DEPARTMENT OF TRANSPORTATION

Traffic Safety Evaluation of Pedestrians and Bicyclists at Rectangular Rapid Flashing Beacons and Pedestrian Hybrid Beacons in Minnesota

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Minnesota Department of Transportation

April 2024

Research Project
Final Report 2024-11

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Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
MN 2024-11		

4. Title and Subtitle	5. Report Date
Traffic Safety Evaluation of Pedestrians and Bicyclists at Rectangular Rapid Flashing Beacons and Pedestrian Hybrid Beacons in Minnesota	April 2024
	6.
7. Author(s) Ian Saari; Mark Wagner, PE	8. Performing Organization Report No.
9. Performing Organization Name and Address Office of Traffic Engineering Minnesota Department of Transportation 1500 W. County Rd B2, MS 725 Roseville, Minnesota 55113	10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No.
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research & Innovation 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes
http://mdl.mndot.gov/

16. Abstract (Limit: 250 words)

To improve the visibility and safety of pedestrian and bicyclist crossings, traffic-safety professionals across Minnesota have installed the Rectangular Rapid Flashing Beacon (RRFB) and Pedestrian Hybrid Beacon (PHB) at numerous locations around the state. The purpose of this evaluation was to determine the safety benefits, if any, for pedestrians and bicyclists after installation of an RRFB or PHB. This report included a before-after analysis as well as a cross-sectional analysis for each type of beacon with a corresponding group of comparison sites. The before-after analysis found that installation of an RRFB resulted in a 67% decrease in fatal crashes and a 62% decrease in bicyclist crashes. Installation of a PHB resulted in a 53% decrease in suspected minor injury crashes, a 67% decrease in pedestrians crashes, and a 50% decrease in bicyclist crashes. The results of the cross-sectional analysis did not indicate that these reductions were statistically significant compared to similar reductions in the control group. Still, the decreases in severe crashes and crashes involving non-motorists at RRFBs and PHBs indicated that both types of beacons could be effective safety treatments.

17. Document Analysis/Descriptors	18. Availability Statement
Flashing beacons, Pedestrian actuated controllers, Pedestrians, Cyclists, Traffic safety	

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	22	

TRAFFIC SAFETY EVALUATION OF RECTANGULAR RAPID FLASHING BEACONS AND PEDESTRIAN HYBRID BEACONS IN MINNESOTA

FINAL REPORT

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APRIL 2024

Published by:

Minnesota Department of Transportation
Office of Research & Innovation
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

ACKNOWLEDGEMENTS

The author(s) would like to thank the following individuals and organizations for their direct and indirect contributions to this document:

Derek Leuer, PE – MnDOT Office of Traffic Engineering
Max Moreland, PE, PTOE – MnDOT Office of Traffic Engineering
Sonja Piper, PE – MnDOT Office of Traffic Engineering
Tiffany Kautz – MnDOT Office of Traffic Engineering

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LIST OF ABBREVIATIONS & DEFINITIONS OF TERMS

Acronym	**Meaning**
KA	Fatal and serious injury crash
KAB	Fatal, serious injury, and minor injury crashes
KABC	Fatal and all injury crashes
MEV	Million entering vehicles
MnDOT	Minnesota Department of Transportation

Crash Severities

- K Crash: Fatal crash. At least one person involved in the crash died as a result of injuries sustained in the crash.
- A Crash: Suspected serious injury crash. The crash resulted in a suspected serious injury for at least one person involved in the crash.
- B Crash: Suspected minor injury crash. The crash resulted in a suspected minor injury for at least one person involved in the crash.
- C Crash: Possible injury crash. The crash resulted in a possible injury for at least one person involved in the crash.
- PDO Crash: Property damage only crash. The crash resulted in property damage with no injuries for anyone involved in the crash.

Crash Types

- Rear End: The front of a vehicle strikes the rear of another vehicle travelling in the same direction.
- Pedestrian/Bicycle: A crash involving a vehicle and a pedestrian, bicyclist, or other non-motorist (skating, wheelchair, etc.)

