DEPARTMENT OF TRANSPORTATION

Traffic Safety Evaluation at Reduced Conflict Intersections in Minnesota

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Office of Traffic Engineering

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Between 2010 and 2020, 49 Reduced Conflict Intersections (RCIs) were installed on Minnesota Department of Transportation (MnDOT) roadways. The RCI is an alternative intersection layout that is intended to provide safety benefits by limiting the number of points within an intersection that two or more vehicle paths might intersect. Both a before-after analysis at RCIs and a cross-sectional analysis comparing RCIs to untreated intersections were conducted. With the installation of an RCI, both analyses yielded statistically significant decreases in fatal and serious injury crashes, angle crashes, and fatal and serious injury angle crashes. Statistically significant increases in rear-end crashes were found. Both analyses showed no significant changes to sideswipe crashes or total crashes. Based on these results, severity shift in crashes has been seen at the RCIs in Minnesota. The overall number of crashes have not changed, but the high-severity crashes have been reduced while property damage crashes have increased. The large decreases in severe crashes at RCI locations indicate the RCI can be an effective safety treatment.

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TRAFFIC SAFETY EVALUATION AT REDUCED CONFLICT INTERSECTIONS IN MINNESOTA

FINAL REPORT

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LIST OF ABBREVIATIONS & DEFINITIONS OF TERMS

Acronym	**Meaning**
KA	Fatal and Serious Injury Crash
MEV	Million Entering Vehicles
MnDOT	Minnesota Department of Transportation
RCI	Reduced Conflict Intersection
RCUT	Restricted Crossing U-Turn

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.
- N Crash: Property damage only crash. The crash resulted in property damage with no injuries for anyone involved in the crash.

Crash Types:

- Angle: The front of a vehicle strikes the side of another vehicle at a perpendicular angle.
- Rear End: The front of a vehicle strikes the rear of another vehicle travelling in the same direction.
- Sideswipe: A vehicle strikes another vehicle in an indirect way that results in the sides of each vehicle colliding with one another. This can occur when vehicles are travelling in either the same or opposite directions.
- Intersection Related: This can include any type of crash but is specifically noted by the officer writing the crash report that it occurred in a manner or at a location that is related to an intersection.

Other Definitions:

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

EXECUTIVE SUMMARY

Between 2010 and 2020, 49 Reduced Conflict Intersections (RCIs) were installed on Minnesota Department of Transportation (MnDOT) roadways. The RCI is an alternative intersection layout that is intended to provide safety benefits by limiting the number of points within an intersection that two or more vehicle paths might intersect. Specifically, the design of the intersection is intended to reduce the likelihood that vehicles travelling in different directions will collide at various angles thereby reducing the number of crashes that result in fatalities or serious injuries. This report includes the results of both a before-after analysis at RCIs and a cross-sectional analysis comparing RCIs to untreated intersections.

With the installation of an RCI, the before-after analysis yielded the following statistically significant results:

- 69% decrease in fatal and serious injury crashes
- 70% decrease in angle crashes
- 100% decrease in fatal and serious injury angle crashes
- 103% increase in rear-end crashes

The cross-sectional analysis delivered similar results. There were clear and statistically significant reductions in the number of fatal and serious injury crashes reported after these intersections were converted to RCIs. Both analyses showed no significant changes to sideswipe crashes or total crashes. Based on these results, severity shift in crashes has been seen at the RCIs in Minnesota. The overall number of crashes have not changed, but the high-severity crashes have been reduced while property damage crashes increased.

The large decreases in severe crashes at RCI locations indicate the RCI can be an effective safety treatment.

CHAPTER 1: INTRODUCTION

A Reduced Conflict Intersection (RCI), also known as a Restricted Crossing U-Turn (RCUT) or J-turn, is an at-grade intersection design used on high-speed, multi-lane expressways. The goal of an RCI is to improve safety by reducing the number and severity of angle crashes. From 2015 through 2019, 18% of all fatal and serious injury crashes in Minnesota were caused by angle crashes at intersections. Figure 1.1 shows the layout of a standard at-grade expressway intersection and Figure 1.2 shows the layout of an RCI.

