Evaluating Driver and Pedestrian Behaviors at Enhanced, Multilane, Midblock Pedestrian Crossings

Case Study in Portland, Oregon

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This study examined driver and pedestrian behaviors at two enhanced midblock pedestrian crossings in Portland, Oregon. One crossing was at a five-lane arterial with a posted speed of 35 mph and featured eight rectangular rapid flash beacon (RRFB) assemblies and a narrow median refuge. The other crossing was at a suburban arterial with a posted speed of 40 mph, four travel lanes, and a two-way left-turn lane. The crossing was enhanced with four RRFB assemblies and a median island with a Z-crossing, or Danish offset, designed to encourage pedestrians to face oncoming traffic before they completed the second stage of their crossing. Approximately 62 h of video was collected at the two locations. A total of 351 pedestrian crossings were analyzed for driver compliance (yielding) rates, pedestrian activation rates, pedestrian delay, and conflict avoidance maneuvers. The suburban arterial crossing was also evaluated to determine its effectiveness at diverting pedestrians to cross at the crossing instead of away from the crosswalk, as well as pedestrian compliance with the Z-crossing. The study found that average driver yield rates at both sites were slightly greater than 90% when the RRFB was activated, consistent with previous studies. RRFB actuation rates ranged from 83% to more than 90%. The results also showed that approximately 52% of all crossings at the marked crosswalk at the second location were made by diverted pedestrians and that the enhanced crossing captured about 82% of all crossings near the crosswalk. Finally, approximately 52% of the pedestrians who used the crosswalk followed the Z-crossing pattern through the median.

In 2010, more than 4,000 pedestrians were killed on public roadways in the United States. Approximately 79% of the fatalities occurred away from intersections (*1*). Providing safe midblock crossings is a priority for many agencies, which often struggle to determine the appropriate crosswalk treatments for each context. As suggested in NCHRP Report 562, a way to improve midblock crossings is to provide enhanced treatments (e.g., design features supplementing standard crosswalk markings, such as rectangular rapid flash beacons (RRFBs) and medians islands) (*2*). These treatments have the potential to reduce crashes (*3*), increase rates of drivers yielding to crossing pedestrians (*4–9*), reduce delay for crossing pedestrians (*4*), consolidate scattered pedestrian crossings to a single location, and improve pedestrian awareness of oncoming vehicles (*10*).

This study examined two marked midblock pedestrian crossings in Portland, Oregon, each of which has RRFBs. Approximately 62 h of video was collected at the two locations and analyzed for various measures of effectiveness, including driver compliance rates, conflict avoidance maneuvers, pedestrian activation rates, and pedestrian delay. A total of 351 pedestrian crossings were analyzed. One site was located in an area where pedestrians have not used a marked crosswalk in the past, so the newly enhanced site was also evaluated to determine its effectiveness at attracting crossing pedestrians. This crossing also featured a Z-pattern cutout in the median island and pedestrian compliance with the Z-crossing was also reviewed.

Although the study examined only two sites with RRFBs, many crossings were observed. The study contributes to the body of research documenting high driver yielding rates. The study also contributes by reviewing pedestrian crossing paths at Z-crossings and examining how many pedestrians were attracted out-of-direction to use the enhanced crossing. These topics have not received much attention in the literature.

PRIOR RESEARCH

RRFBs are a relatively recent innovation for improving the visibility of crossing pedestrians at midblock crosswalks. These devices were approved for use in a 2008 FHWA Interim Approval memorandum (*11*). A description of the operation of the devices and guidelines for their implementation can be found in the FHWA memo.

Much of the literature on RRFBs has focused on driver behavior, in particular, yield rates. Shurbutt et al. completed a study with the largest data set to date on driver yielding rates (*7*). The study examined 22 sites, mostly in Florida, but also two sites in Illinois and one in Washington, D.C. The sites were on a variety of road types, ranging from two to five lanes, with speeds varying from 30 to 40 mph, and average daily traffic (ADT) volumes from approximately 5,000 to 30,000 vehicles. Some sites were examined over a period of up to two years and there were at least 40 observations for each site in each time period. The study found an overall average yielding rate of approximately 83%, with four-beacon installations having a higher average rate (88%) compared with two-beacon installations (81%). The sites that were reviewed over two years show that yielding rates remained relatively high over time.