Other Definitions:

- Site-Year: One year of data at a site.

EXECUTIVE SUMMARY

To improve the visibility and safety of pedestrian and bicyclist crossings, traffic safety professionals across Minnesota have installed the Rectangular Rapid Flashing Beacon (RRFB) and Pedestrian Hybrid Beacon (PHB) at numerous locations around the state. Between 2009 and 2021, 147 RRFBs and 8 PHBs were installed.

The purpose of this evaluation is to determine the safety benefits, if any, for pedestrians and bicyclists after installation of an RRFB or PHB. This report includes a before-after analysis as well as a cross-sectional analysis for each type of beacon with a corresponding group of comparison sites. The before-after analysis finds that installation of an RRFB results in a 67% decrease in fatal crashes and a 62% decrease in bicyclist crashes, while installation of a PHB results in a 53% decrease in suspected minor injury crashes, a 67% decrease in pedestrians crashes, and a 50% decrease in bicyclist crashes.

The results of the cross-sectional analysis found that both treatment sites and control group sites experienced crash reductions and that the differences between the two groups were not statistically significant. Still, the decreases in severe crashes and crashes involving non-motorists at RRFBs and PHBs indicate that both types of beacons can be effective safety treatments.

CHAPTER 1: INTRODUCTION

According to Minnesota Motor Vehicle Crash Facts[1], 947 pedestrian crashes and 561 bicyclist crashes with vehicles occurred in 2022. In the Minnesota Strategic Highway Safety Plan[2], pedestrians are a Strategic Focus Area with crash prevalence increasing, and bicyclists are a Connected Focus Area with crash prevalence remaining steady. Two of the treatments available to traffic engineers and transportation practitioners are the Rectangular Rapid Flashing Beacon (RRFB) and Pedestrian Hybrid Beacon (PHB), both of which are considered proven safety countermeasures by FHWA.[3]

RRFBs consist of two, rectangular-shaped yellow LED indications, mounted below the pedestrian warning sign and above the diagonal downward arrow plaque pointing to the crossing. RRFBs flash with an alternating high frequency when activated to enhance conspicuity of pedestrians at the crossing to drivers. The flashing pattern can be activated with pushbuttons or passive (e.g., video or infrared) pedestrian detection, and remains unlit when not activated. Figure 1.1 shows a typical RRFB assembly.

Figure 1.1 – Typical RRFB Installation

Pedestrian hybrid beacons (PHB) are a traffic-control device designed to help pedestrians safely cross higher-speed roadways at midblock crossings and uncontrolled intersections. The beacon head consists

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[1] Reports / Statistics - Crash Facts (mn.gov)
[2] Minnesota Strategic Highway Safety Plan - MnDOT (state.mn.us)
[3] Proven Safety Countermeasures | FHWA (dot.gov)

of two red lenses above a single yellow lens. The lenses remain "dark" until a pedestrian desiring to cross the street pushes the call button to activate the beacon, which then initiates a yellow to red lighting sequence consisting of flashing and steady lights that directs motorists to slow and come to a stop, and provides the right-of-way to the pedestrian to safely cross the roadway before it goes dark again.

In general, PHBs are used where it is difficult for pedestrians to cross a roadway, such as when gaps in traffic are not sufficient or speed limits exceed 35 miles per hour. They are very effective at locations where three or more lanes will be crossed or average annual daily traffic volumes are above 9,000 vehicles. Installation of a PHB must also include a marked crosswalk and pedestrian countdown signal.[4] Figure 1.2 shows an example PHB installation.

Figure 1.2 – Example PHB Installation

[4] [Pedestrian Hybrid Beacons | FHWA (dot.gov)]

CHAPTER 2: METHODOLOGY

2.1 LOCATIONS

For this evaluation 147 RRFB were selected from an inventory maintained by the MnDOT Office of Traffic Engineering and 8 PHB sites were identified from existing sources including MnDOT Districts, State Aid for Local Transportation, and local agencies. RRFB and PHB locations are shown in Figures 2.1 and 2.2, respectively.

