DEPARTMENT OF TRANSPORTATION

TRAFFIC SAFETY EVALUATION OF RETROREFLECTIVE SIGNAL BACKPLATE BORDERS AT SIGNALIZED INTERSECTIONS IN MINNESOTA

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Between 2016 and 2021, MnDOT installed retroreflective signal backplate borders at 116 signalized intersections in Minnesota. Retroreflective signal backplate borders are intended to further increase visibility of the signal head both during the day and at night. The goal of installing retroreflectivity to backplates is to reduce crashes at the intersection by drawing more attention to the current phase of the signal. Backplates with retroreflective borders are listed as a Federal Highway Administration Proven Safety Countermeasure with a listed safety benefit of a 15% reduction in total crashes. With the installation of retroreflective signal backplates on MnDOT signals, the changes in crash rates were not found to be statistically significantly different from similar locations that did not have retroreflective signal backplates. These results indicate there has been little impact on crash rates in the few years after the installation of retroreflective signal backplates.

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FINAL REPORT

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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.

Other Definitions:

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

EXECUTIVE SUMMARY

Between 2016 and 2021, MnDOT installed retroreflective signal backplate borders at 116 signalized intersections in Minnesota. The vast majority of these were installed in 2019. Retroreflective signal backplate borders are intended to further increase visibility of the signal head both during the day and at night. The goal of installing retroreflectivity to backplates is to reduce crashes at the intersection by drawing more attention to the current phase of the signal. Backplates with retroreflective borders are listed as a Federal Highway Administration Proven Safety Countermeasure with a listed safety benefit of a 15% reduction in total crashes.

The purpose of this evaluation is to review the crash history at signalized intersections in Minnesota with retroreflective backplates to determine the crash impacts of installing the retroreflective borders on backplates. This report includes the results of a before-after crash analysis at signals with retroreflective backplates and compares those results against signals without retroreflective signal backplates.

With the installation of a retroreflective signal backplates on MnDOT signals, the changes in crash rates were not found to be statistically significantly different from similar locations that did not have retroreflective signal backplates. These results indicate there was little impact on crash rates in the few years after the installation of retroreflective signal backplates.

It should be noted that this evaluation does not create a policy, practice, or care within the Minnesota Department of Transportation. The purpose of this evaluation at this time is purely exploratory.

CHAPTER 1: INTRODUCTION

Signal backplates are a border around a signal head that are intended to improve the visibility of the signal. These borders are typically black. More recently, some signal heads have been outfitted with a retroreflective backplate that is yellow. This is typically done by applying retroreflective tape to an existing signal backplate. The purpose of the retroreflective backplate is to further increase visibility of the signal both day and night. The goal of installing retroreflectivity to backplates is to reduce crashes at the intersection by drawing more attention to the current phase of the signal. Backplates with retroreflective borders are listed as a Federal Highway Administration Proven Safety Countermeasure with a listed safety benefit of a 15% reduction in total crashes (https://highways.dot.gov/safety/proven-safety-countermeasures/backplates-retroreflective-borders).

Figure 1.1 shows an image of a signal head without a backplate, Figure 1.2 shows an image of a signal head with a standard black backplate, and Figure 1.3 shows an image of a signal with a retroreflective backplate.

Figure 1.1 – Signal Head without a Backplate

Figure 1.2 – Signal Head with a Black Backplate

Figure 1.3 – Signal Head with a Retroreflective Backplate

The purpose of this evaluation is to review the crash history at signalized intersections in Minnesota with retroreflective backplates to determine the impact of installing the retroreflective borders on backplates. Crashes at signals with retroreflective backplates will also be compared against crashes at signals with standard black backplates.

CHAPTER 2: RETROREFLECTIVE SIGNAL BACKPLATES IN MINNESOTA

MnDOT first installed retroreflective signal backplates at one intersection in 2016 and one in 2018. In 2019, a project was conducted that converted backplates to retroreflective backplates at 102 signalized intersections. Several more were installed in subsequent years totaling 117 intersections between 2016 and 2021 where retroreflective backplates were installed.

In addition to MnDOT intersections, a number of local agencies in Minnesota have installed retroreflective backplates at signals on their roadways.

