
26 and Under	***22%***	2%	7%	42%	27%
60 and Over	***34%***	2%	5%	23%	36%

Figure 6.10: Display following Alternating Flashing Red indication

The results for all respondents show that there is confusion regarding the alternating flashing red indication. Less than a third of the respondents chose the correct answer. The most common wrong answer was that the solid red display followed the alternating flashing red display.

6.3 SURVEY DISCUSSION

The results of this survey demonstrate that the PHB is not widely recognized, especially when it is given out of context, and there is confusion about the sequence of the six indications. The vast majority of respondents answered that they had not seen a PHB before or were not sure if they had. Of the respondents that said they had seen a PHB before, a large majority responded that it was installed at a rail crossing.

Many respondents did not understand the meaning of the various indications of the PHB. Younger and older drivers responded well to the dark signal, indicating that they knew to continue through the signal. Most responded that it is necessary to stop for the red indication, but there appears to be confusion with the alternating flashing red indication. A low percentage of drivers responded that you must stop but may proceed through if the crossing is clear, which is the purpose of the indication. If drivers do not proceed when they are stopped at the crossing and it is clear, it decreases the efficiency of the PHB. Almost half of respondents said that the indication was for a train, which is an incorrect answer.

A large percentage of drivers responded that they did not know the signal indication for the PHB. Of those that selected a signal indication, the results are varied for each of the signal indications. The lowest percentage responded correctly to what follows the flashing yellow indication and the solid red indication. The PHB does not follow a traditional signal progression and respondents appeared to select indications that correspond to a traditional signal, such as selecting a solid red indication after a solid yellow.

Overall the results of the survey demonstrate that drivers are not familiar with PHBs and do not understand the sequencing. Other studies have recommended an educational campaign to accompany installations to increase understanding of the PHB and its indications. The results of the research strongly suggest that a public education campaign on the different indications of the signal should precede the deployment of a new signal. Currently, the PHB and RRFB are not included in the Oregon Driver's Manual.

6.4 OBSERVATIONS AT PHB INSTALLATIONS IN PORTLAND

The PHB was included in the 2009 MUTCD providing guidance on its installation. Portland has two PHB systems that differ from the guidance in the MUTCD, mainly in that they utilize a different sequence and have more than one marked crosswalk at the beacon. The PHB installation at NE Sandy Blvd. and NE 18th Avenue in Portland was observed on three occasions for up to one hour each visit to gain insight into the sequence used and system operation with multiple crosswalks.

The PHBs at this location were activated in September 2007 and replaced half signals. Sandy Blvd is a four lane arterial road. NE Sandy Blvd. at NE 18th Avenue is a skewed intersection as shown below in Figure 6.13.

Figure 6.11: Aerial view of PHB at NE Sandy Blvd. and NE 18th Avenue in Portland, OR

Crosswalks are striped for each crossing and there are no advance stop bars. A mast arm with a PHB centered over each lane is installed over the far crosswalk from the driver perspective. A pedestrian crossing sign and diagonal downward pointing arrow sign are side-mounted at the near crossing for drivers as shown in Figure 6.12.

Figure 6.12: PHB installation at NE Sandy Blvd. and NE 18th Avenue looking east

The beacon sequence utilizes a short Flashing Red indication between the Steady Red and Dark indications and vehicles mostly remained stopped during this indication. Some pedestrians cleared the crossing before the pedestrian clearance interval ended or activated the system and began crossing if no vehicles were in sight. This increased vehicle delay and decreased efficiency of the crossing by stopping and holding vehicles when the crossing was clear. The Alternating Flashing Red indication of the MUTCD sequence allows vehicles to precede if the crossing is clear, which reduces vehicle delay.

During on-site visits, compliance was observed to be very high, however no records were made. When the system was activated by a pedestrian, vehicles stopped behind the near crosswalk as they would for a traditional traffic signal. No vehicles stopped between the crosswalks or blocked the intersection. There is not sufficient data to answer the research question of whether two crosswalks can be installed with PHBs.

Soon after the PHB was installed, the Alternating Flashing Red indication was changed to a Steady Red indication for several reasons. It was found that drivers of queued vehicles proceeded through the crossing when the beacon changed to Alternating Flashing Red without checking to see if the crossing was clear. Pedestrians were observed entering the crossing during the Flashing Don't Walk interval, which is when drivers have an Alternating Flashing Red indication in the MUTCD sequence. Pedestrians and bicyclists, who assume protection until the countdown timer gets to zero, were confused by this and if they suddenly entered the crossing during this indication they make it more difficult for motorists to see them at the crossing (*City of Portland Bureau of Transportation 2010).*

A City of Portland study about the PHB installation at E. Burnside Street and NE 41st Avenue found initial motorist compliance was lower than previous studies on PHBs, but a follow-up review two years after installation showed compliance was 97% (*City of Portland Bureau of Transportation 2010*).

7.0 GUIDELINE DEVELOPMENT FOR PHBS AND RRFBS

Numerous factors must be considered when selecting an appropriate pedestrian crosswalk treatment for a specific location. . These include driver compliance expectations; roadway characteristics such as traffic volumes, crossing distance, posted speed, and geometry; pedestrian volumes and pedestrian characteristics; the surrounding environment such as land use; and visibility especially if there are nearside transit stops; and cost considerations.

Several recommendations for the installation of RRFB and PHB devices have been developed that are based on the findings of the literature review, field testing results, the PHB survey, and observations. The guidelines and the accompanying decision tree matrix are intended to be used by engineers in determining whether an RRFB or PHB or other pedestrian traffic control device should be installed.

7.1 DRIVER COMPLIANCE EXPECTATIONS FOR PHBS AND RRFBS

7.1.1 PHBS

The PHB was not included in the field study, since it is already included in the MUTCD and there were a limited number of test sites that were MUTCD compliant when developing the field study. It should be noted that several studies have found that they achieve compliance rates approaching 100% (*Turner et. al 2006; Fitzpatrick et. al. 2006*). PHBs are expensive to install since most are in overhead applications. It is recommended that PHBs be installed in high risk environments. PHBs are also recommended where overhead mounts are the only solution because the main cost is in the overhead mounts and the PHB has a much higher compliance than other overhead-mounted treatments such as beacons. If the posted speed is 35 mph or less, PHBs can be side-mounted which is less expensive than an overhead installation.

7.1.2 RRFBS

RRFB installations include those with and without median-mounted devices. An installation with a median-mounted device in this report refers to a treatment that has a side-mounted sign and device and a sign and device mounted on a median island for each direction. An installation without a median-mounted device refers to one that has a side-mounted crossing sign and device on each side of the roadway.

The RRFB treatment with a median had a compliance rate of 86.4% in the field study. This is similar to results reported by other researchers (*Shurbutt 2009*). The extra sign and RRFB in the median increases visibility of the crossing but it also increases the cost compared to RRFBs installed on both sides of the road as additional posts are required. The RRFB treatment with a median is the recommended installation and should be used in situations with obstructed visibility.

The RRFBs without a median had a compliance rate of 75.9% in the field testing. The City of Springfield reported that the cost of RRFBs is slightly greater than traditional beacon treatments. Because of the high compliance rates compared to beacon treatments in the literature review (*Shurbutt 2009*) and similar compliance found in the field testing, it is recommended that RRFBs be considered over traditional treatments such as beacons when a crossing warrants an upgraded treatment.

The field study results showed that the overhead beacon treatment in Philomath had a compliance rate of 77.1%. The literature review showed that overhead beacon treatments had a much lower compliance rate compared to an RRFB treatment installed at the same crossing (*Shurbutt 2009*). Another study showed a large range of compliance rates for overhead beacons, from the 15.5% to the 71.2% (*Fitzpatrick et al. 2006*).

7.2 ROADWAY CHARACTERISTICS AND ENVIRONMENTAL CONSIDERATIONS

The literature review and field testing identified several factors that have shown to increase crash rates at pedestrian crossings. This section discusses how the speed limit, median islands, visibility of the crossing treatment, crossing length, traffic volume, and the surrounding environment affect the safety of the crossing.

7.2.1 Posted Speed Limit

Research shows that crash rates increase with higher speeds at uncontrolled crossings (*Zegeer 2006*) and that drivers are less likely to yield to pedestrians when approaching non-signalized crossings at higher speeds (*Gårder 2004*). From the literature review, the RRFB was used in sites with a posted speed of 45 mph or less, with most installed where the speed limit was 35 mph or less. The RRFB installation on Main Street in Springfield with a posted speed of 40 mph had good compliance (86.4%) in the field testing.

Shurbutt *(2009)* recommends using RRFBs as advance warning devices; however the initial studies showed a -0.1% decrease in driver compliance and a slight increase in yielding distance when a RRFB is used as an advance warning sign. RRFBs have been installed at two intersections on the Bend Parkway where the posted speed is 45 mph. The installations include RRFBs as advance warning devices and at the crosswalk along with advance stop bars and signage, a high visibility ladder striped crosswalk, and “do not pass” markings in advance of the crosswalks. This unique installation is located on a roadway with limited access and high visibility and has shown an excellent increase in compliance.

Research has shown that the effectiveness of PHBs does not change with speed (*Fitzpatrick 2006*), but similar research has not been done for RRFBs. For this reason, it is recommended that RRFBs be installed at locations with posted speed limits 35 mph or less unless there is high visibility. Both the Springfield site in the field study with a posted speed of 40 mph and the Bend Parkway locations with a posted speed of 45 mph have good visibility and medians and show good compliance. In the case of Bend, there are advance warning RRFBs.

The City of Boulder, Colorado recommends that speeds over 40 mph be reduced to 40 mph, if possible, when an RRFB is being considered or a PHB should be installed (*City of Boulder 2011*).