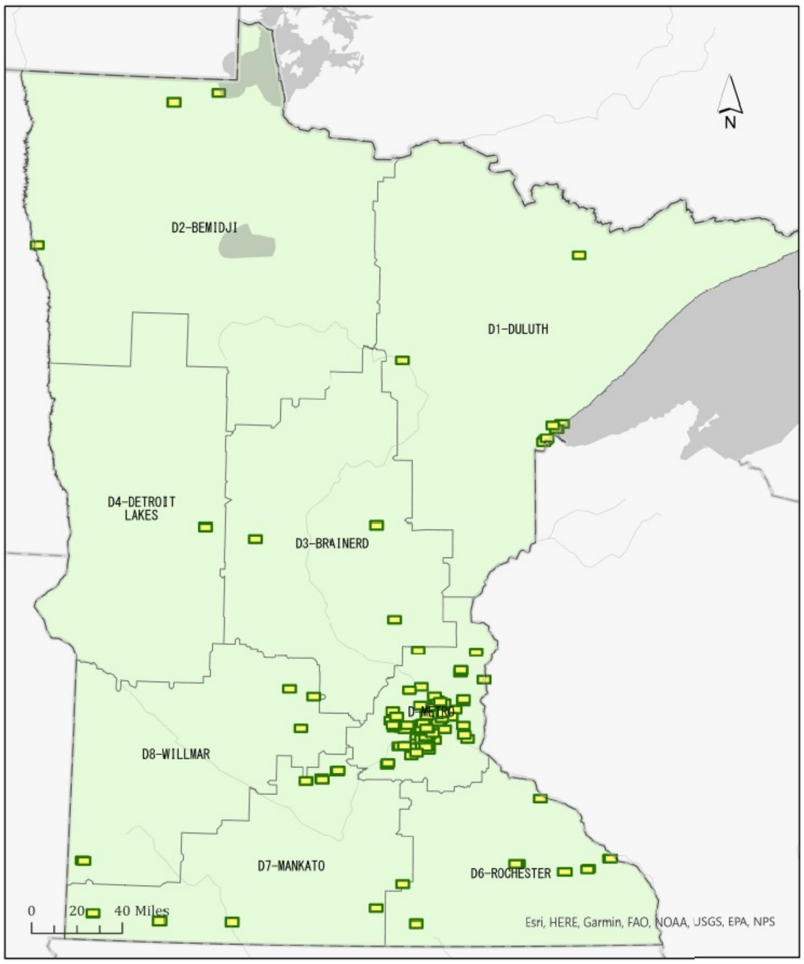

Figure 2.1 – Rectangular Rapid Flashing Beacon Locations

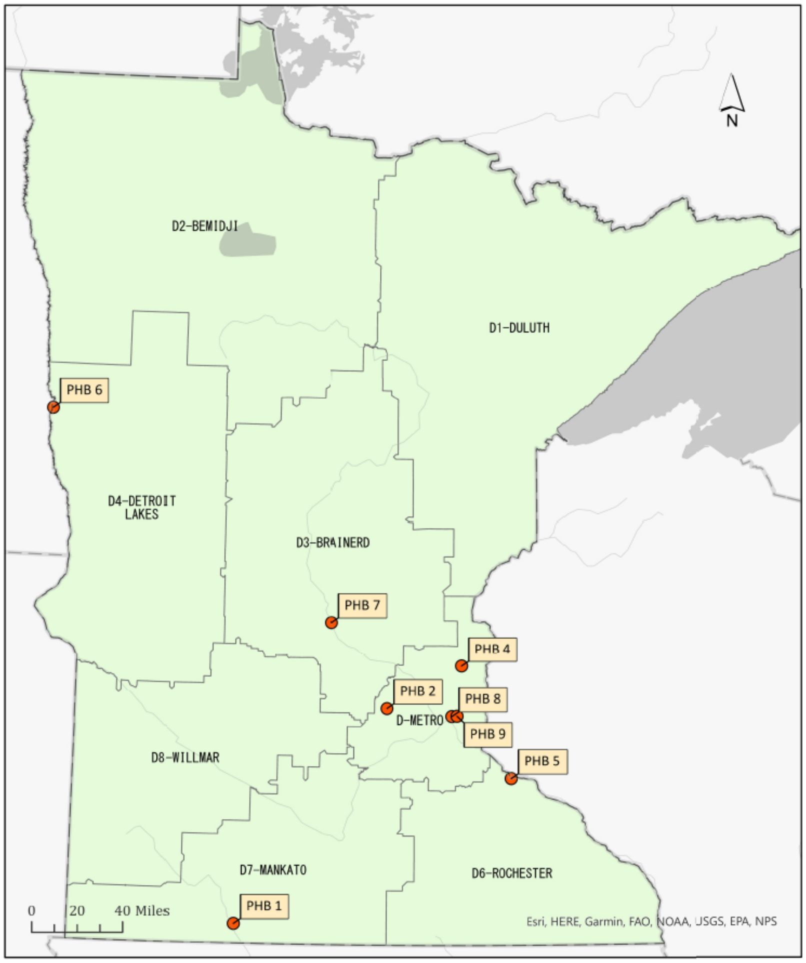

Figure 2.2 – Pedestrian Hybrid Beacon Locations

The analysis includes a comparison between the RRFB and PHB intersections and similar intersections without these treatments. A comparison intersection was identified for each intersection with an RRFB or PHB. These comparison intersections were identified using the following criteria:

- Similar routes or route system types intersecting both sites
- Presence of pedestrian crossing signing and/or marked crosswalks
- Similar crash history at locations before study (if possible)
- Similar traffic volumes at location
- Similar style of intersection (**where applicable**)

2.2 CRASH DATA

For this evaluation, crash data for the years 2006 through 2021 was collected for treatment and control sites. Crash data for these years was collected at each location using a 300-foot buffer around the intersection. Crashes within this buffer were reviewed and removed from the analysis is if the crash occurred during the year of treatment installation or was not associated with the intersection (i.e., happened in a nearby parking lot).

2.3 ANALYSIS OVERVIEW

Two different types of analyses were conducted as part of this evaluation. Those analyses are:

A before-after analysis

This analysis focuses on comparing the crashes in a period before an RRFB or PHB was installed to a period after the treatment was installed at the same locations. The before and after periods for each site include the same number of site-years.