At the MnDOT intersections with retroreflective backplates, all signal heads get the retroreflective backplates whereas local agencies may install retroreflective backplates on all signal heads or just some of the signal heads at an intersection.

CHAPTER 3: METHODOLOGY

3.1 LOCATIONS

As mentioned, there are 117 signalized intersections on MnDOT roadways that received retroreflective signal backplates between 2016 and 2019. Since those installations, two intersections have been converted to something other than a signal. Furthermore, four of the intersections are a part of interchanges, one has some restricted movements, and one is a continuous green-T intersection. Due to the uniqueness of those six intersections, they were not included in the analysis. That left 109 MnDOT intersections with retroreflective signal backplates to be analyzed in this evaluation. Those locations are shown in Figure 3.1.

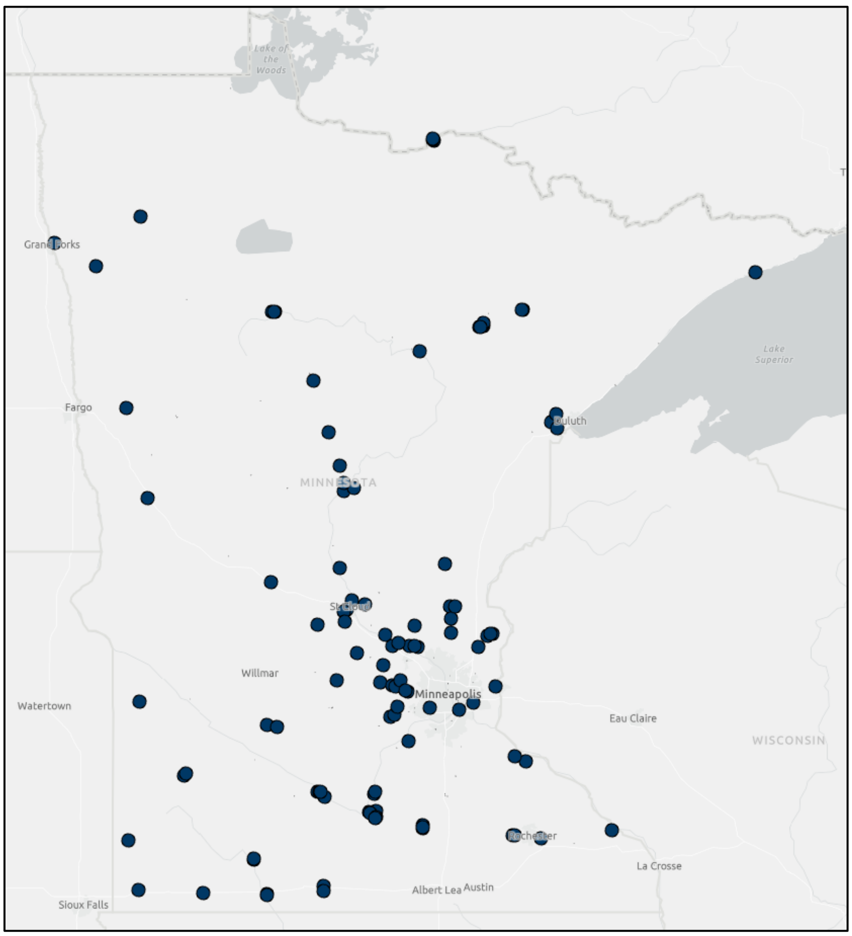

Figure 3.1 – Locations of Intersections with Retroreflective Signal Backplates for Evaluation

The analysis includes a comparison between the intersections with retroreflective signal backplates and signalized intersections without retroreflective signal backplates. To identify those comparison locations, a comparison intersection was identified for each intersection with retroreflective signal backplates. These comparison intersections were identified by being similar in layout and with similar entering volumes. All comparison intersections are also on the MnDOT roadway network. Those locations are shown in Figure 3.2.