7.2.2 Median Islands

As described earlier, a raised median island is required for a four-treatment installation of RRFBs. Median islands have been shown to have many other benefits as discussed in the literature review including simplifying the crossing for pedestrians, higher crossing compliance rates, improving efficiency at the crossing, and providing a refuge for trapped pedestrians (*FHWA 2009*). The installation of a median is highly recommended if roadway geometry allows.

7.2.3 Visibility of the Crossing Treatment

For crossing treatments to be effective, they need to be placed in a location where drivers are able to see them. Several things can obstruct the visibility of a crossing or a treatment. Crossings located in visually-cluttered environments such as locations with a large number of signs or vegetation and roads with geometry that limits sight distance need to be designed ensure adequate visibility for motorists. The PHB at E. Burnside and 41st Avenue is located along a winding road with a large number of trees that obstruct the side-mounted signs, but the overhead PHB is still visible as shown below in Figure 7.1.Note the blocked sign on the right edge of the road.

Figure7.1: Winding road and trees along E. Burnside at 41st Avenue

Buses at near side transit stops and heavy vehicles obstruct the visibility of side-mounted treatments making overhead placement of the devices an option to be considered. When possible, the transit stop should be located to the far side of the intersection.

Visibility of the pedestrian is also important; the pedestrian must be clearly conspicuous to all approaching drivers when standing on the curb. The Olympic Street crossing in Springfield in the field study had a large transit lane/shoulder that made it more difficult to notice the pedestrian on the sidewalk. In addition, pedestrian crossings that include large shoulders, wide bike lanes, or a parking lane, separate a pedestrian on the curb from the motorists' field of vision. Curb extensions make pedestrians more visible.

For crossings with obstructed visibility, a median island with RRFBs located in the median should be considered for installation. RRFBs installed on a median increase visibility by maintaining the devices at a height closer to the driver's eye level. Overhead devices are effective if visibility is limited for side-mounted devices and a median island is not feasible. PHBs should be installed if an overhead device is needed, because the reported driver compliance rates for PHBs are higher than RRFBs, however there may be locations where overhead and side-mounted beacons may be a preferred treatment.

7.2.4 Crossing Distance

Longer crossing distances mean more time that pedestrians are in the crossing and exposed to vehicles compared to shorter crossing distances. Research shows that longer crossing distances and crossings with more lanes can be more dangerous than shorter crossings (*Baltes and Chu 2002; Petritsch 2005; Zegeer 2005; Zegeer 2006; Harwood Mar. 2008*). Bike lanes add extra width to a pedestrian crossing and this can be another obstacle. Typical bike lanes are five feet wide and if there are bikes lanes in both directions this can add ten or more feet to the crossing distance. Activation of both RRFBs and PHBs should account for the time that an average pedestrian needs to safely complete the crossing. In determining the timing, the characteristics of the pedestrians likely to use the crossing should be considered. If elderly pedestrians are likely to use the crossing, slower walking speeds should be assumed and the timing should be adjusted accordingly.

More than one lane of traffic in a direction creates an opportunity for a multiple threat situation to occur at crossings. A multiple threat situation is when a vehicle is stopped in one lane at a crossing for a pedestrian and a vehicle behind the stopped vehicle changes lanes to pass the stopped vehicle, not realizing that a pedestrian is in the crossing. Several of these conflicts were noted at the US 30 at Bay Street crossing in Astoria. For crossings with more than two lanes of traffic in one direction, multiple threat issues become even more significant. For crossings with two lanes of traffic in a direction, a pedestrian refuge island large enough for installation of an RRFB is recommended. If this is not feasible, or there are more than two lanes in a direction, a PHB is recommended. The new Oregon Bicycle and Pedestrian Design Guide recommends the use of advance stop bars at mid-block crossings and at uncontrolled intersections on multi-lane roads (*ODOT 2011*).

7.2.5 Traffic Volume

Research shows that higher traffic volumes are associated with more pedestrian crashes at intersections and uncontrolled crossings on arterial and collector roadways (*Zegeer 2006; Harwood 2008*). Higher traffic volumes on roadways produce fewer gaps for pedestrians and make it more challenging for pedestrians to make good choices about when to cross. This can lead to pedestrians making riskier choices on when to complete their crossing. If feasible, the use of a median island to provide a pedestrian refuge and to break up the crossing should be considered.

When there are high traffic volumes and large distances between the travel lane and curb, an enhanced treatment such as a bulb out should be considered to improve the driver line of sight to pedestrians at the curb. In high traffic volume situations, a side-mounted RRFB, preferably with a median should be considered. If a median is not feasible, a PHB is recommended.

They City of Boulder has had RRFB installations for several years and have found that RRFBs may not be appropriate in locations where there is a combination of high traffic and high pedestrian volumes because it can lead to an increase in traffic delays and crashes. PHBs are recommended for these situations (*City of Boulder 2011*).

7.2.6 Surrounding Environment

It is important to consider the environment surrounding a crosswalk when deciding on a pedestrian crossing treatment. Studies have shown several factors that are correlated to higher pedestrian crash rates. Higher crash rates occur around urban areas, shopping centers, schools and parks (*Jensen 1998; Zegeer 2006; Wedagama 2006; Clifton and Kreamer-Fults 2007*). Transit stops, the number of commercial retail properties within 0.1 miles of the crossing, the percentage of neighborhood residents living within 0.25 miles of the intersection that are younger than 18, and the number of non-residential driveways within 50 feet of an intersection are all positively associated with pedestrian crashes (*Harwood 2008; Schneider 2010*).

All of the field study locations were located in an environment that fits one or more of the categories above. The characteristics of the surrounding environment and the number of other environmental factors that are present need to be considered when selecting an appropriate pedestrian crossing treatment. For crossings that are in an environment with one or more of the above characteristics, an upgraded treatment such as an RRFB should be considered. Installation of RRFBs on a median should be considered if feasible and, in some circumstances, a PHB device should be installed. Additionally consideration of using consistent pedestrian crossing treatments is suggested.

7.3 COST CONSIDERATIONS

Every installation of pedestrian crossing treatments has unique costs associated with them. There may be opportunity costs associated with providing a pedestrian crossing treatment in conjunction with other roadway improvements. Overhead-mounted devices usually cost more than side-mounted devices due to the cost of overhead hardware and extra construction costs related to traffic control. Side-mounted device hardware is usually less expensive than overhead-mounted device hardware. It is strongly recommended that RRFB be installed with a raised median on roadways that have more than one travel lane in each direction. In general the off-the-shelf hardware for a RRFB is considerably less expensive than a PHB, and only slightly more expensive than a standard beacon. This is particularly important if there are several locations that are candidates for some type of treatment.

7.4 RECOMMENDED GUIDELINES

The 2009 MUTCD includes installation guidelines for PHBs and the FHWA provides installation guidance for RRFBs. Additional guidance is provided that is based on the literature review and field study.

7.4.1 Posted Speed Limit

RRFBs are recommended for roadways with speed limits of 35 mph or less. RRFBs should be considered for posted speeds up to 40 mph if there is clear visibility of the crossing and a median island is present. The City of Boulder Colorado recommends that speed limits of 45 mph or more should be evaluated to lowering the speed to 40 mph if an RRFB installation is to be considered, otherwise a PHB is recommended. In Oregon, the Bend Parkway, which has a posted speed of 45 mph, has two unique RRFB installations that use the RRFB as an advance warning sign and additional pavement markings as part of the installation and compliance is very good.

PHBs can be considered for crossings on roadways with speed limits in excess of 40 mph following the guidance in the MUTCD.

7.4.2 Median Islands

A median island should be required with RRFBs installations where the posted speed is above 35 mph and provided wherever the roadway geometry permits. The RRFB treatments installed in the median and have several benefits at pedestrian crossings.

7.4.3 Visibility

RRFBs on a median or an overhead PHB should be installed at crossings with obstructed visibility for side-mounted devices. Obstructions include near side transit stops, trees, visual clutter, roadway geometry, and a large volume of heavy vehicles. A PHB should be considered if a median is not feasible. An RRFB or a side-mounted PHB is recommended for crossings with clear visibility.

RRFBs should be installed on a median if there is a significant separation such as a large shoulder, parking lane, bike lane or transit only lane between the travel lane and edge of the curb that separates the pedestrian from the field of vision of the driver. A bulbout is recommended if feasible.

7.4.4 Crossing Distance

To avoid multiple threat situations, a median treatment should be considered if there is long crossing distance that includes more than one vehicle lane in each direction. A PHB is recommended if a median treatment is not feasible.

7.4.5 Traffic Volume

The City of Boulder uses 1,500 vehicles per day as a baseline volume for any crossing treatment with the caveat, that at school crossings where the peak hour vehicle traffic may exceed 150 vehicles per hour or 10% of the ADT they can be considered as well. Further school locations are defined where 10 or more student pedestrians are crossing per hour (*City of Boulder 2011*).

In general traffic engineering practice, higher ADT thresholds such as an ADT of 5,500 for crossings with no medians, and 9,000 for crossing with a median are usually considered as baseline volumes for an advance treatment such as an RRFB. This corresponds to an expected wait time in excess of 45 seconds (LOS F) for a pedestrian waiting for a 15 second gap in traffic during the peak hour.

7.4.6 Pedestrian Crossings

The number and type of pedestrians using the crossing is a consideration as well. A minimum number of 20 pedestrians using the crosswalk in an hour should be considered for an upgraded treatment such as an RRFB. If a high number of vulnerable pedestrians, such as persons 65 and over or under 18, 10 pedestrians in an hour should be considered the minimum threshold for installing an upgraded treatment. However, recorded pedestrian-involved crashes may be justification for considering a crossing where there are lower pedestrian volumes.

7.4.7 Surrounding Environment

A RRFB treatment should be considered if there are a substantial number of pedestrians using the crossing as would often be the case in the proximity of parks, schools, and shopping centers In urban areas where there are a high number of at-risk populations such as those under 18 and the elderly a RRFB should be considered, especially if the crossing is within 50 feet of a non-residential driveway.