A cross-sectional analysis

This analysis compares before-after crash data at locations where an RRFB or PHB was installed to similar locations without these treatments.

CHAPTER 3: RESULTS

3.1 BEFORE-AFTER ANALYSIS

The before-after analysis compares crash data at locations before the RRFB or PHB was installed and after the treatment was installed.

3.1.1 Question Addressed

How do crashes change after an RRFB or PHB is installed at a crossing?

3.1.2 Locations

The 147 RRFB and 8 PHB treatment locations as discussed in section 2.1 were utilized for the analysis.

3.1.3 Crash Data

The before-after crash data at the 155 locations with an RRFB or PHB and associated control sites was collected and compiled. The year of installation was not included in the crash analysis, and the number of years used in the before period was set to match the number of years in the after period, with 2021 being the most recent year of data. Table 3.1 shows that compiled crash data.

Table 3.1 - Before-After Crash Data at RRFB Treatment Sites – All Crashes

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	2487	1388	-44%
K+A Crashes	48	27	-44%
K Crashes	6	2	-67%
A Crashes	42	25	-41%
B Crashes	215	140	-35%
C Crashes	500	200	-60%
PDO Crashes	1724	1021	-41%

Table 3.2 - Before-After Crash Data at RRFB Treatment Sites – Non-Motorized Crashes Only

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	149	81	-46%
K+A Crashes	18	15	-17%
K Crashes	2	1	-50%
A Crashes	16	14	-13%
B Crashes	55	31	-44%
C Crashes	71	27	-62%
PDO Crashes	5	8	+60%