Two other studies of RRFBs have been completed in Oregon. One of the studies evaluated a total of 207 crossings at three sites

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in Bend and found an average yielding rate of approximately 80% (*6*). The other study reviewed 101 crossings at two sites in Astoria and Springfield, with a combined average yielding rate of about 81% (*5*). Researchers from Western Michigan University evaluated five sites in Michigan, with a total of 60 to 120 observations per site (440 total crossings observed). The researchers found an average yielding rate of 75%, which was only slightly lower than the 77% yielding rate the same study found for sites with pedestrian hybrid beacons (PHBs) (*9*). A study of more than 600 crossings at a multi-use trail crossing in Florida determined an average yield rate of around 54% (*4*). This rate was substantially lower than those of the other studies; however, the Michigan and Shurbutt studies did include two sites with yield rates of 55% and 62%, respectively.

The driver yielding rates at crossings featuring an RRFB are generally higher than the yielding rates found by Turner et al. for other advisory treatments (e.g., overhead beacons or in-pavement flashers) (*8*). At the higher end of the range of yielding rates found in the reviewed studies, the rates approached those of active control treatments (i.e., PHBs and standard traffic signals) found by Turner et al. and exceeded those found by the Michigan study, although the Michigan study suggested that yielding rates may increase at the PHB sites once drivers become accustomed to them. This was a significant finding because RRFBs are a relatively low-cost solution compared with a midblock traffic signal or a PHB (*9*). Therefore, RRFBs represent a cost-effective solution for improving driver yielding rates at a midblock crossing where active or red control may not be warranted or affordable.

Pedestrians often make crossing decisions based on the distance they have to travel to reach the crosswalk (*12*). There is limited research on the ability of enhanced midblock crossings to entice pedestrians to travel out of their way to use the improved crosswalk. One study of sites in Las Vegas with high-visibility signage and markings and median islands noted that there was no change in the proportion of crosswalk users that diverted from their shortest route to use the crosswalk after the improvements were implemented (*10*). None of the studies of RRFBs reviewed for this paper considered the topic.

Z-crossings, also called Danish offsets, attempt to improve pedestrian behavior while providing a refuge for pedestrians in the center of the road. Z-crossings include a median refuge island that is cut out in a zigzag pattern that directs pedestrians to face oncoming traffic before completing the second stage of their crossing. The previously referenced Las Vegas study examined one site with a Z-crossing. The study found that the crossing improved driver yielding behavior at a similar rate as a standard median refuge island. The study also found that pedestrian behavior did not improve after implementation of the Z-crossing, but nearly every pedestrian was noted as looking for oncoming traffic in the before period, rendering it virtually impossible to improve this behavior in the after period. No literature was found on how often pedestrians follow the zigzag pattern encouraged by the Z-crossing.

STUDY SITES

The following is a description of the two study sites. Both were located in southwest Portland, Oregon, in areas that can be characterized as suburban in their land use patterns.

Site 1. Southwest Barbur Boulevard South of Southwest Hamilton Street

The observed crosswalk on Southwest Barbur Boulevard (OR 99W) is shown in Figure 1. The Oregon Department of Transportation (DOT) and the regional transit agency, TriMet, installed the enhanced crossing in February 2012. There is high pedestrian crossing activity at this location, with more than 200 activations of the RRFB each weekday, according to data provided by the Oregon DOT. This activity is likely caused by bus stops located on both sides of the highway. There are eight bus routes that stop on both sides of the highway at this crossing. The surrounding area is residential and many of the residents commute via bus transit.

(a) (b)

FIGURE 1 Observed crosswalk on Southwest Barbur Boulevard: (*a*) plan view and (*b*) crossing [road section has five travel lanes and median island (ADT = 30,700; posted speed limit = 35 mph)]. [Source for (*a*): Google Maps.]