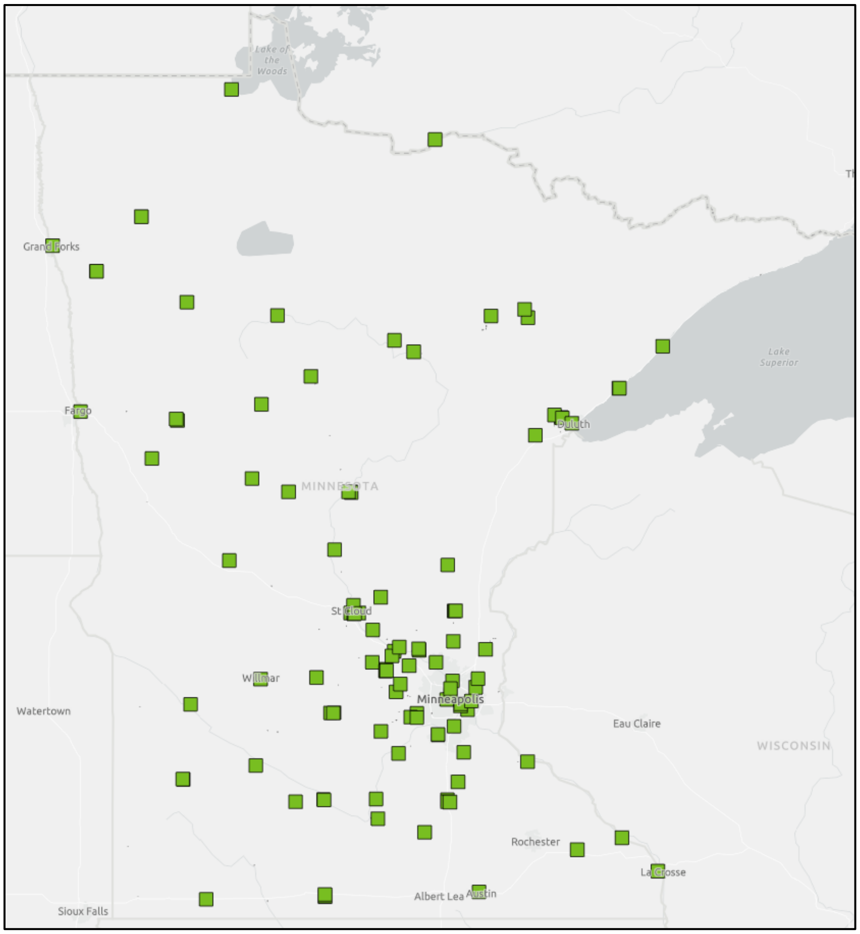

Figure 3.2 – Locations of Comparison Intersections for Evaluation

3.2 CRASH DATA

For comparison purposes, all crash data in this evaluation is analyzed by site-year. Crashes that occurred during the year of installation at each location are not included in the analysis due to varying installation dates and some sites where the actual date of install is unknown. The analysis in this evaluation was conducted in 2023, so the most recent year of data analyzed was from 2022 as there was not a complete year of data for 2023 at the time of analysis.

Crash data for the applicable years was collected spatially at each intersection. Crashes that were located within the bounds of the turn lanes of the intersection and/or associated with the intersection were included.

Appendix A highlights all fatal and suspected serious injury crashes that occurred at signals with retroreflective signal backplates, including in the year of installation.

3.3 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 existing signalized intersections comparing the crashes in a period before retroreflective backplates were installed to a period after retroreflective backplates were 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 with retroreflective backplates to similar locations without retroreflective backplates.

CHAPTER 4: RESULTS

4.1 BEFORE-AFTER ANALYSIS

The before-after analysis compares crash data at signalized intersections before the retroreflective backplates were installed and after the retroreflective backplates were installed.

4.1.1 Question Addressed

How do crashes change after retroreflective backplates are installed at a signalized intersection?

4.1.2 Locations

The analysis for this evaluation was conducted in the year 2023. Without having a full year of crash data for 2023, only crash data through 2022 was used. The 109 locations with retroreflective backplates discussed in section 3.1 were utilized for the analysis.

4.1.3 Crash Data

The before-after crash data at the 109 signalized intersections with retroreflective backplates 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 2022 being the most recent year of data. Table 4.1 shows that compiled crash data. The total entering volumes (sum of daily volumes at each site) were 2,093,467,560 vehicles in the before scenarios and 1,962,336,696 vehicles in the after scenarios. Crash rates, in units of crashes per million entering vehicles (MEV), for the before-after scenarios are also included in Table 4.1.