When feasible, transit stops should be located on the far side of a pedestrian crossing. If there is a near-side bus stop that cannot be relocated an overhead PHB is recommended.

7.4.8 Combination of Factors

For crossings with more than one of the environmental characteristics described above, or where a combination of roadway characteristics are present it may be appropriate to install a PHB or RRFBs on a median with advance heads. For example, if the crossing is on a road with two or more lanes of traffic in both directions and is near a park, a four-device RRFB may be more appropriate than a two device RRFB. A PHB, either side-mounted or overhead should be considered for crossings with additional considerations in high risk environments.

7.4.9 Other Considerations

To increase the visibility and safety for vehicles and pedestrians at crossings, additional features should be considered when installing RRFBs and PHBs. These include:

- Advance devices
- Advance stop bars and signage
- No lane change markings
- Ladder crosswalks/high visibility crossings
- Message communication to pedestrians

7.5 SELECTION OF A TREATMENT

It is assumed that before selecting a crossing treatment the following activities have been completed: an engineering study, a crash history analysis, and basic calculations for MUTCD crossing treatment warrants. After completion of these steps, additional considerations for the selecting of crossing treatments have been identified and incorporated in the decision matrix shown in Figure 7.2.

Users begin at the top category, which is the posted speed limit, and work down considering all of the categories until they reach the suggested treatment level. Suggested treatments were developed considering all the roadway characteristics and environmental aspects. The matrix visually shows how combinations of factors may justify a higher compliance treatment. Engineering judgment should be used in selecting the appropriate treatment for each crossing. This matrix is not designed to cover all situations. The Bend Parkway approach of using additional RRFBs as advance warning signs is an example of an application of that deviates from the matrix.

7.5.1 Terminology

The terminology used in the decision tree matrix is described below.

Speed: It has been assumed that at speeds greater than 40 mph a pedestrian crossing treatment that has higher compliance such as a PHB or full signal is required. At speeds of 40 mph or less, there are a number of pedestrian treatment options.

Median: It is assumed that median refers to raised medians.

Obstructed Visibility: In general, this refers to obstructions to the driver's field of vision that prevent the driver from seeing side-mounted signs or pedestrians at the edge of the roadway. It should be noted that the driver's cone of vision decreases as speed increases.

More than 3 lanes or high traffic volumes: This addresses whether there are sufficient gaps in traffic for a pedestrian to cross the road. As the number of lanes and traffic volumes increase, there are fewer gaps for pedestrians to cross the roadway.

High-Risk Surrounding Environment: This refers to surrounding land use patterns that may produce visual clutter. The traditional traffic analysis and warrants do not always consider environmental features that contribute to the need for pedestrian crossing treatments. Typical factors include: transit stops, retail and housing, schools, recreation and senior centers, and schools that can all be pedestrian traffic generators, and can include more vulnerable pedestrians, such as people with disabilities or young children.

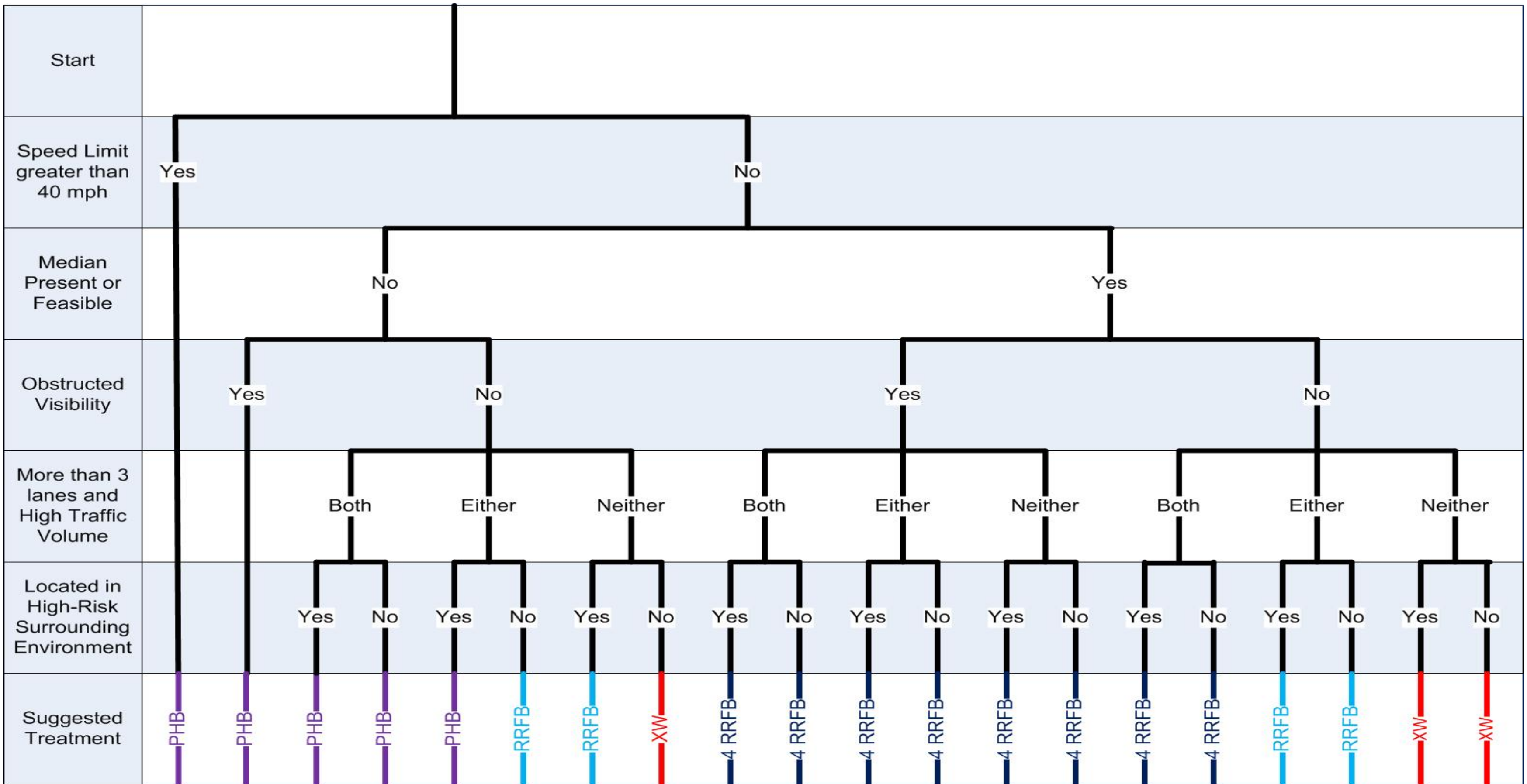
Suggested Treatments:

PHB: Pedestrian Hybrid Beacon

4 RRFB: RRFBs mounted at the edge of the road and on the median facing each direction of travel. This installation requires for posts.

RRFB: RRFB mounted at the edge of the road with no median present.

XW is a marked cross walk, but does not include any beacons or flashing warning devices.



High Risk Surrounding Environment (check those that apply)

- □ Near Side Transit Stop
- □ Visual Clutter
- □ Schools
- □ Senior/Recreation Center
- □ Shopping

PHB: Pedestrian Hybrid Beacon
RRFB: Non-median installation of RRFB
4 RRFB: Median installation of RRFB
XW: Crosswalk

Figure 7.2: Crosswalk treatment decision matrix

8.0 SUMMARY AND CONCLUSIONS

8.1 SUMMARY

The review of the literature conducted as part of the project has shown that PHBs and RRFBs are highly effective alternative pedestrian traffic control devices. The literature review also showed that PHBs and RRFBs initially were installed in particular regions of the country, however this is changing and both types of devices are being installed much more widely as alternatives to the traditional pedestrian-activated flashing beacon.

The MUTCD and other traffic control guidance documents generally use the volume of traffic volume and number of pedestrians as a warrant for the deployment of a device. The limited field data collection and field studies conducted as part of this project showed that there are underlying environmental impacts that affect the effectiveness of these devices. These impacts should also be considered. The most significant is the need to consider surrounding land use, visual clutter and the placement of near side bus stops at pedestrian crossings.

The field study conducted in this project was designed to compare side- and overhead-mounted beacons and RRFBs. The field study results indicated that the environment surrounding the crossing has an impact on compliance and that the presence of a median can increase compliance.

The PHB study verified that drivers are confused about what these devices are and how they operate. It is strongly recommended that a Public Education program be provided by a local jurisdiction when these devices are deployed for the first time in an area. Including information about these devices as well as RRFBs on the ODOT website should be considered.

The Guidelines that have been developed as part of this project were based on the literature review and the Oregon field study. The major recommendation is that RRFBs be installed on medians when side-mounted devices are considered and at locations with posted speeds of 40 mph or less unless additional features such as stripping, signing , and advance warning RRFBs are used. In areas where high compliance is required and where a side-mounted device is not possible, such as locations with near side transit stops, heavy vehicles, an overhead PHB is recommended. For the first deployment of a PHB in an area, a public education program is recommended during the early deployment of the PHB.

A decision tree matrix is a visual display of the guidelines, but underlying this is a requirement for conducting an engineering study at all sites, adhering to traffic engineering warrants, and uing engineering judgment.

8.2 CONCLUSIONS

These guidelines are designed to support existing traffic engineering design manuals and the associated warrants. The deployment of alternative pedestrian traffic control devices must be consistent and respond to the needs of the local community. It is important, that when new technologies or new applications of existing technologies are deployed that they be evaluated over time to determine the effectiveness of the treatment.