The crosswalk is marked with 9-ft-long longitudinal lines at 5-ft center-to-center spacing (3-ft gap) from curb to curb with a median refuge island. A total of six RRFB assemblies are installed at the crossing location, three facing each direction of traffic. One assembly is located on the side of the road and another is located in the median. The third assembly on each side is installed overhead. There are also two RRFB assemblies in advance of the crossing, one in each direction. The RRFBs are activated by one of four push buttons: one on each side of the road and two in the median refuge area. Each button activates all six assemblies at once. Advance stop bars for approaching motor vehicle traffic are placed approximately 50 ft in advance of the crosswalk, with Stop Here for Pedestrian (R1-5b) signs. The crossing is situated on a horizontal curve and on a grade of approximately 2%.

This section of Southwest Barbur Boulevard has two 11-ft-wide travel lanes and a 10-ft bike lane in the southbound direction. In the northbound direction, there are three 11-ft-wide travel lanes and a 5-ft bike lane. There is a bus pullout in the southbound direction. The total cross-section width is approximately 85 ft, including the bus pullout and the 10-ft median island. The sidewalk on the east side of the road comes from the north and ends at the crossing. On the west side of the road there is a short section of sidewalk connecting the crossing to the bus stop and a dirt trail that connects the crossing and bus stop uphill through a forested slope to Southwest Terwilliger Boulevard.

Site 2. Southwest Beaverton–Hillsdale Highway Near Southwest 62nd Avenue

The second crosswalk is located on Southwest Beaverton–Hillsdale Highway approximately 225 ft east of Southwest 62nd Avenue, as shown in Figure 2. The City of Portland installed the raised median island and marked crosswalk in 2007 and the RRFB in late 2012. There are nearby bus stops (1,018 boardings and alightings per week in 2011 (*13*)), apartments, and a large nursing home and respite care center. According to data provided by the City of Portland, there are approximately 120 activations of the RRFB each weekday.

As shown in Figure 2, the crosswalk is marked with 10-ft-long longitudinal lines at 5-ft center-to-center spacing (3-ft gap) and there is a median refuge island that directs pedestrians in a Z-crossing to the second stage of the crossing. Four RRFB assemblies are installed at this location, with one mounted at the edge of the sidewalk on each side of the road and two mounted in the median island so that two assemblies are facing each direction of motor vehicle traffic. The RRFBs are push button activated, with buttons located at each end of the crosswalk, as well as two in the median. The RRFBs are synchronized so that all four assemblies flash when any button is depressed. Pedestrians are also given an audible warning that oncoming traffic may not stop when the RRFBs are activated. Advance stop lines for approaching motor vehicle traffic are placed approximately 50 ft in advance of the crosswalk.

This section of the Beaverton–Hillsdale Highway has two 12-ft-wide travel lanes, a 5-ft bike lane in each direction, and a 14-ft-wide center turn lane, giving it a total cross-section width of approximately 72 ft. There are also sidewalks on both sides of the road that continue beyond the immediate area of the crosswalk.

METHODOLOGY

Data were collected at each site through the use of traffic-monitoring cameras. Video recording started at 5:00 p.m. on Monday, February 25, 2013, and ended around 11:00 a.m. on Thursday, February 28. The cameras were programmed to record from 6:00 a.m. to 7:30 p.m. Excluding the early morning when there was fog on the camera lens, approximately 31.5 h of video for each site was reviewed in total.

Two observers reviewed the video for each site, overlapping their efforts over 4 h of video to check for interobserver agreement, which is measured as the number of yielding and nonyielding instances that the observers agree on divided by the sum of the yielding and nonyielding instances they agree on and do not agree on. The interobserver agreement rate was 80% for the Southwest Barbur Boulevard site and 90% for the Beaverton–Hillsdale Highway site. These rates are within the ranges seen in previous studies of driver yielding rates (*7, 14*).