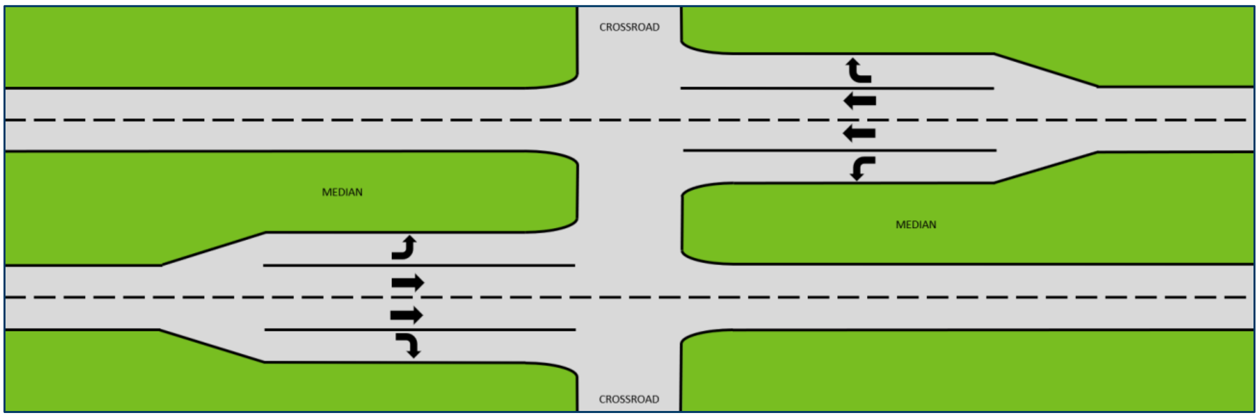

Figure 1.1 - Standard At-Grade Expressway Intersection Layout

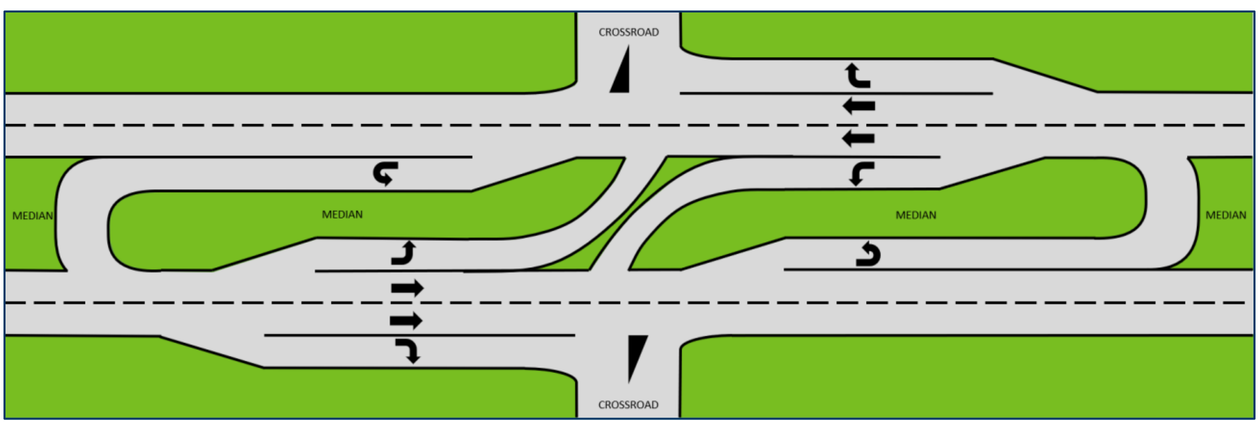

Figure 1.2 - Standard At-Grade Expressway Intersection Layout

At an RCI, vehicles on the mainline retain full access while those on the crossroad may only make right turns. Vehicles on the crossroad wishing to either turn left onto the mainline or continue straight through on the crossroad must make a right turn onto the mainline then make a U-turn to get onto the opposing direction of the mainline. Those vehicles can then turn right onto the crossroad or stay on the mainline. While the travel distance for those vehicles is increased, travel time is typically not significantly impacted due to the need to only find gaps in one direction of opposing traffic at a time at an RCI.

With the RCI eliminating the option for vehicles on the crossroad to travel straight through the middle of the intersection, the overall likelihood of right-angle crashes is reduced. Right-angle crashes, commonly referred to as T-bone crashes, often have severe outcomes.

High-speed roadways with wide medians and/or side-street stop-controlled intersections may present greater risk of severe angle crashes. Potential solutions at these sites include signals, RCIs, or grade separation. Signalization often does not protect angle crashes while grade separation is often cost prohibitive. This RCIs are a lower-cost strategy that may be more effective at reducing these severe angle crashes.

The purpose of this evaluation is to review the crash history at RCIs in Minnesota to determine what impact the installation of RCIs has on crashes and crash severity. Crashes at RCIs will also be compared against crashes at rural signals on high-speed roadways as well as at low-volume interchanges.

CHAPTER 2: HISTORY OF RCIs IN MINNESOTA

The first RCI in Minnesota was installed during 2010 in Willmar. As of the end of 2020, there were 49 RCIs in Minnesota. There are 34 more RCIs that are either already planned or under consideration for construction in the next few years. Table 2.1 lists the number of RCIs constructed each year in Minnesota.

Table 2.1 - Number of RCIs Constructed Each Year in Minnesota

Year	Number of RCIs Constructed
2010	1
2011	0
2012	4
2013	1
2014	3
2015	2
2016	2
2017	8
2018	7
2019	14
2020	7

The RCIs in Minnesota include a variety of layouts. RCIs are at both four and three-leg intersections, include U-turns on either both sides or just one side of the intersection, have medians that have one or two left turning movements, and have U-turn distances that range from 350 feet to 2100 feet away from the center of the intersection. One RCI in Minnesota is signalized while the rest are unsignalized.

Many of the earlier RCI locations were likely selected as reactive safety treatments due to high crash rates and/or frequent severe crashes. Some of the later RCIs were selected as proactive safety treatments.

Appendix A lists traits and locations of each of the existing RCIs in Minnesota.