Table 3.3 - Before-After Crash Data at PHB Treatment Sites – All Crashes

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	304	212	-30%
K+A Crashes	3	1	-67%
K Crashes	1	0	-100%
A Crashes	2	1	-50%
B Crashes	19	9	-53%
C Crashes	51	44	-14%
PDO Crashes	231	158	-32%

Table 3.4 - Before-After Crash Data at PHB Treatment Sites – Non-Motorized Crashes Only

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	10	4	-60%
K+A Crashes	0	0	0%
K Crashes	0	0	0%
A Crashes	0	0	0%
B Crashes	6	3	-50%
C Crashes	4	1	-75%
PDO Crashes	0	0	0%

3.1.4 Crash Analysis

To compare the before and after crash samples, paired samples t-tests and Wilcoxon signed-rank tests were used. Both tests are mathematically similar, and these two tests are designed to compare two related samples, where each sample has their own independent observations. That said, the skewed distributions of the sample data made it necessary to use of the Wilcoxon signed-rank test for several of the before-after crash comparisons.

The analysis and testing were focused on five crash severities/types, which are listed below.

- Total crashes
- Fatal (K) and suspected serious injury (A) crashes
- Rear-End Crashes
- Pedestrian Crashes
- Bicyclist Crashes

The Wilcoxon signed-rank test results in a p-value which is compared to a predetermined threshold significance level of 0.05 in this case. When the p-value is below the significance level, the null hypothesis is rejected in favor of the alternative hypothesis suggesting there is a significant difference in the before-after results. The results are shown in Table 3.5.

Table 3.5 - Results of Statistical Tests for Before-After Analysis at RRFB Treatment Locations

Category	% Change	Paired t-test p-value	Wilcoxon p-value	Significant?
Total Crashes	-44%	<0.001	---	Yes
K+A Crashes	-44%	---	0.025	Yes
K Crashes	-67%	---	0.102	No
A Crashes	-41%	---	0.049	Yes
Rear-End Crashes	-30%	<0.001	---	Yes
Pedestrian Crashes	-31%	---	0.362	No
Bicyclist Crashes	-62%	---	<0.001	Yes

Table 3.6 - Results of Statistical Tests for Before-After Analysis at PHB Treatment Locations

Category	% Change	Paired t-test p-value	Wilcoxon p-value	Significant?
Total Crashes	-30%	0.259	---	No
K+A Crashes	-67%	---	0.414	No
K Crashes	-100%	---	0.317	No
A Crashes	-50%	---	0.655	No
Rear-End Crashes	-29%	0.786	---	No
Pedestrian Crashes	-67%	0.227	---	No
Bicyclist Crashes	-50%	0.563	---	Yes

In Table 3.5, the testing results show that the installation of an RRFB results in statistically significant reductions in total crashes, fatal plus serious injury crashes, serious injury (A) crashes, and rear-end crashes at a significance level of 0.05. In Table 3.6 installation of a PHB did not result in statistically significant reductions.

3.2 CROSS-SECTIONAL ANALYSIS

The cross-sectional analysis takes the group of locations that have and RRFB or PHB at them (treatment sites) and compares the before-after crash data there against the before-after crash data at a group of similar intersections without the treatment (control sites).

3.2.1 Question Addressed

How much of the crash impacts at intersections can be attributed to installation of an RRFB or PHB?

3.2.2 Locations

The 147 RRFB treatment and control locations and 8 PHB treatment and control locations as discussed in section 2.1 were utilized for the analysis.

3.2.3 Crash Data

The cross-sectional analysis involved a before period and an after period at the treatment and control sites. At the treatment sites, the same data from the before-after analysis was utilized. At the control sites, the before and after periods were set to match those of the matching treatment sites. Tables 3.7 and 3.8 show the compiled crash data for RRFB control group locations while tables 3.9 and 3.10 show the same data for PHB control group locations.