For any application it is important to evaluate the site to determine not only the traditional engineering factors such as posted speed limits, vehicle and pedestrian volumes, and roadway geometry but also surrounding land use, vegetation, transit stops, and type and number of heavy vehicles. A longitudinal study may also reveal unanticipated considerations. It is always good engineering practice to conduct before and after studies and to insure that the new technology is performing as it was anticipated.

8.3 FUTURE STUDIES

The following issues have been identified as potential topics for future research:

- Compare effectiveness of the flashing sequence used in the Portland PHBs with that described in the MUTCD.
- Study the effectiveness of the side-mounted PHB in Klamath Falls.
- Investigate the use of RRFBs at Roundabouts.
- Complete a comprehensive evaluation of RRFB installations in Oregon after installations have been in place for several years.

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APPENDIX A:
MUTCD CHAPTER 4F: PEDESTRIAN HYBRID BEACONS

CHAPTER 4F. PEDESTRIAN HYBRID BEACONS

Section 4F.01 Application of Pedestrian Hybrid Beacons

Support:

01 A pedestrian hybrid beacon is a special type of hybrid beacon used to warn and control traffic at an unsignalized location to assist pedestrians in crossing a street or highway at a marked crosswalk.

Option:

02 A pedestrian hybrid beacon may be considered for installation to facilitate pedestrian crossings at a location that does not meet traffic signal warrants (see Chapter 4C), or at a location that meets traffic signal warrants under Sections 4C.05 and/or 4C.06 but a decision is made to not install a traffic control signal.

Standard:

03 **If used, pedestrian hybrid beacons shall be used in conjunction with signs and pavement markings to warn and control traffic at locations where pedestrians enter or cross a street or highway. A pedestrian hybrid beacon shall only be installed at a marked crosswalk.**

Guidance:

04 *If one of the signal warrants of Chapter 4C is met and a traffic control signal is justified by an engineering study, and if a decision is made to install a traffic control signal, it should be installed based upon the provisions of Chapters 4D and 4E.*

05 *If a traffic control signal is not justified under the signal warrants of Chapter 4C and if gaps in traffic are not adequate to permit pedestrians to cross, or if the speed for vehicles approaching on the major street is too high to permit pedestrians to cross, or if pedestrian delay is excessive, the need for a pedestrian hybrid beacon should be considered on the basis of an engineering study that considers major-street volumes, speeds, widths, and gaps in conjunction with pedestrian volumes, walking speeds, and delay.*

06 *For a major street where the posted or statutory speed limit or the 85th-percentile speed is 35 mph or less, the need for a pedestrian hybrid beacon should be considered if the engineering study finds that the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding total of all pedestrians crossing the major street for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure 4F-1 for the length of the crosswalk.*

07 *For a major street where the posted or statutory speed limit or the 85th-percentile speed exceeds 35 mph, the need for a pedestrian hybrid beacon should be considered if the engineering study finds that the plotted point representing the vehicles per hour on the major street (total of both approaches) and the corresponding total of all pedestrians crossing the major street for 1 hour (any four consecutive 15-minute periods) of an average day falls above the applicable curve in Figure 4F-2 for the length of the crosswalk.*

08 *For crosswalks that have lengths other than the four that are specifically shown in Figures 4F-1 and 4F-2, the values should be interpolated between the curves.*

Section 4F.02 Design of Pedestrian Hybrid Beacons

Standard:

01 **Except as otherwise provided in this Section, a pedestrian hybrid beacon shall meet the provisions of Chapters 4D and 4E.**

02 **A pedestrian hybrid beacon face shall consist of three signal sections, with a CIRCULAR YELLOW signal indication centered below two horizontally aligned CIRCULAR RED signal indications (see Figure 4F-3).**

03 **When an engineering study finds that installation of a pedestrian hybrid beacon is justified, then:**

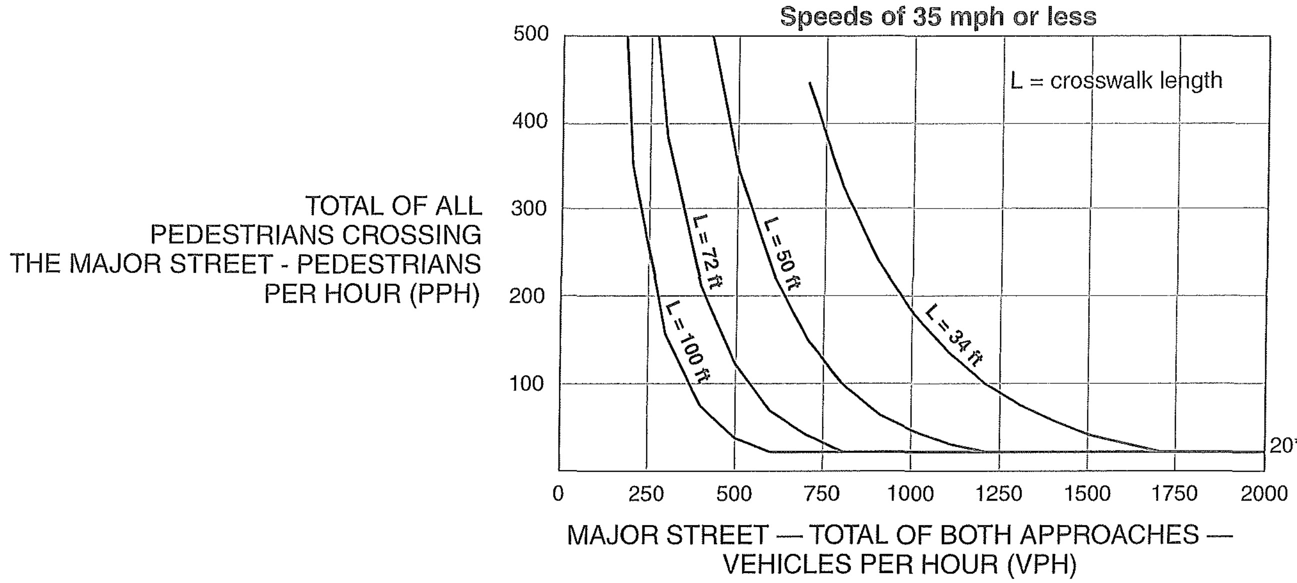
- **A. At least two pedestrian hybrid beacon faces shall be installed for each approach of the major street,**
- **B. A stop line shall be installed for each approach to the crosswalk,**
- **C. A pedestrian signal head conforming to the provisions set forth in Chapter 4E shall be installed at each end of the marked crosswalk, and**
- **D. The pedestrian hybrid beacon shall be pedestrian actuated.**

Guidance:

04 *When an engineering study finds that installation of a pedestrian hybrid beacon is justified, then:*

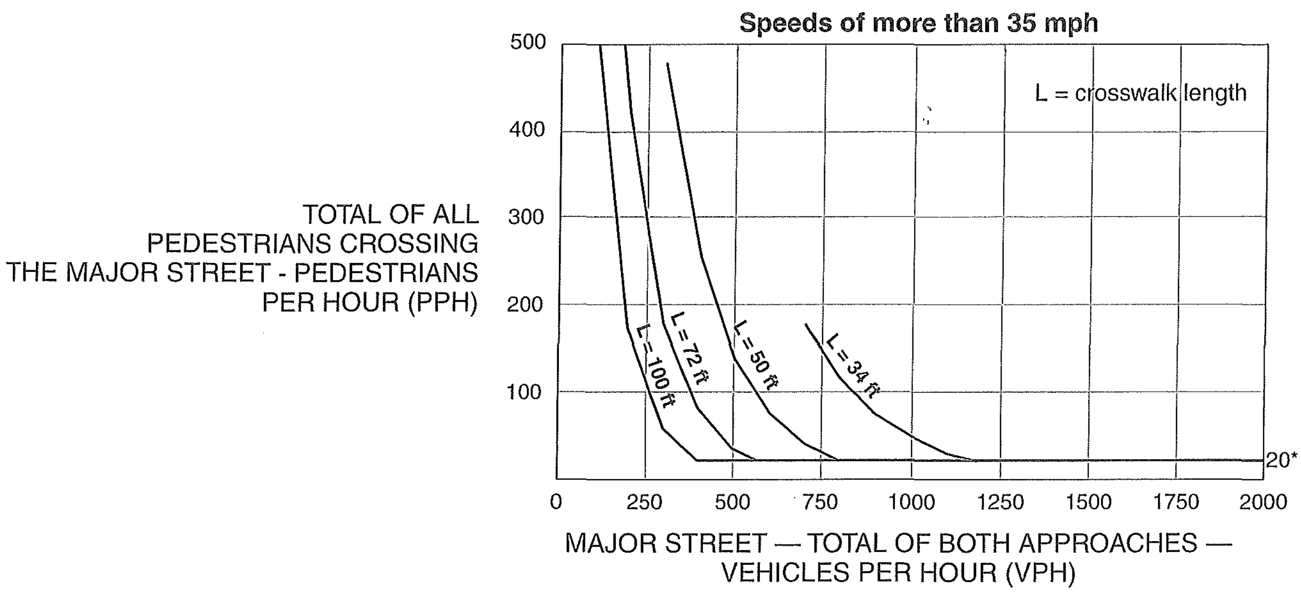
- *A. The pedestrian hybrid beacon should be installed at least 100 feet from side streets or driveways that are controlled by STOP or YIELD signs,*

Figure 4F-1. Guidelines for the Installation of Pedestrian Hybrid Beacons on Low-Speed Roadways