CHAPTER 3: METHODOLOGY

3.1 LOCATIONS

As mentioned, there are 49 RCIs that have been constructed in Minnesota through the year 2020. Appendix A lists traits and locations of each of the existing RCIs in Minnesota. Figure 3.1 shows those locations on a map. As mentioned, there are also 34 locations where RCIs are either planned or under consideration to be constructed in the next few years.

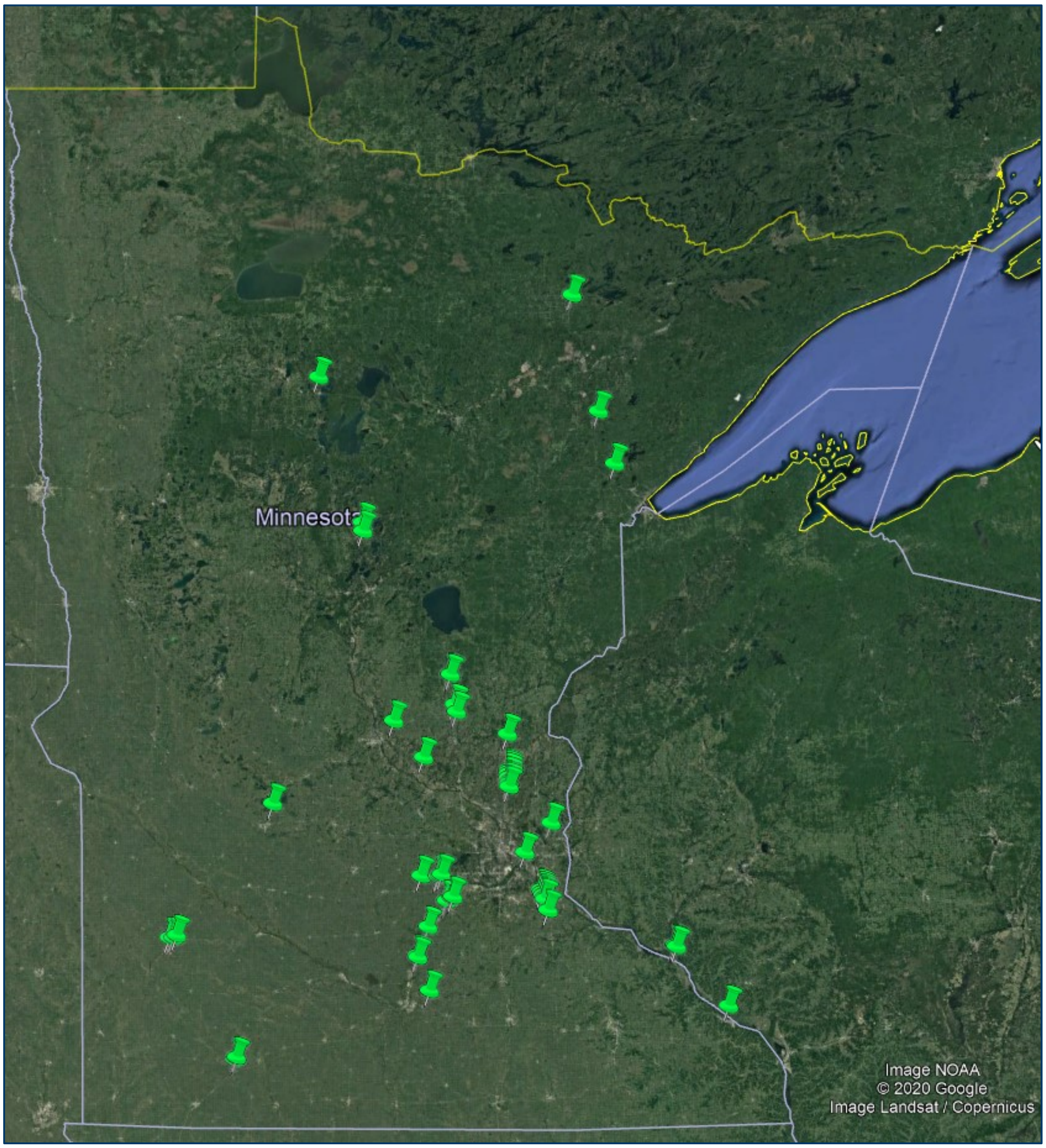

Figure 3.1 - RCI Locations in Minnesota

Four locations with existing RCIs are not included in any analysis in this evaluation. Those locations are:

MN 65 & Viking Boulevard in East Bethel

This is a signalized RCI with dual right turn lanes and dual U-turn lanes. This is not included in the analysis because the layout and operations of this RCI are significantly different from the other RCI locations. This RCI was constructed in 2019.

MN 62 & Carmen Lane in Mendota Heights

This intersection is located within 1/3 of a mile of signalized intersections on either side along MN 62. After review of the crashes at this intersection, 21 of the 25 crashes since 2015 (this RCI was constructed in 2017) are clearly due to congestion/signal backups along MN 62 while the other four crashes here might also be due to congestion/signal backups along MN 62. Because of the overwhelming influence of the adjacent signals on the crashes at this location, it is not included in the analysis. No K or A crashes have been reported at this intersection since 2015.