Table 4.1 - Before-After Crash Data at Intersections with Retroreflective Backplates

Crash Severity/Type	Before # of Crashes	After # of Crashes	Before Crash Rate	After Crash Rate
Total Crashes	1653	1519	0.790	0.774
KA Crashes	21	25	0.010	0.013
KABC Crashes	463	399	0.221	0.203
Rear End Crashes	942	762	0.450	0.388
Angle Crashes	314	399	0.150	0.203
Property Damage Only Crashes	1190	1119	0.568	0.570
Darkness Crashes	389	347	0.186	0.177

4.1.4 Crash Analysis

To compare the before-after crash data samples, a Wilcoxon signed-rank test was used. This test is used to compare two related (or dependent) samples with independent observations. However, the Wilcoxon signed-rank test does not require normality in the data which was needed given the unique distribution of the sample data. The Wilcoxon Signed Rank Test tests 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 paired observations at the retroreflective backplates sites is equal to zero (i.e., the two distributions are the same). The alternative hypothesis being tested is that the median difference between pairs of the sample observations is not equal to zero (i.e., the two distributions are different).

The analysis and testing were focused on a number of crash severities/types. Seven crash severities/types are focused on in this analysis and listed below.

- Total crashes
- Fatal (K) and suspected serious injury (A) crashes
- Fatal and all injury crashes (severities KABC)
- Rear-end crashes. A common crash type at intersections.
- Angle crashes. A common crash type at intersections that often results in severe crashes.
- Property damage only crashes.
- Darkness crashes. This includes crashes that occurred in either darkness or sunrise/sunset times when visibility is decreased from daylight conditions. The retroreflectivity of the backplates is intended to improve signal visibility during low light conditions.

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 4.2.

Table 4.2 - Results of Wilcoxon Signed-Rank Test for Before-After Analysis at Intersections with Retroreflective Backplates (Treatment Intersections)

Category	Change in Crash Rate	p-value	Significant?
Total Crashes	-2.0%	0.440	No
KA Crashes	+27.0%	0.566	No
KABC Crashes	-8.1%	0.564	No
Rear End Crashes	-13.7%	0.024	Yes
Angle Crashes	+35.6%	0.002	Yes
Property Damage Only Crashes	+0.3%	0.578	No
Darkness Crashes	-4.8%	0.226	No

As seen in Table 4.2, the addition of retroreflective signal backplates at these locations did not have a statistically significant impact on the total, KA, KABC, property damage only, or darkness crash rates at the intersections. There was a statistically significant decrease in rear and crashes and a statistically significant increase in angle crashes. Looking just at the results of Table 4.2, it does not appear the addition of retroreflective signal backplates on MnDOT signals had much of a positive benefit. However, it should be noted that the after period for these crash rates was 2020 through 2022 which saw increases in fatal and serious injury crash rates statewide. Therefore, the cross-sectional analysis will be a more telling analysis of the crash impacts of these signalized intersections by utilizing a control group.

4.1.5 Additional Analysis

Table 4.2 shows that the KA crash rates did increase in the after period compared to the before period. Though it was a statistically insignificant increase in crash rates, it warrants a look into the KA crashes that are happening at locations where retroreflective signal backplates have been installed. Using the crash data from the before-after analysis plus the data from the year of installation, all KA crashes were grouped into eight categories by type of crash. Those results can be seen in Figure 4.1.