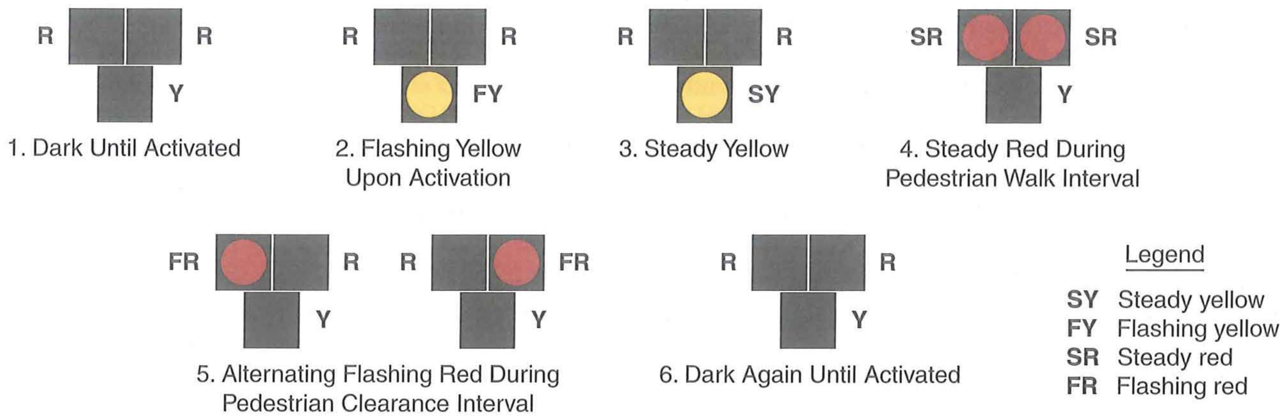
* Note: 20 pph applies as the lower threshold volume

Figure 4F-2. Guidelines for the Installation of Pedestrian Hybrid Beacons on High-Speed Roadways



* Note: 20 pph applies as the lower threshold volume

Figure 4F-3. Sequence for a Pedestrian Hybrid Beacon



B. Parking and other sight obstructions should be prohibited for at least 100 feet in advance of and at least 20 feet beyond the marked crosswalk, or site accommodations should be made through curb extensions or other techniques to provide adequate sight distance,

C. The installation should include suitable standard signs and pavement markings, and

D. If installed within a signal system, the pedestrian hybrid beacon should be coordinated.

05 *On approaches having posted or statutory speed limits or 85th-percentile speeds in excess of 35 mph and on approaches having traffic or operating conditions that would tend to obscure visibility of roadside hybrid beacon face locations, both of the minimum of two pedestrian hybrid beacon faces should be installed over the roadway.*

06 *On multi-lane approaches having a posted or statutory speed limits or 85th-percentile speeds of 35 mph or less, either a pedestrian hybrid beacon face should be installed on each side of the approach (if a median of sufficient width exists) or at least one of the pedestrian hybrid beacon faces should be installed over the roadway.*

07 *A pedestrian hybrid beacon should comply with the signal face location provisions described in Sections 4D.11 through 4D.16.*

Standard:

08 **A CROSSWALK STOP ON RED (symbolic circular red) (R10-23) sign (see Section 2B.53) shall be mounted adjacent to a pedestrian hybrid beacon face on each major street approach. If an overhead pedestrian hybrid beacon face is provided, the sign shall be mounted adjacent to the overhead signal face.**

Option:

09 A Pedestrian (W11-2) warning sign (see Section 2C.50) with an AHEAD (W16-9P) supplemental plaque may be placed in advance of a pedestrian hybrid beacon. A warning beacon may be installed to supplement the W11-2 sign.

Guidance:

10 *If a warning beacon supplements a W11-2 sign in advance of a pedestrian hybrid beacon, it should be programmed to flash only when the pedestrian hybrid beacon is not in the dark mode.*

Standard:

11 **If a warning beacon is installed to supplement the W11-2 sign, the design and location of the warning beacon shall comply with the provisions of Sections 4L.01 and 4L.03.**

Section 4F.03 Operation of Pedestrian Hybrid Beacons

Standard:

01 **Pedestrian hybrid beacon indications shall be dark (not illuminated) during periods between actuations.**

02 **Upon actuation by a pedestrian, a pedestrian hybrid beacon face shall display a flashing CIRCULAR yellow signal indication, followed by a steady CIRCULAR yellow signal indication, followed by both steady CIRCULAR RED signal indications during the pedestrian walk interval, followed by alternating flashing CIRCULAR RED signal indications during the pedestrian clearance interval (see Figure 4F-3). Upon termination of the pedestrian clearance interval, the pedestrian hybrid beacon faces shall revert to a dark (not illuminated) condition.**

03 **Except as provided in Paragraph 4, the pedestrian signal heads shall continue to display a steady UPRAISED HAND (symbolizing DONT WALK) signal indication when the pedestrian hybrid beacon faces are either dark or displaying flashing or steady CIRCULAR yellow signal indications. The pedestrian signal heads shall display a WALKING PERSON (symbolizing WALK) signal indication when the pedestrian hybrid beacon faces are displaying steady CIRCULAR RED signal indications. The pedestrian signal heads shall display a flashing UPRAISED HAND (symbolizing DONT WALK) signal indication when the pedestrian hybrid beacon faces are displaying alternating flashing CIRCULAR RED signal indications. Upon termination of the pedestrian clearance interval, the pedestrian signal heads shall revert to a steady UPRAISED HAND (symbolizing DONT WALK) signal indication.**

Option:

04 Where the pedestrian hybrid beacon is installed adjacent to a roundabout to facilitate crossings by pedestrians with visual disabilities and an engineering study determines that pedestrians without visual disabilities can be allowed to cross the roadway without actuating the pedestrian hybrid beacon, the pedestrian signal heads may be dark (not illuminated) when the pedestrian hybrid beacon faces are dark.

Guidance:

05 *The duration of the flashing yellow interval should be determined by engineering judgment.*

Standard:

06 **The duration of the steady yellow change interval shall be determined using engineering practices.**

Guidance:

07 *The steady yellow interval should have a minimum duration of 3 seconds and a maximum duration of 6 seconds (see Section 4D.26). The longer intervals should be reserved for use on approaches with higher speeds.*

APPENDIX B:
FHWA—INTERMIM APPROVAL FOR OPTIONAL USE OF RECTANGULAR RAPID FLASHING BEACONS

U.S. Department of Transportation
Federal Highway Administration

Memorandum

Sent via Electronic Mail

Subject: **INFORMATION**: MUTCD – Interim Approval for Optional Use of Rectangular Rapid Flashing Beacons (IA-11)

Date: July 16, 2008

From: Anthony T. Furst
Acting Associate Administrator
for Operations

Reply to
Attn. of: HOTO-1

To: Associate Administrators
Chief Counsel
Acting Chief Financial Officer
Directors of Field Services
Federal Lands Highway Division Engineers
Resource Center Director
Division Administrators

Purpose: The purpose of this memorandum is to issue an Interim Approval for the optional use of Rectangular Rapid Flashing Beacons (RRFB) as warning beacons under certain limited conditions. Interim Approval allows interim use, pending official rulemaking, of a new traffic control device, a revision to the application or manner of use of an existing traffic control device, or a provision not specifically described in the Manual on Uniform Traffic Control Devices (MUTCD).

Background: The Florida Department of Transportation, in conjunction with the city of St. Petersburg, has requested that the Federal Highway Administration (FHWA) issue an Interim Approval to allow the use of RRFBs as warning beacons to supplement standard pedestrian crossing and school crossing warning signs at crossings across uncontrolled approaches. The RRFB does not meet the current standards for flashing warning beacons as contained in the 2003 edition of the MUTCD, Chapter 4K which requires a warning beacon to be round in shape and either 8 or 12 inches in diameter, to flash at a rate of approximately once per second, and to be located no less than 12 inches outside the nearest edge of the warning sign it supplements. The RRFB uses rectangular-shaped high-intensity LED-based indications, flashes rapidly in a wig-wag "flickering" flash pattern, and is mounted immediately between the crossing sign and the sign's supplemental arrow plaque.

Research on the RRFB: The city of St. Petersburg has completed experimentation with the RRFB at 18 pedestrian crosswalks across uncontrolled approaches and has submitted their final report. In addition to "before" data, the city collected "after" data at intervals for 1 year at all sites and for 2 years at the first 2 implemented sites. For the first 2 sites, the city collected data for overhead and ground-mounted pedestrian crossing signs supplemented with standard round yellow flashing beacons, for comparison purposes, before the RRFBs were installed. The data show very high rates of motorist "yield to pedestrians" compliance, mostly in the high 80s to close to 100 percent, in comparison to far lower rates (in the 15 to 20 percent range) for standard beacons. The very high yielding rates are sustained even after 2 years in operation, and no identifiable negative effects have been found. The RRFB's very high compliance rates are previously unheard of for any device other than a full traffic signal and a "HAWK" hybrid signal, both of which stop traffic with steady red signal indications. The St. Petersburg data also shows that drivers exhibit yielding behavior much further in advance of the crosswalk with RRFB than with standard round yellow flashing beacons. These data clearly document very successful and impressive positive experience with the RRFBs at crosswalks in that city.

In addition to the St. Petersburg locations, experimentation is underway at 3 sites in Miami-Dade County, FL, 4 sites in Largo, FL, and 2 sites in Las Cruces, NM, and RRFBs are being installed at 3 sites in northern Illinois. Additionally, the District of Columbia has installed RRFBs at one crosswalk and plans to request experimentation with RRFB at several sites. Data from locations other than St. Petersburg is limited but does show results very similar to those found in St. Petersburg. A study of 2 RRFB locations in Miami-Dade County, FL, reported in a TRB paper, found that evasive conflicts between drivers and pedestrians and the percentage of pedestrians trapped in the center of an undivided road because of a non-yielding driver in the second half of the roadway were both significantly reduced to negligible levels. Data so far from the one RRFB site in DC shows driver yielding compliance rates increased from 26 percent to 74 percent after 30 days in operation and advance yielding distances also increased comparable to the St. Petersburg results.