MN 371 & County Road 112 and MN 371 & County Road 168/107 in Pequot Lakes

Both of these are RCIs located on a newly constructed stretch of MN 371 that bypasses the downtown of Pequot Lakes. Since these are on a new stretch of highway, there is no "before" data at these locations. Because of this lack of data for comparison, these locations are not used in this analysis.

3.2 CRASH DATA

For comparison purposes, all crash data in this evaluation is analyzed by site-year. The year of construction at each location is not included in the analysis. The analysis in this evaluation was conducted in 2020, so the most recent year of data analyzed was from 2019 as there was not a complete year of data for 2020 at the time of analysis.

Crash data for the applicable years was collected spatially at each location. At locations where there is an existing RCI, the crashes located within 100 feet beyond the median U-turns on the major road and within 100 feet beyond the stop bar on the minor road were included. At locations where there is not an existing RCI, the crashes located within the turn lanes on the major road and within 100 feet of the stop bar were included. Depending on the location of the median U-turns or the length of turn lanes, the size of the area of crash data collection differs by location.

Detailed crash numbers by year and type at each RCI location can be seen in Appendix B. Appendix C highlights all fatal and suspected serious injury crashes that occurred at locations with an RCI. Appendix D highlights all fatal and suspected serious injury crashes that occurred in the year of construction at RCIs.

3.3 ANALYSIS OVERVIEW

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

A before-after analysis of locations with an RCI.

This analysis focuses on existing RCI locations comparing the crashes in a period before RCI construction to a period after RCI construction. 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 RCIs to similar locations without RCIs.

A comparison to low-volume interchanges and rural signals.

This analysis compares the crash data at locations with RCIs to locations with low-volume interchanges as well as locations with rural signals.

Each of these three analyses first measures the frequency of motor vehicle crashes, adjusted for traffic volume, at the RCI sites or comparison sites and then conducts a corresponding statistical test on those results.

The first analysis (the before-after analysis) compares crash and traffic volume data from multiple years before and after RCI construction. After that initial test of the RCI locations, the next two analyses complement the first analysis by comparing the RCI sites with other types of comparable intersections.

CHAPTER 4: RESULTS

4.1 BEFORE-AFTER ANALYSIS

The before-after analysis compares crash data at RCI locations before the RCI was installed and after the RCI was installed.

4.1.1 Question Addressed

How do crashes change after an RCI is installed at a location?

4.1.2 Locations

The analysis for this evaluation was conducted in the year 2020. Without having a full year of crash data for 2020, there is no after data for the RCIs constructed in 2019 or 2020. Those locations are therefore not utilized in the analysis as treatment sites.

This leaves 25 RCI locations that have at least one site-year of before and one site-year of after data which totals to 89 site-years of before data and 89 site-years of after data. Figure 4.1 shows the locations of the included sites.

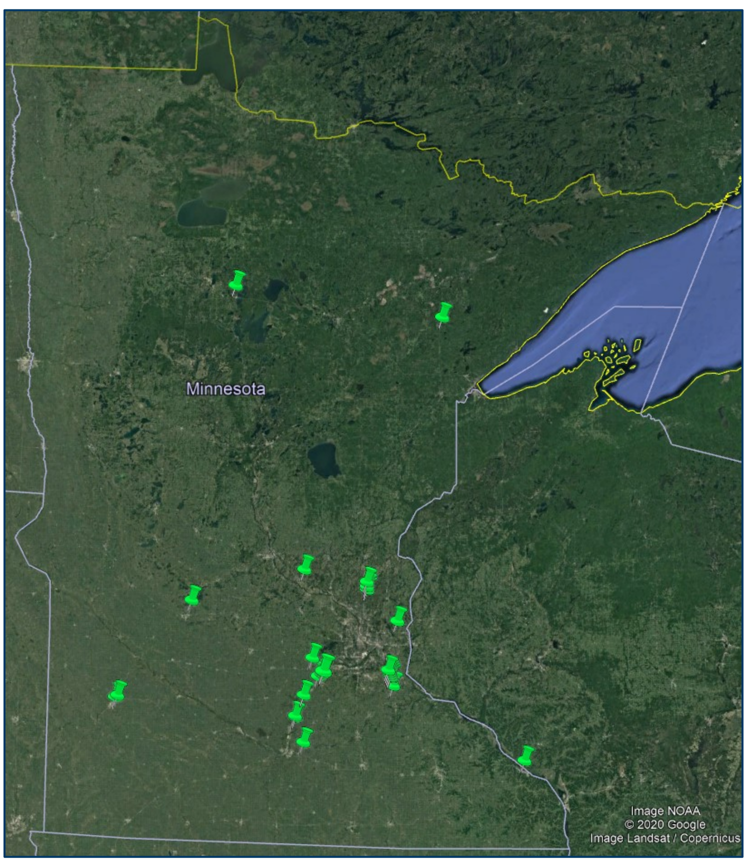

Figure 4.1 – Locations for Before-After Analysis

4.1.3 Crash Data

The before-after crash data at the 25 RCI locations was collected and compiled. Table 4.1 shows that compiled crash data. The total entering volumes (sum of daily volumes at each site) were 696,248,993 vehicles in the before scenarios and 720,974,828 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. A graphical breakdown showing the locations of the after crashes at RCIs for angle, rear end, and sideswipe crashes can be seen in Appendix E.