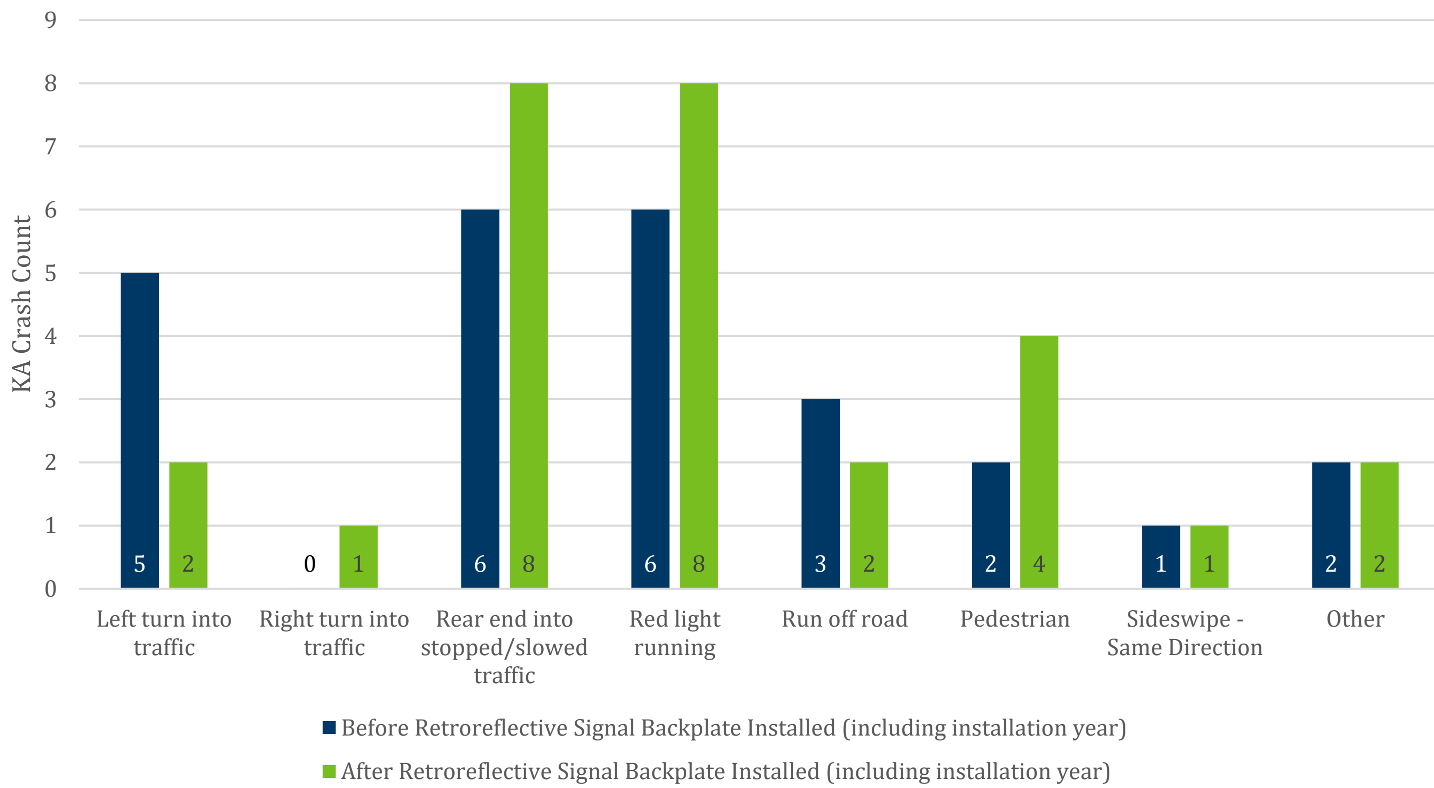

Figure 4.1 – Before and After KA Crash Counts by Category

As shown in Figure 4.1, there were increases in the number of KA crashes that involved right turning into traffic, rear ends, red light running, and pedestrians. The increase in some of these crash types indicates retroreflective signal backplates may not be having the desired impacts. However, the largest change in KA crashes with the addition of retroreflective signal backplates is a decrease in left turning crashes. Some agencies exclusively put retroreflective signal backplates on left turn signal heads, and the decrease seen here may indicate that is an appropriate use. However, more data and analysis would be needed to determine if retroreflective signal backplates can be tied to a reduction in left turning crashes.

4.2 CROSS-SECTIONAL ANALYSIS

The cross-sectional analysis takes the group of signalized intersections that have retroreflective backplates at them (treatment sites) and compares the before-after crash data there against the before-after crash data at a group of similar signalized intersections with backplates that are not retroreflective (control sites).

4.2.1 Question Addressed

How much of the crash impacts at signalized intersections can be attributed to the retroreflective backplates?