(a) (b)

FIGURE 2 Observed crosswalk on Beaverton–Hillsdale Highway: (*a*) plan view and (*b*) crossing [road section has four travel lanes and median island (ADT = 26,400; posted speed limit = 40 mph; SW = southwest; ave = avenue)]. [Source for (*a*): Google Maps.]

In addition to basic descriptive crossing information (e.g., pedestrian or bike, crossing direction), the reviewers collected data for each crossing event related to several measures of effectiveness, as described below.

Driver Behavior

The following measures were collected regarding driver behavior.

Driver Yielding Behavior

Observations were made of each vehicle approaching the intersection when a pedestrian was present. Each vehicle was coded as yielding or not yielding to the crossing pedestrian at the time the vehicle would be required to yield by Oregon law. The Oregon DOT yellow change interval formula, which is the same as the yellow clearance interval formula recommended by the Institute of Transportation Engineers, was used to determine the distance at which an approaching motor vehicle should have sufficient time to yield (*15*). The recommended perception–reaction time of 1 s and deceleration rate of 10 ft/s^2 were used. An adjustment for a 2% grade was included at the Barbur Boulevard site and the northbound speed was assumed to be 45 mph (the posted speed changes just downstream of the crossing, so it was likely many approaching vehicles were driving 45 mph). These distances were approximately 292 ft for the northbound direction and 180 ft for the southbound direction at the Barbur Boulevard site and 232 ft for both directions at the Beaverton–Hillsdale Highway site.

A landmark at these calculated distances was identified in each direction at each location. If a vehicle had already passed the landmark when the pedestrian prepared to cross, then it was only recorded if the vehicle did yield; however, if the vehicle had not yet passed the landmark, then whether the vehicle yielded or not was recorded. To avoid overstating driver yield rates, the reviewers assumed that a vehicle should have yielded when it was not clear if it should or should not have yielded. These data were collected from both stages of the crossing to identify whether yielding behavior varied across the duration of the crossing.

Avoidance Maneuvers

Reviewers noted any precautionary or emergency avoidance maneuvers taken by either the crossing pedestrian or an approaching motor vehicle to avoid a potential collision. The types of maneuvers the reviewers looked for included emergency braking or stopping, swerving, or lane changes.

Stranded Pedestrians

A concern with two-stage crossings is that pedestrians may become stranded in the center island after completing the first stage of their crossing. Therefore, reviewers noted any instance where a pedestrian became stranded. The measure of whether a pedestrian was stranded was taken to be a wait of 5 s or more in the center island, which was used to be consistent with previous studies (*7, 14*).

Pedestrian Behavior

The following measures of pedestrian behavior were collected.

Pedestrian Activation Rate

The reviewers noted whether the crossing pedestrian actuated the RRFB with the push button. The reviewers also noted whether the RRFB was already flashing if the pedestrian did not use the push button.

Pedestrian Delay

One of the benefits of increased driver yielding behavior is reduced delay for crossing pedestrians. The reviewers noted how long pedestrians had to wait from when they arrived at the crosswalk to when they were able to start their crossing for all instances where the pedestrian was not able to cross nearly immediately (i.e., within 2 to 3 s).

Diverted Crossings

A primary impetus for installing the enhanced crossing at the Beaverton–Hillsdale Highway site was to consolidate crossings in the area to a single location with improved visibility. Therefore, observations were made of pedestrian crossing paths to evaluate the effectiveness of the marked crosswalk at attracting crossing pedestrians who might otherwise have crossed away from the crosswalk or at the uncontrolled Southwest 62nd Avenue intersection (which is a legal, although unmarked, crosswalk). The reviewers noted the number of pedestrians who traveled out-of-direction to use the crosswalk (e.g., unloaded from a bus, walked east to the crosswalk, crossed the street, and then walked west on the other side of the road). Further, the reviewers commented if the diverted pedestrian walked past the Southwest 62nd Avenue intersection to reach the marked crosswalk, indicating that the individual bypassed the opportunity to use a legal crosswalk to reach the marked midblock crosswalk. Because of the camera angle, this information could only be recorded for southbound crossings. Figure 3 shows the common diverted crossing paths that were observed at this crosswalk.