Table 4.1 - Before-After Crash Data at RCIs

Crash Severity/Type	Before # of Crashes	After # of Crashes	Before Crash Rate	After Crash Rate
K Crashes	10	1	0.014	0.001
A Crashes	12	6	0.017	0.008
KA Crashes	22	7	0.032	0.010
B Crashes	59	26	0.085	0.036
C Crashes	79	56	0.113	0.078
N Crashes	186	245	0.267	0.340
Total Crashes	346	334	0.497	0.463
Angle Crashes	127	39	0.182	0.054
KA Angle Crashes	15	0	0.022	0.000
Intersection Related Crashes	209	133	0.300	0.184
Rear-End Crashes	56	118	0.080	0.164
Sideswipe Crashes	35	48	0.050	0.067

4.1.4 Crash Analysis

To compare the before-after crash data samples, a Wilcoxon signed-rank test was used. Like a paired samples t-test, 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 RCIs 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 six crash severities/types. These are based on both the expected benefits of RCIs as well as commonly heard concerns about RCIs. These focus types are listed below.

- Fatal (K) and suspected serious injury (A) crashes. RCIs are an alternative intersection intended to improve safety by reducing crashes with these serious outcomes.

- Angle crashes. This is the target crash type RCIs are intended to reduce.
- K and A angle crashes. These are the most severe outcome types of the target crash type that RCIs are intended to reduce.
- Rear-end crashes. It is commonly heard that RCIs will contribute to an increase in rear-end crashes.
- Sideswipe crashes. It is commonly heard that RCIs will contribute to an increase in sideswipe crashes.
- Total crashes. RCIs are intended to reduce the most severe types of crashes at the intersections they are installed at, but not necessarily intended to reduce overall 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 4.2.

Table 4.2 - Results of Wilcoxon Signed-Rank Test for Before-After Analysis at RCIs

Category	Change in Crash Rate	p-value	Significant?
KA Crashes	-69.3%	0.030	Yes
Angle Crashes	-70.3%	0.001	Yes
KA Angle Crashes	-100.0%	0.005	Yes
Rear-End Crashes	+103.5%	0.002	Yes
Sideswipe Crashes	+32.4%	0.316	No
Total Crashes	-6.8%	0.737	No

As seen in Table 4.2, the conversion of these intersections to RCIs resulted in statistically significant decreases in fatal and serious injury crashes (KA crashes), angle crashes, and fatal and serious injury angle crashes. Additionally, there was found to be a statistically significant increase in rear-end crashes as a result of the conversions to RCIs. Though there were increases in sideswipe crashes and decreases in total crashes, these changes were not found to be statistically significant.

As seen in Table 4.1, the crash rates for all injury type crashes decreased with the installation of RCIs, but the crash rates for non-injury crashes (property damage only crashes) increased. With no statistically significant change in total crashes shown in Table 4.2, the data is suggesting the installation of RCIs result in a severity shift of crashes from higher to lower severities.

It is noted that the crash reporting system behind the crash data in Minnesota underwent changes in the beginning of 2016. While this upgrade improved the crash data system in many ways, a change in the percentage of injury severity crashes was found. Two injury severity definitions were changed to align with national standard definitions, though the underlying scale used to rank crash severity remained unchanged.

- “A – Incapacitating injury” became “A – Suspected serious injury”
- “B – Non-incapacitating injury” became “B – Suspected minor injury”

As the result of these label changes, Minnesota experienced a dramatic increase in A and B severity crashes from 2015 to 2016 (increasing by 83% and 51% for A and B crashes, respectively). Based on this change, some of the locations in the before-after analyses may have been impacted. However, Table 4.1 shows that A and B severity crashes both experienced large decreases at the RCI locations. This emphasizes the decreases seen at RCI locations.

4.2 CROSS-SECTIONAL ANALYSIS

The cross-sectional analysis takes a group of locations that have RCIs 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 RCIs (control sites).

4.2.1 Question Addressed

How much of the crash reduction can be attributed to RCIs?

4.2.2 Locations

For this comparison, only RCI locations that had at least three years of “after” data were included. There are 13 locations that have RCIs during this 2017 through 2019 period.

For the control group, these locations should be similar to the treatment sites but cannot have had an RCI at them during the entire 2017 through 2019 period. The sites that were included in this group were the seven locations where RCIs were constructed in 2020, the 34 locations with future RCIs planned/considered, and one additional location that was a potential RCI site but ended up with a more standard intersection reconstruction in 2020. That totaled to 42 locations for the control group.

When determining control sites to be used in a comparison group against treatment sites, locations are typically chosen that have similar characteristics to the treatment sites. Since the control group in this evaluation is made up of sites that are also selected for RCIs, the characteristics are therefore similar to the treatment sites. However, these locations for future RCIs may have been chosen due to a crash history at the site which could introduce some bias into the results of the comparison. RCI location selection is not exclusively based on crash history and, due to the similar characteristics of these intersections, this control group is used in the analysis with the potential bias noted.

Figure 4.2 shows the locations of the control and treatment sites used in this analysis.