FHWA Evaluation of Results: The Office of Transportation Operations has reviewed the available data and considers the RRFB to be highly successful for the applications tested (uncontrolled crosswalks). The RRFB offers significant potential safety and cost benefits, because it achieves very high rates of compliance at a very low relative cost in comparison to other more restrictive devices that provide comparable results, such as full midblock signalization. The components of RRFB are not proprietary and can be assembled by any jurisdiction with off-the-shelf hardware. The FHWA believes that the RRFB has a low risk of safety or operational concerns. However, because proliferation of RRFBs in the roadway environment to the point that they become ubiquitous could decrease their effectiveness, use of RRFBs should be limited to locations with the most critical safety concerns, such as pedestrian and school crosswalks across uncontrolled approaches, as tested in the experimentation.

At a recent meeting of the National Committee on Uniform Traffic Control Devices, the Signals Technical Committee voted to endorse the future inclusion of the RRFB for uncontrolled crosswalks into the MUTCD and recommended that FHWA issue an Interim Approval for RRFB. The FHWA believes this indicates a consensus in the practitioner community in support of optional use of RRFB. This Interim Approval does not create a new mandate compelling installation of RRFB but will allow agencies to install this type of flashing beacon, pending official MUTCD rulemaking, to provide a degree of enhanced pedestrian safety at uncontrolled crosswalks that has been previously unattainable without costly and delay-producing full traffic signalization.

Conditions of Interim Approval: The FHWA will grant Interim Approval for the optional use of the RRFB as a warning beacon to supplement standard pedestrian crossing or school crossing signs at crosswalks across uncontrolled approaches to any jurisdiction that submits a written request to the Office of Transportation Operations. A State may request Interim Approval for all jurisdictions in that State. Jurisdictions using RRFB under this Interim Approval must agree to comply with the technical conditions detailed below, to maintain an inventory list of all locations where the devices are placed, and to comply with Item F at the bottom of Page 1A-6 of the 2003 MUTCD, Section 1A.10 which requires:

> "An agreement to restore the site(s) of the Interim Approval to a condition that complies with the provisions in this Manual within 3 months following the issuance of a Final Rule on this traffic control device. This agreement must also provide that the agency sponsoring the Interim Approval will terminate use of the device or application installed under the Interim Approval at any time that it determines significant safety concerns are directly or indirectly attributable to the device or application. The FHWA's Office of Transportation Operations has the right to terminate the interim approval at any time if there is an indication of safety concerns."

1. General Conditions:

   a. An RRFB shall consist of two rapidly and alternately flashed rectangular yellow indications having LED-array based pulsing light sources, and shall be designed, located, and operated in accordance with the detailed requirements specified below.

   b. The use of RRFBs is optional. However, if an agency opts to use an RRFB under this Interim Approval, the following design and operational requirements shall apply, and shall take precedence over any conflicting provisions of the MUTCD for the approach on which RRFBs are used:

2. Allowable Uses:

   a. An RRFB shall only be installed to function as a Warning Beacon (see 2003 MUTCD Section 4K.03).

   b. An RRFB shall only be used to supplement a W11-2 (Pedestrian) or S1-1 (School) crossing warning sign with a diagonal downward arrow (W16-7p) plaque, located at or immediately adjacent to a marked crosswalk.

   c. An RRFB shall not be used for crosswalks across approaches controlled by YIELD signs, STOP signs, or traffic control signals. This prohibition is not applicable to a crosswalk across the approach to and/or egress from a roundabout.

   d. In the event sight distance approaching the crosswalk at which RRFBs are used is less than deemed necessary by the engineer, an additional RRFB may be installed on that approach in advance of the crosswalk, as a Warning Beacon to supplement a W11-2 (Pedestrian) or S1-1 (School) crossing warning sign with an AHEAD: (W16-9p) plaque. This additional RRFB shall be supplemental to and not a replacement for RRFBs at the crosswalk itself.

3. Sign/Beacon Assembly Locations:

   a. For any approach on which RRFBs are used, two W11-2 or S1-1 crossing warning signs (each with RRFB and W16-7p plaque) shall be installed at the crosswalk, one on the right-hand side of the roadway and one on the left-hand side of the roadway. On a divided highway, the left-hand side assembly should be installed on the median, if practical, rather than on the far left side of the highway.

   b. An RRFB shall not be installed independent of the crossing signs for the approach the RRFB faces. The RRFB shall be installed on the same support as the associated W11-2 (Pedestrian) or S1-1 (School) crossing warning sign and plaque.

4. Beacon Dimensions and Placement in Sign Assembly:

   a. Each RRFB shall consist of two rectangular-shaped yellow indications, each with an LED-array based light source. Each RRFB indication shall be a minimum of approximately 5 inches wide by approximately 2 inches high.

   b. The two RRFB indications shall be aligned horizontally, with the longer dimension horizontal and with a minimum space between the two indications of approximately seven inches (7 in), measured from inside edge of one indication to inside edge of the other indication.

c. The outside edges of the RRFB indications, including any housings, shall not project beyond the outside edges of the W11-2 or S1-1 sign.

d. As a specific exception to 2003 MUTCD Section 4K.01 guidance, the RRFB shall be located between the bottom of the crossing warning sign and the top of the supplemental downward diagonal arrow plaque (or, in the case of a supplemental advance sign, the AHEAD plaque), rather than 12 inches above or below the sign assembly. (See attached example photo.)

5. Beacon Flashing Requirements:

a. When activated, the two yellow indications in each RRFB shall flash in a rapidly alternating "wig-wag" flashing sequence (left light on, then right light on).

b. As a specific exception to 2003 MUTCD Section 4K.01 requirements for the flash rate of beacons, RRFBs shall use a much faster flash rate. Each of the two yellow indications of an RRFB shall have 70 to 80 periods of flashing per minute and shall have alternating but approximately equal periods of rapid pulsing light emissions and dark operation. During each of its 70 to 80 flashing periods per minute, one of the yellow indications shall emit two rapid pulses of light and the other yellow indication shall emit three rapid pulses of light.

c. The flash rate of each individual yellow indication, as applied over the full on-off sequence of a flashing period of the indication, shall not be between 5 and 30 flashes per second, to avoid frequencies that might cause seizures.

d. The light intensity of the yellow indications shall meet the minimum specifications of Society of Automotive Engineers (SAE) standard J595 (Directional Flashing Optical Warning Devices for Authorized Emergency, Maintenance, and Service Vehicles) dated January 2005.

6. Beacon Operation:

a. The RRFB shall be normally dark, shall initiate operation only upon pedestrian actuation, and shall cease operation at a predetermined time after the pedestrian actuation or, with passive detection, after the pedestrian clears the crosswalk.

b. All RRFBs associated with a given crosswalk (including those with an advance crossing sign, if used) shall, when activated, simultaneously commence operation of their alternating rapid flashing indications and shall cease operation simultaneously.

c. If pedestrian pushbuttons (rather than passive detection) are used to actuate the RRFBs, a pedestrian instruction sign with the legend PUSH BUTTON TO TURN ON WARNING LIGHTS should be mounted adjacent to or integral with each pedestrian pushbutton.

d. The duration of a predetermined period of operation of the RRFBs following each actuation should be based on the MUTCD procedures for timing of pedestrian clearance times for pedestrian signals.

e. A small light directed at and visible to pedestrians in the crosswalk may be installed integral to the RRFB or push button to give confirmation that the RRFB is in operation.

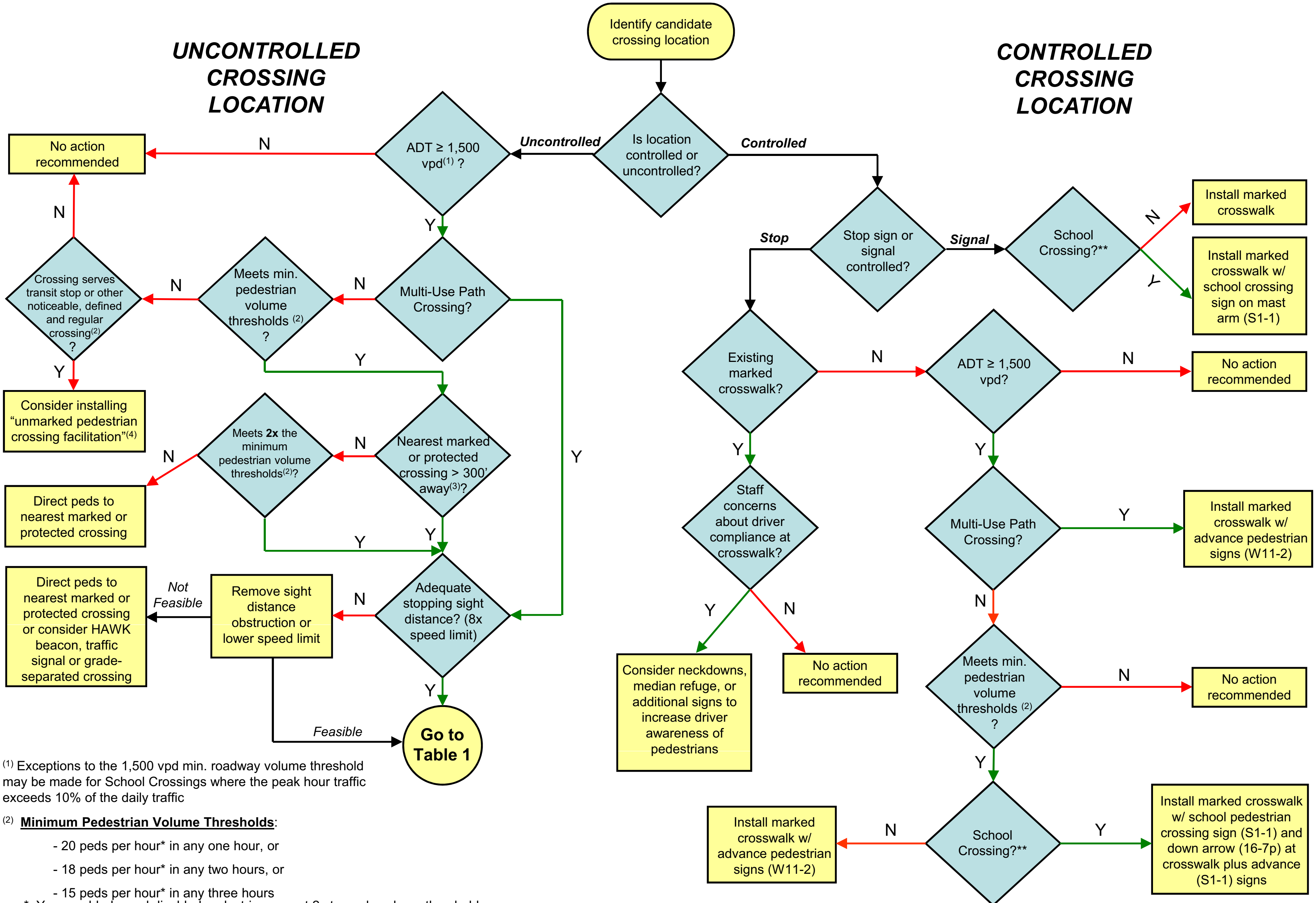
7. Other:

a. Except as otherwise provided above, all other provisions of the MUTCD applicable to Warning Beacons shall apply to RRFBs.