The reviewers were able to see all instances of crossings that were not at a crosswalk within approximately 225 ft of the marked

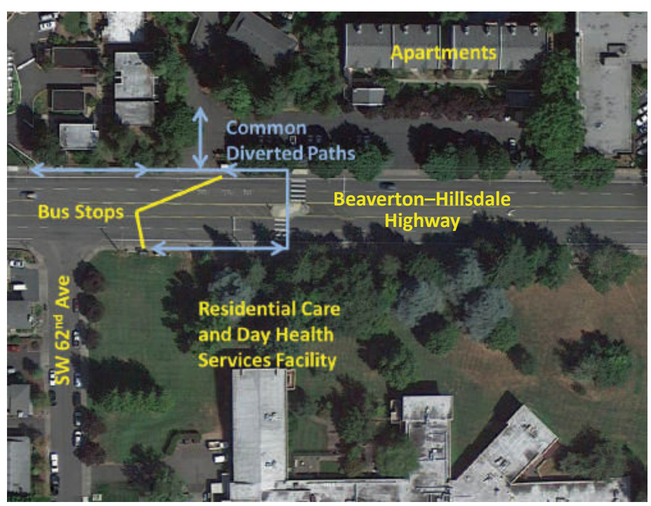

FIGURE 3 Common observed diverted crossing paths at Beaverton–Hillsdale Highway site. (Source: Google Maps.)

midblock crossing. For each of these crossings, the reviewer noted the side of the crosswalk and whether the pedestrian eventually passed by the marked crosswalk. It can be inferred that those who did not pass by the crosswalk before or after crossing the street were taking the shortest path to their destination, while those who did pass by the crosswalk were not attracted to the enhanced crossing. The number of individuals making an out-of-direction crossing was compared with the number of individuals crossing away from a crosswalk to determine the level of attractiveness of the marked crosswalk.

Use of Z-Crossing Pattern

For each crossing in the marked crosswalk, the reviewers recorded whether the pedestrian followed the Z-crossing pattern of the cutout in the median island or just walked over the curbing and completed the crossing in a more direct path.

RESULTS

The following summarizes the results of the analysis of the measures described above.

Driver Behavior

Driver Yielding Behavior

Motor vehicle driver yielding rates were calculated according to the following:

$$\frac{\text{number of drivers yielding}}{\text{total number of drivers with opportunity to yield}}$$

The rates were analyzed on the basis of whether the RRFB was activated. Breaking out the crossings by whether the RRFB was activated allowed insight on the effectiveness of the RRFB on improving driver yielding rates. Further segregating the data by the stage of crossing showed the minimum yielding rate experienced by pedestrians when crossing the road, since the crossings had two stages and pedestrians experienced each stage separately. Figure 4 and Table 1 summarize the observed yielding rates by stage of crossing and RRFB activation.

TABLE 1 Driver Yielding Rates

		Driver Yielding Rate (%)	
Crossing Stage	RRFB Activation	SW Barbur Boulevard	SW Beaverton–Hillsdale Highway
1	Yes	85	82
	No	No observations	15
2	Yes	100	99
	No	75	65
Overall	Yes	92	91
	No	75	45

The figure shows that driver yielding rates increased significantly when the RRFB was activated. The yielding rate for crossings when the RRFB was not activated is comparable to the rate found by Turner et al. for high-visibility crossings (*8*). The sample size of vehicles present at crossings when the RRFB was not activated was particularly small at the Southwest Barbur Boulevard site, so it was difficult to draw any conclusions from that sample. The Southwest Barbur Boulevard sample only included vehicles in the second stage of the crossing, which tended to have higher yield rates. However, the difference in yielding rates when the RRFB was activated compared with when it was not activated at the Beaverton–Hillsdale Highway site was significant (two-sample z-test of proportions, p-value $< .001$).