Table 3.7 - Before-After Crash Data at RRFB Control Group Sites – All Crashes

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	2722	1422	-48%
K+A Crashes	39	25	-36%
K Crashes	8	3	-63%
A Crashes	31	22	-29%
B Crashes	195	142	-27%
C Crashes	576	206	-64%
PDO Crashes	1912	1049	-45%

Table 3.8 - Before-After Crash Data at RRFB Control Group Sites – Non-Motorized Crashes Only

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	133	81	-39%
K+A Crashes	13	10	-23%
K Crashes	4	1	-75%
A Crashes	9	9	0%
B Crashes	48	34	-29%
C Crashes	66	26	-61%
PDO Crashes	6	11	+83%

Table 3.9 - Before-After Crash Data at PHB Control Group Sites – All Crashes

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	367	302	-18%
K+A Crashes	7	3	-57%
K Crashes	0	0	---
A Crashes	7	3	-57%
B Crashes	20	20	0%
C Crashes	56	37	-34%
PDO Crashes	284	242	-15%

Table 3.10 - Before-After Crash Data at PHB Control Group Sites – Non-Motorized Crashes Only

Crash Severity/Type	Before # of Crashes	After # of Crashes	% Change
Total Crashes	12	17	+42%
K+A Crashes	2	2	0%
K Crashes	0	0	---
A Crashes	2	2	0%
B Crashes	2	7	+250%
C Crashes	8	6	-25%
PDO Crashes	0	2	100%

3.2.4 Crash Analysis

Before conducting the cross-sectional analysis, a before-after analysis was conducted on the crash data for the control sites. The method used for this matched the method used in the before-after analysis of the treatment sites. Tables 3.11 and 3.12 show the results of that analysis.

Table 3.11 - Results of Statistical Tests for Before-After Analysis at RRFB Control Group Sites

Category	% Change	Paired t-test p-value	Wilcoxon p-value	Significant?
Total Crashes	-48%	<0.001	---	Yes
K+A Crashes	-36%	---	0.091	Yes*
K Crashes	-63%	---	0.132	No
A Crashes	-29%	---	0.304	No
Rear-End Crashes	-22%	<0.001	---	Yes
Pedestrian Crashes	-32%	---	0.103	No
Bicyclist Crashes	-47%	---	0.027	Yes

*Statistically significant at 0.10

Table 3.12 - Results of Statistical Tests for Before-After Analysis at PHB Control Group Sites

Category	% Change	Paired t-test p-value	Wilcoxon p-value	Significant?
Total Crashes	-18%	0.568	---	No
K+A Crashes	-57%	---	0.046	Yes
K Crashes	---	---	0.999	No
A Crashes	-57%	---	0.046	Yes
Rear-End Crashes	-14%	0.751	---	No
Pedestrian Crashes	+80%	0.620	---	No
Bicyclist Crashes	+14%	0.871	---	No

As can be seen in Table 3.11, the RRFB control sites had statistically significant changes at the level of $p < 0.05$ in total crashes, rear-end crashes, and bicyclist crashes. in the before and after periods. The reduction for fatal plus serious injury crashes was significant at the level of $p < 0.10$. In table 3.12, the PHB control sites had statistically significant reductions in fatal plus serious injury crashes and serious injury (A) crashes at the level of $p < 0.05$.

For the cross-sectional crash data analysis, a Mann-Whitney U-Test was used. Like with the previous analysis, it is necessary to use a nonparametric test because the sampled crashes are not normally distributed. Also like the previous test, a Mann-Whitney U test the assumptions of a null hypothesis, although this test will not be comparing averages by relying on differences in group means. Since this test converts all of the observed values into two ordinal sets of ranks, the measure we are using for each group's average will be its median (or middle) value.

For this analysis, the null hypothesis being tested is that the median difference between pairs of observations from the two groups (treatment and control) is equal to zero. The alternative hypothesis being tested is that the median difference between pairs of observations from the two groups is not equal to zero. Here, the observations being compared are the sites' crash reduction factors, or the observed percentage decrease in crashes at the treatment and control sites.