Any questions concerning this Interim Approval should be directed to Mr. Scott Wainwright at **scott.wainwright@dot.gov** or by telephone at 202-366-0857.

Example of RRFB with W1-2 sign and W16-7p plaque at crosswalk across uncontrolled approach. [Photo courtesy of City of St. Petersburg, Florida]

APPENDIX C:
CITY OF BOULDER PEDESTRIAN CROSSING INSTALLATION GUIDELINES



(1) Exceptions to the 1,500 vpd min. roadway volume threshold may be made for School Crossings where the peak hour traffic exceeds 10% of the daily traffic

(2) **Minimum Pedestrian Volume Thresholds**:

- 20 peds per hour* in any one hour, or
- 18 peds per hour* in any two hours, or
- 15 peds per hour* in any three hours

* Young, elderly, and disabled pedestrians count 2x towards volume thresholds

** School Crossing defined as a crossing location where ten or more student pedestrians per hour are crossing.

(3) Distance to nearest marked or protected crossing may be reduced to 200’ in urban conditions, subject to engineering judgment, where 1) the crosswalk does cross any auxiliary lanes, and 2) crossing treatments and crossing activity would not create undue restriction to vehicular traffic operations.

(4) An “unmarked pedestrian crossing facilitation” is any treatment that improves a pedestrian’s ability to cross a roadway, short of the marked, signed and enhanced crossings detailed in Table 1. Installation of this type of pedestrian facilitation is subject to engineering judgment and may include curb ramps and/or a raised median refuge. However, no effort is made to attract pedestrians or recommend that pedestrians cross at this location. The treatments simply provide an improvement for a low volume pedestrian crossing where pedestrians are already crossing and will like continue to cross.

City of Boulder Pedestrian Crossing Treatment Installation Guidelines

Figure 1 – Pedestrian Crossing Treatment Flowchart

Table 1 - Criteria for Crossing Treatments at Uncontrolled Locations

Roadway Configuration	# of lanes crossed to reach a refuge[1]	# of multiple threat lanes[2] per crossing	Roadway ADT and Posted Speed															
			1,500-9,000 vpd				9,000-12,000 vpd				12,000-15,000 vpd				> 15,000 vpd			
			≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph	≤ 30 mph	35 mph	40 mph	≥ 45 mph
2 Lanes (one way street)	2	1	A	B	C	E	A	B	C	E	B	B	C	E	B	C	C	E
2 Lanes (two way street with no median)	2	0	A	B	C	E	A	B	C	E	B	B	C	E	B	C	C	E
3 Lanes w/Raised Median	1 or 2	0 or 1	A	B	D	E	A	C	D	E	B	D	D	E	C	D	D	E
3 Lanes w//Striped Median	3	0 or 1	C	C	D	E	C	C	D	E	C	C	D	E	C	D	D	E
4 Lanes (two way street with no median)	4	2	A	D	D	E	B	D	D	E	B	D	D	E	D	D	D	E
5 Lanes w/Raised Median	2 or 3	2	A	B	D	E	B	C	D	E	B	C	D	E	C	C	D	E
5 Lanes w/Striped Median	5	2	D	D	D	E	D	D	D	E	D	D	D	E	D	D	D	E
6 Lanes (two way street with or without median)	3 to 6	4	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F	F

Notes:

1. Painted medians can never be considered a refuge for a crossing pedestrian. Similarly, a 4 foot wide raised median next to a left turn lane can only be considered a refuge for pedestrians if the left turning volume is less than 20 vehicles per hour (meaning that in most cases the left turn lane is not occupied while the pedestrian is crossing).
2. A multiple threat lane is defined as a through lane where it is possible for a pedestrian to step out from in front of a stopped vehicle in the adjacent travel lane (either through or turn lane).

Treatment Descriptions:

A ***Install marked crosswalk with enhanced road-side signs***

<u>Specific Guidance</u>: Install marked crosswalk with "State Law - Yield to Pedestrian" signs mounted on the side of the roadway with standard (W11-2) advance pedestrian warning signs; use S1-1 signs for School Crossing locations.

B ***Install marked crosswalk with enhanced road-side and in-roadway (bollard mounted) signs***

<u>Specific Guidance</u>: Install marked crosswalk with "State Law - Yield to Pedestrian" signs mounted on the side of the roadway and on in-roadway bollards; use standard (W11-2) advance pedestrian warning signs; use S1-1 signs for School Crossing locations.

C ***Install marked crosswalk with enhanced signs and geometric improvements to increase pedestrian visibility and reduce exposure***

<u>Specific Guidance</u>: For 2 or 3-lane roadways, install marked crosswalk with "State Law - Yield to Pedestrian" signs mounted on the side of the roadway and on in-roadway bollards or median mounted signs; use standard (W11-2) advance pedestrian warning signs; use S1-1 signs for School Crossing locations. Add neckdowns or median refuge islands to shorten the pedestrian crossing distance and increase pedestrian visibility to motorists.

D ***Install marked crosswalk with enhanced signs, pedestrian activated RRFBs, and geometric improvements to increase pedestrian visibility and reduce exposure***

<u>Specific Guidance</u>: Install raised median refuge island (unless it is a one-way street or one already exists) to shorten the pedestrian crossing distance and increase pedestrian visibility to motorists. [If a median refuge can not be constructed on a two-way street, Go To Scenario F]*. Install marked crosswalk with "State Law - Yield to Pedestrian" signs WITH pedestrian activated RRFBs mounted on the side of the roadway and on median mounted signs; use standard (W11-2) advance pedestrian warning signs; use S1-1 signs for School Crossing locations. Consider adding neckdowns at the crossing if on-street parking exists on the roadway and storm drain considerations will allow. [Note: If pedestrian volume falls above the RRFB limit line on Figure 2, consider Hawk beacon, pedestrian traffic signal, or grade-separated crossing.]*

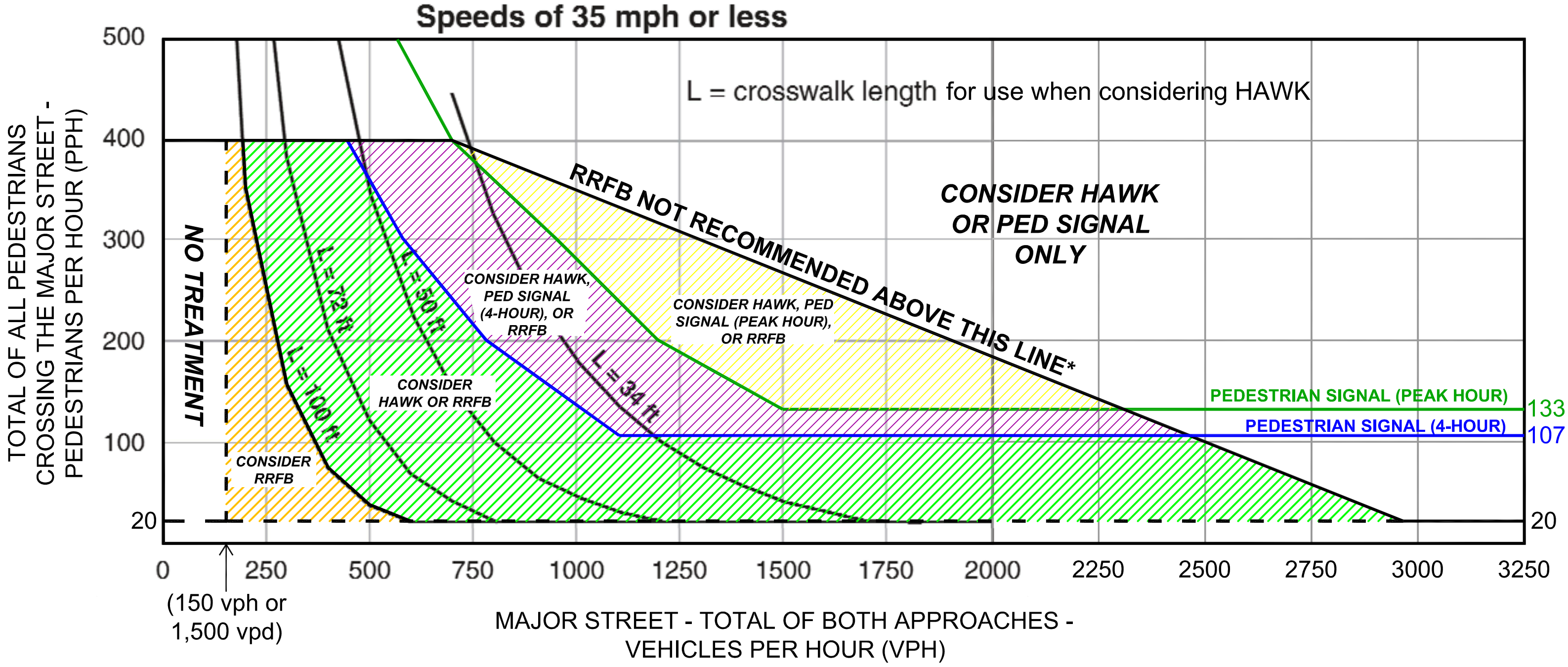
E ***Do not install marked crosswalk at uncontrolled crossing. Determine if the speed limit can be effectively reduced to 40 mph AND a raised refuge median can be installed. If so, utliize Scenario D criteria above. If this is not possible, or if pedestrian volume falls above the RRFB limit line on Figure 2, consider HAWK beacon, pedestrian traffic signal, or grade-separated crossing.***