Figure 4 also shows that yielding rates were higher for the second stage of the crossing at both sites. This was particularly true for crossings where the RRFB was not activated. The higher yielding rates indicate that delay for pedestrians was most likely to be highest when pedestrians were waiting to cross the first half of the road; pedestrians were not likely to be stranded in the center island waiting to complete the second half of the crossing. This finding was confirmed by the study's observations, which found that of 299 crossings with the RRFB activated, only one, or approximately 0.3% of these crossings, resulted in a pedestrian stranded (i.e., having to wait longer than 5 s to continue crossing) in the median

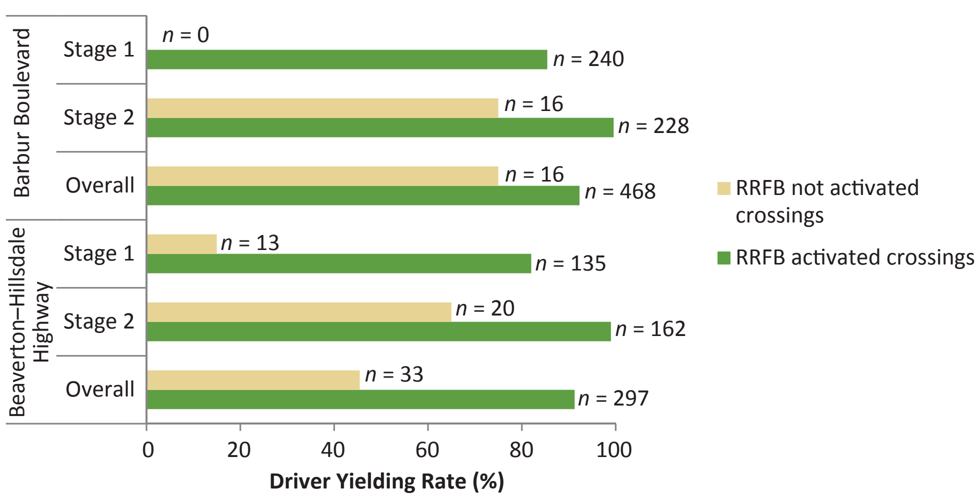

FIGURE 4 Driver yielding rates by RRFB actuation (n = number of vehicles).

island. There were six observations of stranded pedestrians in the 41 instances where the RRFB was not activated, which translates to approximately 15% of all crossings where the RRFB was not activated.

Overall the yielding rates at the two locations when the RRFB was activated were comparable to those from the previous studies discussed earlier in this paper. The yielding rates were higher than the average of any of the other studies, which ranged from 54% to 83%, although only slightly higher than the rate for four-beacon installations found by the Shurbutt study, which was 88%. But the yielding rates found in the present study were within the overall range of rates seen in these efforts.

Avoidance Maneuvers

There were only two observed instances where drivers made sudden avoidance maneuvers. Both were instances of hard braking. In one instance, the vehicle was noted to have been close to the crosswalk when the RRFB was actuated. There was also one observed instance of a cyclist making a slight maneuver to avoid a crossing pedestrian.

Pedestrian Behavior

Pedestrian Actuation Rate

There were a total of 351 observed crossings at the two marked crosswalks. Not all pedestrians activated the RRFB at their crosswalk, and some pedestrians entered the crosswalk when the RRFB was still flashing from a previous actuation. Table 2 summarizes the use of the RRFB at each of the two study sites, including whether cars were present that should have yielded to the pedestrian at the time of the crossing.

The table shows that the RRFB was activated when possible (i.e., it was not already flashing) approximately 92% of the time at the Southwest Barbur Boulevard site and 83% of the time at the Beaverton–Hillsdale Highway site. The difference in actuation rates between the sites is significant (two-sample z-test of proportions, p-value = .007). The Southwest Barbur Boulevard site had the higher use rate and was on a higher-speed roadway (45 mph) with a longer crossing (85 ft) compared with the Beaverton–Hillsdale Highway site (40 mph and 72 ft).