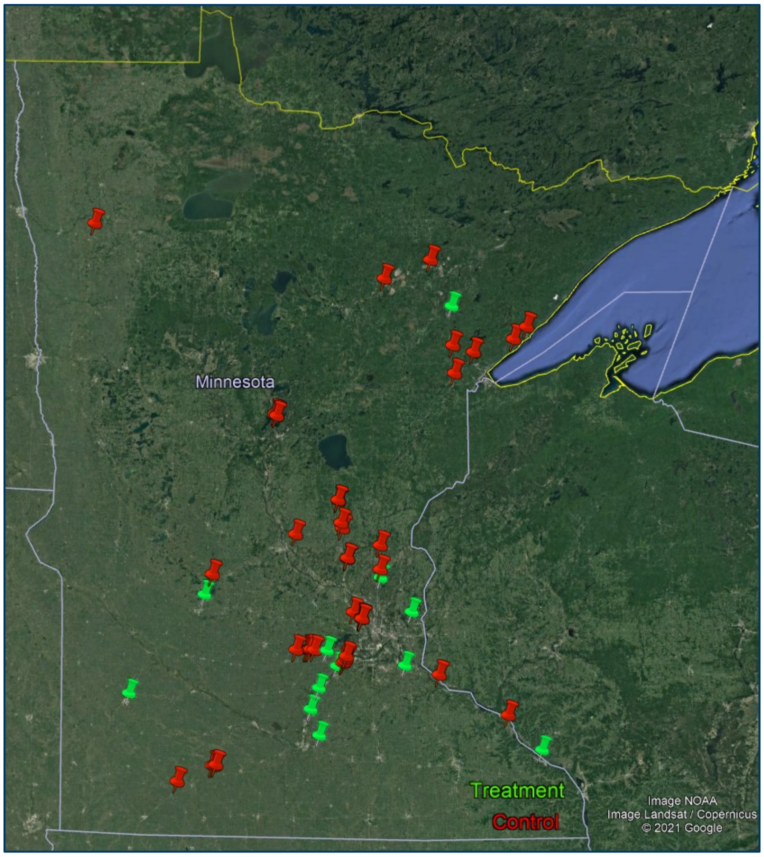

Figure 4.2 – Locations for Cross-Sectional Analysis

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 before period was a three-year period before an RCI was installed, and the after period was the three years from 2017 through 2019 where an RCI was in place. At the control sites, the before period was the three years from 2013 through 2015 and the after period was the three years from 2017 through 2019. The change in crash rates from before to after at the treatment sites was compared to the change in crash rates from before to after at the control sites.

For this cross-sectional analysis, all the before periods in this analysis were before 2016 and all the after periods in this analysis were after 2016. These time periods were selected to allow for a comparison between the treatment and control groups so that neither group was disproportionally impacted by the 2016 statewide changes to the crash data.

The cross-sectional crash data at the 13 RCI locations and 42 non-RCI locations was collected and compiled. Table 4.3 shows the entering volumes for each scenario that were used in the analysis. 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)	284,836,328	301,404,590	800,142,753	848,273,323

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
K Crashes	4	1	5	3
A Crashes	6	4	7	8
KA Crashes	10	5	12	11
B Crashes	33	11	42	53
C Crashes	37	28	57	43
N Crashes	86	104	196	173
Total Crashes	166	148	307	282
Angle Crashes	57	18	99	114
KA Angle Crashes	7	0	9	11
Intersection Related Crashes	105	55	184	187
Rear-End Crashes	26	61	53	65
Sideswipe Crashes	19	15	41	22

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
K Crashes	0.014	0.003	0.006	0.004
A Crashes	0.021	0.013	0.009	0.009
KA Crashes	0.035	0.017	0.015	0.013
B Crashes	0.116	0.036	0.052	0.062
C Crashes	0.130	0.093	0.071	0.051
N Crashes	0.302	0.345	0.245	0.204
Total Crashes	0.583	0.491	0.384	0.332
Angle Crashes	0.200	0.060	0.124	0.134
KA Angle Crashes	0.025	0.000	0.011	0.013
Intersection Related Crashes	0.369	0.182	0.230	0.220
Rear-End Crashes	0.091	0.202	0.066	0.077
Sideswipe Crashes	0.067	0.050	0.051	0.026

4.2.4 Crash Analysis

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 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 (RCI 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 4.6.

Table 4.6 - Results of Mann-Whitney U-Test for Cross-Sectional Analysis

Category	Treatment % Change	Control % Change	p-value	Significant?	Result Interpretation
KA Crashes	-52.75%	-13.53%	<0.001	Yes	KA crashes at RCIs < KA crashes at controls
Angle Crashes	-70.16%	8.62%	<0.001	Yes	Angle crashes at RCIs < Angle crashes at controls
KA Angle Crashes	-100.00%	15.29%	<0.001	Yes	KA Angle crashes at RCIs < KA Angle crashes at controls
Rear-End Crashes	121.72%	15.68%	<0.001	Yes	Rear-end crashes at RCIs > Rear-end crashes at controls
Sideswipe Crashes	-25.39%	-49.39%	0.098	No*	Sideswipe crashes at RCIs = Sideswipe crashes at controls
Total Crashes	-15.74%	-13.36%	0.890	No	Total crashes at RCIs = Total crashes at controls

*Statistically significant at α = 0.10

As seen in Table 4.6, the RCI sites showed statistically significant decreases in fatal and serious injury (KA) crashes, angle crashes, and fatal and serious injury (KA) angle crashes. These results line up with the goals of RCIs and are similar to what was seen in the before-after analysis. The installation of RCIs also showed a statistically significant increase in rear-end crashes with no statistically significant changes at the 0.05 significance level for sideswipe or total crashes.