<u>Specific Guidance</u>: Consider HAWK beacon, pedestrian traffic signal or grade-separated crossing; application of these treatments will consider corridor signal progression, existing grades, phyiscal contraints, and other engieering factors

F ***Do not install marked crosswalk at uncontrolled crossing with 3 or more THROUGH lanes per direction or where the speed limit is ≥ 45 mph and/or there is not a median refuge on a 5-lane crossing. Consider HAWK beacon, pedestrian traffic signal, or grade-separated crossing.***

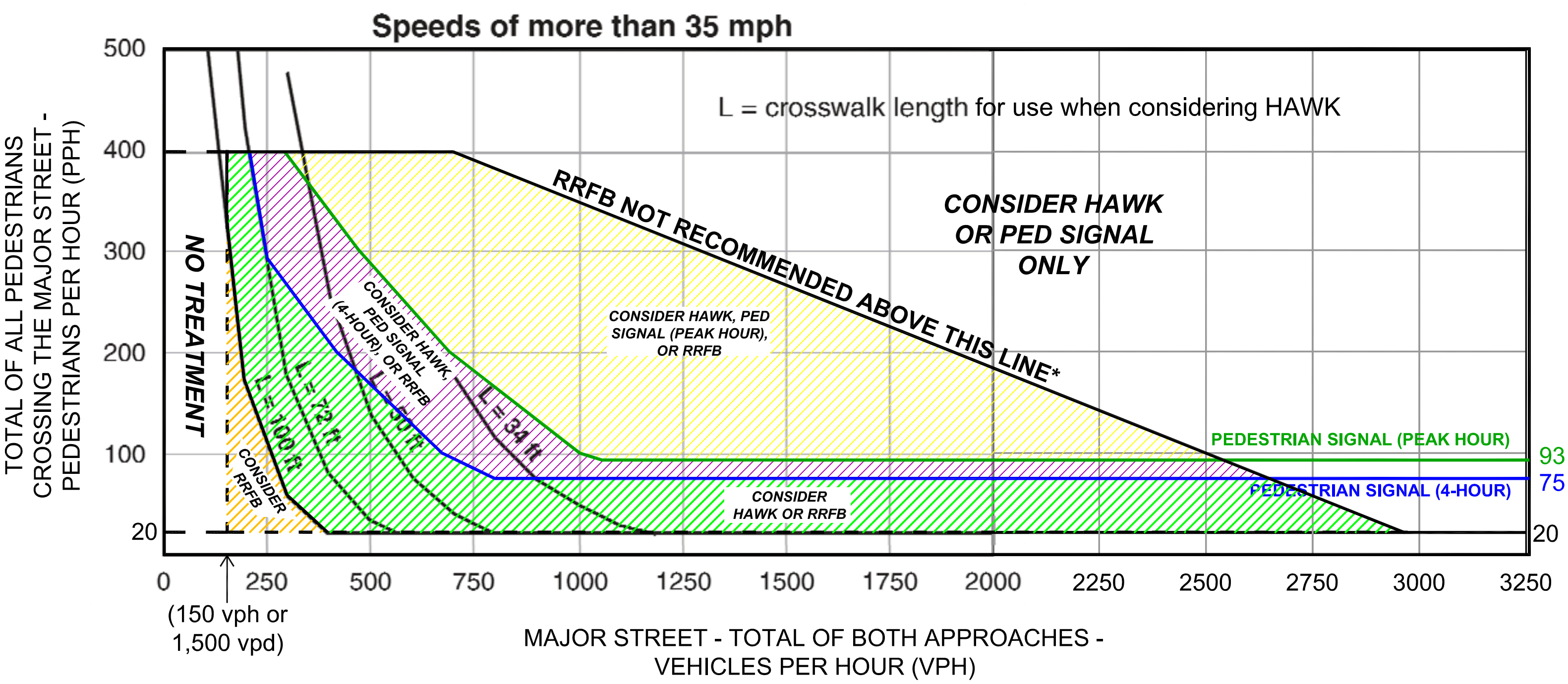
<u>Specific Guidance</u>: Consider HAWK beacon, pedestrian traffic signal or grade-separated crossing; application of these treatments will consider corridor signal progression, existing grades, phyiscal contraints, and other engieering factors

Figure 2a. City of Boulder Guidelines for the Installation of Pedestrian Hybrid (HAWK) Beacons, Pedestrian Signals, or Rectangular Rapid Flash Beacon (RRFB) Signs on Low-Speed Roadways



* RECOMMENDATION BASED ON CITY OF BOULDER SAFETY EVALUATIONS AT EXISTING RRFB SITES AND OBSERVED IMPACTS TO VEHICULAR TRAFFIC OPERATIONS

Figure 2b. City of Boulder Guidelines for the Installation of Pedestrian Hybrid (HAWK) Beacons, Pedestrian Signals, or Rectangular Rapid Flash Beacon (RRFB) Signs on High-Speed Roadways



* RECOMMENDATION BASED ON CITY OF BOULDER SAFETY EVALUATIONS AT EXISTING RRFB SITES AND OBSERVED IMPACTS TO VEHICULAR TRAFFIC OPERATIONS

APPENDIX D:
FIELD DATA COLLECTION FORM

Site: Data Collection Form

SPR 721 Site Documentation Form

Date: ____________________ Time: ____________________

Site: ____________________ Treatment: ____________________

Speed Limit: ____________________ Lanes: ____________________

Median Width (ft): ____________________ Curb to Curb (ft): ____________________

Parking Lane: ____________________ Bike Lane: ____________________

Curb Extension: ____________________ Midblock Crossing: ____________________

Near Sidewalk: ____________________ Far Sidewalk: ____________________

Distance to Transit (ft): ____________________ Distance to Signal: ____________________

Light: ____________________ Weather: ____________________

Signal duration: ____________________ Type of flash: ____________________

Notes: ____________________

Did you take pictures?

* Approaches to crosswalk
* Relevant traffic control devices
* Other Conditions at the site
* Unusual characteristics

Did you sketch the site on the back?

Location:______________

SPR 721 Data Collection Form

Date:______________

Time	Direction		Activation		Pedestrian		Size			Compliance		Conflict	
1	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
2	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
3	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
4	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
5	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
6	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
7	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
8	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
9	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													
10	N	F	Y	N	Stgd	Gen	Ind	Grp	Cls	N__________	F__________	N__________	F__________
Comments:													

APPENDIX E:
PEDESTRIAN HYBRID BEACON SAFETY

1. Have you seen this signal?

1. Yes, I have seen this signal
2. No, I have not seen this signal
3. I am not sure if I have seen this signal

2. Where have you seen this signal? Check all that apply.

1. At an intersection
2. At a rail crossing
3. At a pedestrian crossing
4. At a roundabout
5. Not applicable

Instructions

Please answer the following questions as if you were approaching the signal as a driver

3. What does this Traffic signal mean? Check all that apply

Solid yellow – No flashing

1. You have the right of way and can go
2. You are required to yield
3. You must stop and wait for the appropriate traffic signal
4. A red light is coming next
5. A train is coming

4. What does this Traffic signal mean? Check all that apply

Flashing yellow

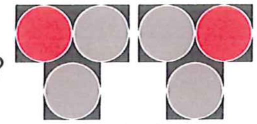
1. You have the right of way and can go
2. You are required to yield
3. You must stop and wait for the appropriate traffic signal
4. A red light is coming next
5. A train is coming

5. What does this Traffic signal mean? Check all that apply

Solid red – No flashing

1. You have the right of way and can go
2. You must stop and make sure roadway is clear before moving
3. You must stop and wait for the appropriate traffic signal
4. A green light is coming next
5. A train is coming

6. What does this Traffic signal mean? Check all that apply



Alternating flashing

1. You have the right of way and can go
2. You must stop and make sure roadway is clear before moving
3. You must stop and wait for the appropriate traffic signal
4. A non flashing red light is coming next
5. A train is coming

7.What does this Traffic signal mean? Check all that apply

No indications lit

1. You have the right of way and can go
2. The power at the signal is out
3. You must stop and wait for the appropriate traffic signal
4. A red light is coming next
5. A yellow light is coming next

8.What signal display will Immediately follow this Indication?

Solid yellow – No flashing

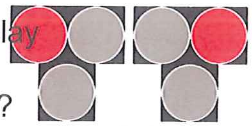
9.What signal display will Immediately follow this Indication?

Flashing yellow

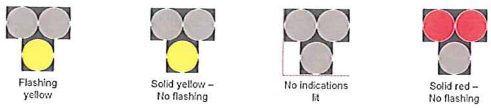
10. What signal display will Immediately follow this Indication?

Solid red – No flashing

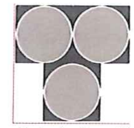
11. What signal display will immediately follow this indication?



Alternating flashing



12.What signal display will Immediately follow this Indication?



No indications lit