Actuation rates were higher at both sites when cars were present than when they were not present. At the Southwest Barbur Boulevard site, the RRFB was activated in 94% of the instances (160 of 170) when observers noted a vehicle as being present, whereas it was only activated 72% of the time (13 of 18) when the reviewers did not observe a vehicle. Similarly, at the Beaverton–Hillsdale Highway crossing, the actuation rate was 89% (112 of 126) when vehicles were present compared with 48% (11 of 23) when vehicles were not present. The sample sizes of crossings when there were no cars present were relatively small, but there did appear to be a clear trend toward higher actuation rates when vehicles were present.

The actuation rates at the two locations were higher than observed in previous studies at two sites with RRFBs in Florida and Oregon. In those studies, the observed actuation rates were 40% (Florida) and 75% (Oregon), although the site in Florida was primarily used by bicyclists and the Oregon study found that bicyclists activated the beacons at a lower rate than pedestrians did. The Oregon study focused on off-peak times when traffic volumes were likely lower (*4, 6*).

Pedestrian Delay

Most of the observed pedestrians were able to proceed with their crossing with minimal delay. If the pedestrian had to wait longer than a few seconds to make his or her crossing, it was typically because a driver did not yield or the cars were far enough away that the pedestrian waited for them to approach and yield before starting to cross. The longest observed delay occurred during a crossing when the RRFB was not activated and was 20 s long, which corresponded to a level of service of C, as defined by the *Highway Capacity Manual 2010.* Only one observed instance where the RRFB was activated was greater than 15 s, indicating that all other crossings, including the second stage of the crossing, were at a level of service A or a level of service B (*16*).

Diverted Crossings

The reviewers observed a total of 221 crossing events in the vicinity of the Beaverton–Hillsdale Highway site. The following list summarizes where the crossings took place and whether the pedestrian crossing at the study crosswalk traveled out of the way to reach the crosswalk:

- Crossings at marked crosswalk:
  - Total = 155 and
  - Out of direction = 81,
- Crossings away from a crosswalk:
  - Total = 33 and
  - Passed by RRFB = 11, and
- Crossings at Southwest 62nd Avenue = 33.

TABLE 2 RRFB Actuation Rates

	Number of Crossings, by Location					
	SW Barbur Boulevard			SW Beaverton–Hillsdale Highway		
Crossing Type	Cars Present	No Cars Present	Total	Cars Present	No Cars Present	Total
RRFB activated	160	13	173	112	11	123
RRFB not activated	10	5	15	14	12	26
RRFB already flashing	4	4	8	6	0	6
Total	174	22	196	132	23	155

The majority, approximately 70% (155 of 221), of the observed crossings in the immediate vicinity of the marked crosswalk took place at the crosswalk itself. Removing from consideration the 33 observed crossings at the legal but unmarked crosswalk at Southwest 62nd Avenue revealed that 82% (155 of 188) of the observed pedestrians used the marked crosswalk. This percentage was greater than the 71% compliance rate seen at marked midblock crosswalks without additional treatments in a study by Sisiopiku and Akin (*12*). More than half the pedestrians, approximately 52%, who used the marked crosswalk traveled out-of-direction to use the crosswalk.

Of the 33 crossings away from either crosswalk, 11 passed by the marked crosswalk before or after crossing the road, an indication that most (22) of them crossed away from a crosswalk to avoid out-of-direction travel. The analysis of these crossings provided some evidence that the enhanced crosswalk was attractive enough to draw 60% of the pedestrians in the immediate vicinity of the enhanced crosswalk that would have traveled a shorter path if they had crossed before reaching the crosswalk. [That is, 81 out-of-direction/(81 out-of-direction + 33 at Southwest 62nd Avenue + 22 away from crosswalk).] Further, of the crossings in the immediate vicinity that were not out-of-direction, 87% [(155 − 81)/(155 − 81 + 11)] chose to use the marked crosswalk instead of crossing at another point along the highway.