4.3 COMPARATIVE LOW-VOLUME INTERCHANGE AND RURAL SIGNAL ANALYSIS

RCIs typically replace side-street, stop-controlled intersections on high-speed expressways. One alternative to the RCI would be a grade separated intersection, or an interchange. Interchanges require more right-of-way and have significantly higher costs associated with them as compared to an RCI. Another alternative to the RCI would be a signalized intersection.

This analysis compares the crash data at interchanges with volumes similar to what would be found at an RCI as well as at signalized intersections with volumes and characteristics similar to what would be found at an RCI to the crash data at RCIs.

4.3.1 Question Addressed

How do RCIs compare with alternative strategies for high-speed expressway intersections?

4.3.2 Locations

There are over 700 interchanges in Minnesota including many that serve very high volumes of traffic. To be able to get a set of interchanges that would be able to be meaningfully compared to RCIs, the volumes had to be considered. High volume interchanges, such as those that serve the meeting of two Interstate Highway System routes, would not be locations where an RCI would ever be considered. Because of that, only low-volume interchanges were selected. Low volume, in this case, means daily volumes of 45,000 or less on the mainline with average daily volumes of 6,000 or less on the minor approaches. These volumes represent the upper end of the volumes seen at RCIs in Minnesota. Using those filters, 225 interchanges were selected and crash data from 2017 through 2019 was used.

Signalized intersections are utilized on a wide variety of intersection types, so to get a meaningful comparison site for RCIs, only signalized intersections that are on high-speed, rural roadways with the same volume constraints as the low-volume interchanges were used. Signalized intersections that include interchange ramps were not included. Using those filters, 19 intersections were selected and crash data from 2017 through 2019 was used.

Like in the cross-sectional analysis, the 13 RCI locations that were fully in place from 2017 through 2019 were used for comparison. Using only 2017 through 2019 data avoids any inconsistencies between the pre-2016 and post-2016 crash data due to the statewide changes previously discussed.

4.3.3 Crash Data

The area included when gathering crash data at RCIs was previously discussed. For low-volume interchanges, all crashes that were located within 100 feet of the physical gore or curb at the outermost connection of the interchange were included. For rural, high-speed signals, all crashes that were in the bounds of the turn lanes on all approaches were included.

The following tables show the total entering volumes, the number of crashes, and crash rates (crashes per MEV) from 2017 through 2019 at the selected locations.

Table 4.7 - 2017-2019 Comparative Analysis Entering Volumes

	RCI (13 sites)	Rural Signals (19 sites)	Low-Volume Interchanges (225 sites)
Total Entering Volume (sum of daily volumes at each site)	301,404,590	339,898,950	3,168,166,785

Table 4.8 - 2017-2019 Comparative Analysis Crash Volumes

Crash Type/Severity	RCI (13 sites)	Rural Signals (19 sites)	Low-Volume Interchanges (225 sites)
K Crashes	1	1	19
A Crashes	4	5	29
B Crashes	11	23	299
C Crashes	28	44	392
N Crashes	104	157	2,628
Total Crashes	148	230	3,367
Angle Crashes	18	49	418
KA Angle Crashes	0	0	14
Intersection Related Crashes	55	167	658
Rear-End Crashes	61	139	722
Sideswipe Crashes	15	4	399

Table 4.9 - 2017-2019 Comparative Analysis Crash Rates

Crash Type/Severity	RCI (13 sites)	Rural Signals (19 sites)	Low-Volume Interchanges (225 sites)
K Crashes	0.003	0.003	0.006
A Crashes	0.013	0.015	0.009
K+A Crashes	0.017	0.018	0.015
Total Crashes	0.491	0.677	1.063
Angle Crashes	0.060	0.144	0.132
KA Angle Crashes	0.000	0.000	0.004
Intersection Related Crashes	0.182	0.491	0.208
Rear-End Crashes	0.202	0.409	0.228
Sideswipe Crashes	0.050	0.012	0.126

Figures 4.3 and 4.4 illustrate the crash rates of some of the target crash types from Tables 4.8 and 4.9.