4.2.2 Locations

For this comparison, the 109 MnDOT intersections with retroreflective signal backplates were each matched to a MnDOT signalized intersection with black backplates. These 109 control locations had layouts and traffic volumes that were similar to the treatment locations. Figures 3.1 and 3.2 found earlier in this report show the locations of the treatment and control sites used in the analysis.

4.2.3 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. Table 4.3 shows the entering volumes for each scenario that were used in the analysis. The treatment sites saw a 6% decrease in entering volumes from the before to after period while the control sites saw a 10% decrease. Table 4.4 shows the compiled crash data. Crash rates, in units of crashes per million entering vehicles (MEV), for the before and after scenarios are shown in Table 4.5.

Table 4.3 - Cross-Sectional Analysis Entering Volumes

	Treatment Before	Treatment After	Control Before	Control After
Total Entering Volume (Sum of daily volumes at each site)	2,093,467,560	1,962,336,696	2,195,755,081	1,986,870,480

Table 4.4 - Cross-Sectional Crash Counts

Crash Severity/Type	Treatment Before # of Crashes	Treatment After # of Crashes	Control Before # of Crashes	Control After # of Crashes
Total Crashes	1653	1519	1532	1414
KA Crashes	21	25	24	17
KABC Crashes	463	399	435	391
Rear End Crashes	942	762	723	622
Angle Crashes	314	399	390	422
Property Damage Only Crashes	1190	1119	1095	1023
Darkness Crashes	389	347	374	367

Table 4.5 - Cross-Sectional Crash Rates

Crash Severity/Type	Treatment Before Crash Rate	Treatment After Crash Rate	Control Before Crash Rate	Control After Crash Rate
Total Crashes	0.790	0.774	0.698	0.712
KA Crashes	0.010	0.013	0.011	0.009
KABC Crashes	0.221	0.203	0.198	0.197
Rear End Crashes	0.450	0.388	0.329	0.313
Angle Crashes	0.150	0.203	0.178	0.212
Property Damage Only Crashes	0.568	0.570	0.499	0.515
Darkness Crashes	0.186	0.177	0.170	0.185

4.2.4 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. Table 4.6 shows the results of that analysis.

Table 4.6 - Results of Wilcoxon Signed-Rank Test for Before-After Analysis at Intersections without Retroreflective Backplates (Control Intersections)

Category	Change in Crash Rate	p-value	Significant?
Total Crashes	+2.0%	0.798	No
KA Crashes	-21.7%	0.341	No
KABC Crashes	-0.7%	0.894	No
Rear End Crashes	-4.9%	0.394	No
Angle Crashes	+19.6%	0.019	Yes
Property Damage Only Crashes	+3.2%	0.792	No
Darkness Crashes	+8.4%	0.940	No

As can be seen in Table 4.6, the control sites did not have statistically significant changes in crash rates in the before and after periods with the exception of angle crashes which saw a statistically significant increase in the after period. This is similar to what was seen at the treatment sites.

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 crash rates are not normally distributed. Also like the previous test, a Mann-Whitney U-Test tests 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 Table 4.7.

Table 4.7 - Results of Mann-Whitney U-Test for Cross-Sectional Analysis

Category	Treatment % Change	Control % Change	p-value	Significant?
Total Crashes	-2.0%	+2.0%	0.945	No
KA Crashes	+27.0%	-21.7%	0.719	No
KABC Crashes	-8.1%	-0.7%	0.879	No
Rear End Crashes	-13.7%	-4.9%	0.690	No
Angle Crashes	+35.6%	+19.6%	0.215	No
Property Damage Only Crashes	+0.3%	+3.2%	0.799	No
Darkness Crashes	-4.8%	+8.4%	0.616	No

As seen in Table 4.7, there are no statistically significant differences in the change in crash rates at the treatment versus the control sites. Therefore, it cannot be ruled out that the changes in crash rates are equal. Even though the treatment sites saw an increase in KA crash rates and the control sites saw a decrease in KA crash rates, the relatively small changes in numbers of KA crashes lead there to be no statistically significant difference between those results. Similarly, though the treatment sites saw greater reductions in the crash rates for total, KABC, rear end, and darkness crashes, the large p-values indicate there is not a strong statistical case to make for those reductions being significant.