Finally, the reviewers were able to see if out-of-direction southbound crossing pedestrians passed by Southwest 62nd Avenue to reach the marked crosswalk. More than half, approximately 56% [24/(24 + 19)], of all southbound crossing pedestrians who walked by Southwest 62nd Avenue chose to continue past Southwest 62nd Avenue to use the marked crosswalk, although it meant traveling out-of-direction.

Use of Z-Crossing Pattern

Of the 155 crossings observed at the Beaverton–Hillsdale Highway crosswalk, the Z-crossing pattern was followed in 78 instances, while the crossing pedestrians walked straight through the median 72 times. In five instances, the camera lens was too fogged to determine the pedestrian's path through the median. Therefore, the intended path of the Z-crossing pattern was observed to be followed approximately 52% of the time. This relatively low compliance rate could be partially because there was only a curb to enforce the crossing pattern. A location with fencing, bollards, or posts may have had a higher compliance rate.

The previous analysis showed that driver yielding rates for the second stage of the crossing were very high (99%) at this location. The adequate sight distance present at the crossing may have allowed pedestrians to feel comfortable crossing straight through the median instead of needing to make an extra effort to determine whether the second stage was safe to cross. And 81 of the 155 crossings at the marked crosswalk were pedestrians traveling out-of-direction. The Z-pattern was followed in only 48% of the diverted crossings, compared with 56% of the time in nondiverted crossings. Although the rates were different, they were relatively similar.

CONCLUSIONS

This study adds to the literature on the effectiveness of RRFBs as measured by driver yield rates. In the study, the yielding rates for drivers when RRFBs were activated were compared with the behaviors when a pedestrian crossed without activating the beacons, rather than a traditional before-after comparison. At the two locations studied, the overall driver yielding rate was 91% to 92%. In addition, the analysis found that yielding rates for the second stage crossing were higher than for the first.

This finding contributes to the observation that almost no pedestrians were stranded in the median island while crossing. Pedestrian delay was minimal. The yielding rates found in this study were comparable to, if slightly higher than, those of previous studies. There were only two sites in the study and both were well-used crosswalks on commuter routes so that driver expectation of crossings was likely high. There were also likely regional differences in driver yielding behavior. The site with overhead and side-mounted assemblies and 30,700 ADT had nearly the same driver yielding rate as the site with only side-mounted assemblies and 26,400 ADT. However, with such a small sample it was not possible to untangle the site-specific differences.

The study results suggest that a marked midblock crossing with an RRFB may encourage more pedestrians to use the enhanced crosswalk even when shorter paths and legal crossings are available. These results were only from one location. For future studies, researchers should use a wide field of view to capture more observations and destinations. Automated video analysis techniques would allow a more thorough analysis of pedestrian walking paths (*17*). A survey could also be used to obtain pedestrian perceptions and attitudes about the enhanced crossing.

The Z-crossing observed in this study was complied with just over half the time. This suggests that the effectiveness of such a treatment may be limited at a location with adequate sight distance and without physical barriers forcing pedestrians to follow the pattern. This study was not able to determine whether those who used the Z-crossing acted in a safer manner than those who did not. The high yield rates observed at the RRFB locations (particularly for the second-stage crossing) may suggest that the additional expense of the Z-feature was not necessary at this location. This finding clearly needs further study before generalizations can be made.

The study did not examine more detailed driver behavior at the crosswalk. According to Oregon law, drivers need only stay stopped until the pedestrian has cleared the lane in front of their vehicle and the adjacent lane. On the basis of anecdotal observations, some drivers wait for the pedestrian(s) to clear the entire crosswalk, adding unnecessary delay for motor vehicles. This finding is not so different from observations made at new PHB installations, which were supported by a recent Oregon DOT survey of drivers not familiar with PHB. That survey found that the majority of respondents did not understand the alternating red phase of the PHB's operation (*5*).

Although the present study aimed to observe avoidance maneuvers, including hard braking by drivers, too few observations were available to make conclusions. These negative aspects appear to have been adequately offset by the high yielding rates and the low cost of the RRFBs.

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