The Mann-Whitney U-Test produces a test statistic with a corresponding p-value, which is then compared to a predetermined alpha level (in this case, alpha = 0.05) to evaluate the null hypothesis. If the test produces a result with a p-value that is less that the threshold significance level, the null hypothesis is rejected in favor of the alternative hypothesis. The results are shown in tables 3.13 and 3.14.

Table 3.13 - Results of Mann-Whitney U-Test for Cross-Sectional Analysis – RRFB Treatment and Control Sites

Category	Treatment % Change	Control % Change	p-value	Significant?
Total Crashes	-44%	-48%%	0.067	Yes*
K Crashes	-67%	-63%	0.829	No
A Crashes	-41%	-29%	0.343	No
Rear-End Crashes	-30%	-22%	0.140	No
Pedestrian Crashes	-31%	-32%	0.563	No
Bicyclist Crashes	-62%	-47%	0.229	No

*Statistically significant at 0.10

Table 3.14 - Results of Mann-Whitney U-Test for Cross-Sectional Analysis – PHB Treatment and Control Sites

Category	Treatment % Change	Control % Change	p-value	Significant?
Total Crashes	-30%	-18%	0.480	No
K Crashes	-100%	0%	---*	No
A Crashes	-50%	-57%	0.490	No
Rear-End Crashes	-29%	-14%	0.041	Yes
Pedestrian Crashes	-67%	+80%	0.027	Yes
Bicyclist Crashes	-50%	+14%	0.891	No

*Omitted due to small sample size.

As seen in table 3.13, there was a statistically significant difference in the percent change between the RRFB treatment and control groups for total crashes at a significance level of 0.10. However, as both groups saw similar reductions in crashes this likely indicates a broader decrease in crashes rather than anything specific to the treatment or control locations. In table 3.14, there was a statistically significant difference in the percent change for rear-end and bicyclist crashes at a significance level of 0.05. For both crash types, the treatment locations experienced a larger percentage reduction and, more specific to bicyclist crashes, PHB locations saw a decrease in crashes while the control locations saw an increase. The difference in percent change for bicycle crashes is unsurprising in the sense that this is an expected outcome of installation of a PHB. The intent is to provide a safer environment for non-motorized users to cross busier, higher-speed roads. The decrease in rear-end crashes is more surprising as installation of a traffic signal tends to increase these types of crashes at an intersection. As a PHB is a type of signal that introduces vehicle stopping and yielding at a location where it was previously unexpected, it is intuitive to think that installation of a PHB would lead to an increase in rear-end crashes. However, the results of this analysis are consistent with the findings from other studies in the Crash Modification Factor (CMF) Clearinghouse[5], which also show a 12-36% reduction in rear-end crashes with installation of a PHB.

[5] CMF Clearinghouse

CHAPTER 4: CONCLUSIONS

The analysis showed statistically significant reductions in bicycle crashes at RRFB sites and rear-end, pedestrian, and bicycle crashes at PHB treatment sites. Therefore, the decreases in severe crashes and crashes involving non-motorists at RRFB and PHB treatment sites in this analysis indicated that both types of beacons can be effective safety treatments. In addition, the analysis found large reductions in fatal and suspected serious injury crashes at RRFB and PHB treatment sites, although these results were not found to be statistically significant.

Similar results were found in the cross-sectional analysis, which showed that several of the before-after crash reductions observed at the beacon sites were statistically significant improvements. While these results were promising, some of the crash reductions observed at RRFB and PHB sites were correlated with similar reductions in their respective control groups. Still, the large overall crash decreases in severe crashes and crashes involving non-motorists at RRFB and PHB locations indicated that both types of beacons can be effective safety treatments for pedestrians and bicyclists.

Further study could delve into other potential distinctions between sites. While the treatment and control groups possessed similar site characteristics, future evaluation efforts might be able to illuminate specific differences (e.g., non-motorized demand, location at intersection and at mid-block crossing placements for RRFBs, etc.) among the sites. Knowledge of how often either type of pedestrian beacon is activated and flashing when crashes occur could provide insights into driver and non-motorist behaviors related to these two crossings.