The results seen here are different than what was expected since backplates with retroreflective borders are an FHWA Proven Safety Countermeasure. It should be noted that all of the signals analyzed in this study are MnDOT signals which are already designed to a high standard with things such as black backplates, intersection lighting, and signals oriented over travel lanes. It is possible that due to these pre-existing design standards the retroreflective signal backplates had a minimal impact on MnDOT signals whereas they may have a more significant impact on some other signal systems. However, more study would be needed to determine if that is the case.

CHAPTER 5: CONCLUSIONS

The results of the analyses conducted show that the addition of retroreflective signal backplates on MnDOT signalized intersections did not result in impacts to crash rates that were statistically significantly different from similar signalized intersections without retroreflective signal backplates. These findings contradict what was expected since backplates with retroreflective borders are listed as an FHWA Proven Safety Countermeasure. It is possible that MnDOT signals were already designed with enough features to make them visible, so that adding retroreflective borders to the backplates did little to increase conspicuity.

Future analysis that includes signals with retroreflective backplates that are not on the MnDOT network may be beneficial. Additionally, future analysis that includes more years of after data could also help draw a clearer picture of the impacts of backplates with retroreflective borders.

APPENDIX A
SIGNALS WITH RETROREFLECTIVE BACKPLATES KA CRASH DETAILS

Details about the KA crashes that occurred at signals after retroreflective backplates were installed are included in Table A.1.

Table A.1: K & A Severity Crashes at Signals with Retroreflective Backplates

Location	Install Year	Crash Year	Crash Severity	Description
MN 7/Main Street, St Bonifacius	2019	2021	A	Red light running
US 8/Bennet Road, Lindstrom	2019	2019	A	Right turn into pedestrian
US 53/13th St, Virginia	2020	2022	A	Left turn into pedestrian
US 2/CSAH 11/Moberg Drive, Bemidji	2019	2019	K	Red light running
US 2/Menards Entrance, Bemidji	2019	2020	A	Rear end into stopped/slowed traffic
US 10/CSAH 31, Hawley	2019	2020	A	Rear end into stopped/slowed traffic
US 169/TH 282, Jordan	2019	2020	A	Rear end into stopped/slowed traffic
US 169/TH 282, Jordan	2019	2022	K	Rear end into stopped/slowed traffic
US 169/TH 282, Jordan	2019	2022	A	Rear end into stopped/slowed traffic
MN 15/CSAH 29, Sauk Rapids	2019	2021	A	Red light running
MN 15/CSAH 29, Sauk Rapids	2019	2020	A	Red light running
MN 65/CSAH 5, Isanti	2019	2020	K	Rear end into stopped/slowed traffic
US10/Rolling Ridge Rd, Becker	2019	2021	A	Red light running
US10/Rolling Ridge Rd, Becker	2019	2022	A	Rear end into stopped/slowed traffic
US 169/CSAH 4, Zimmerman	2019	2021	A	Red light running
US 14/2nd Ave, Byron	2019	2021	A	Rear end into stopped/slowed traffic
US 14/2nd Ave, Byron	2019	2022	K	Rear end - other
US 14/Jacobs Street, New Ulm	2019	2019	A	Left turn into traffic
US 169/Howard St, Hibbing	2019	2021	K	Pedestrian crossing

Table A.1 (continued)

US 59/Ryans Road, Worthington	2019	2022	A	Left turn into traffic
US 169/Webster Road, Mankato	2019	2021	K	Run off road
US 169/MN 22 South Junction, St. Peter	2019	2021	A	Sideswipe/Cut Off
US 169/MN 22 South Junction, St. Peter	2019	2022	A	Run off road
US 169/MN 99/Broadway, St Peter	2019	2020	K	Left turn into pedestrian
US 53/Ugstad Rd, Hermantown	2019	2020	A	Spinout - ice
US 53/Ugstad Rd, Hermantown	2019	2021	A	Red light running
MN 61/Lower Afton Road, St. Paul	2019	2020	K	Red light running
US 75/MN 23, Pipestone	2019	2022	A	Right turn into traffic