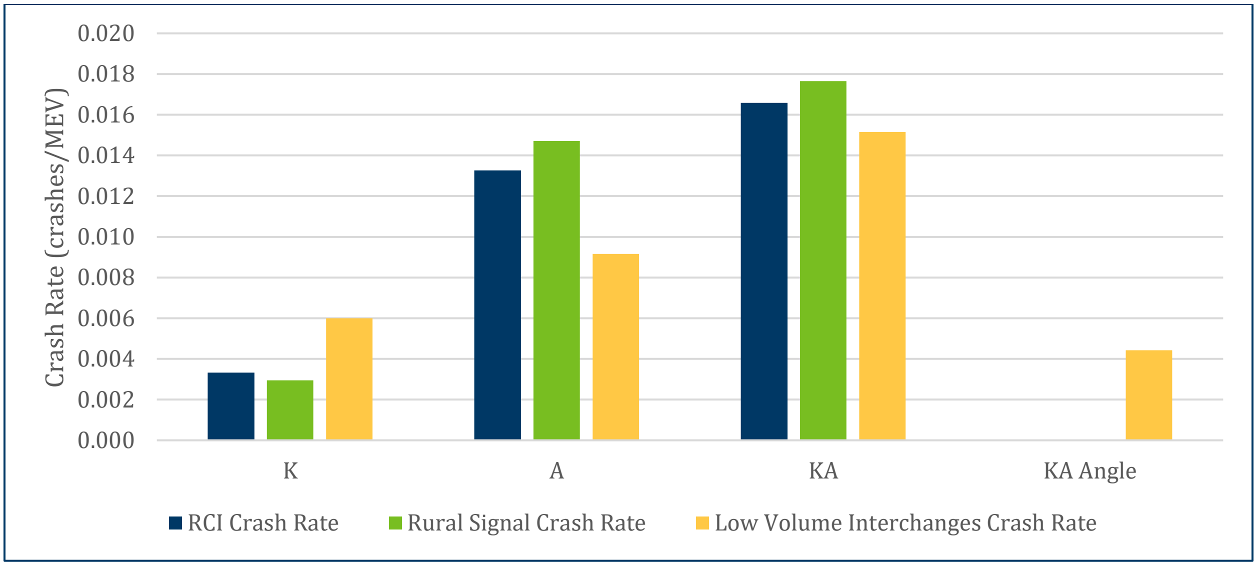

Figure 4.3 – Comparative Analysis Severe Crash Rates

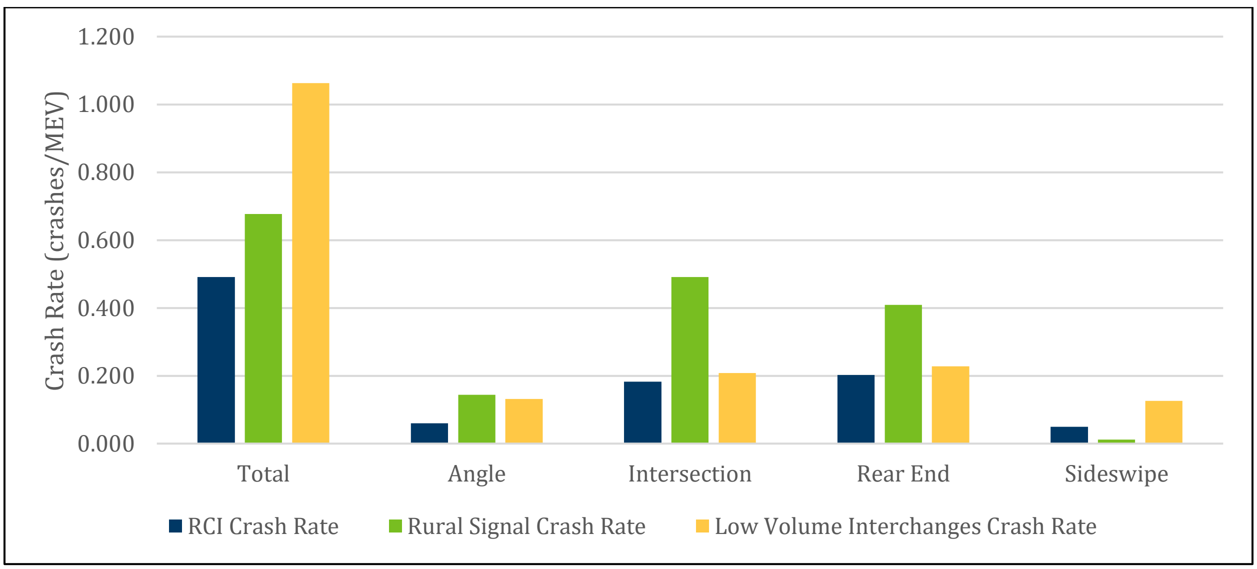

Figure 4.4 – Comparative Analysis Other Crash Rates

4.3.4 Crash Analysis

Using the crash and traffic volume data, any statistically significant differences between crash rates for these three intersection types were checked. As with the earlier analyses, the observed data are not normally distributed, so the original plan to use an ANOVA had to be substituted in favor of the nonparametric version of the test, the Kruskal-Wallis rank sum test.

A Kruskal-Wallis test is another type null hypothesis test, and it is ideal for this final analysis because it allows for the comparison of three or more groups at a time. The calculation for the Kruskal-Wallis also differs slightly from the other two nonparametric tests, which use medians as their average values, while this test computes and compares groups' mean ranks. Though that is a small mathematical distinction, for the purpose of this report, there is not a meaningful difference between the median and mean rank values of the sample groups, so the distinction has little practical significance. This report will continue to use the term median as the average value tested for the Kruskal-Wallis test since, in many cases, they can end up being the same.

For the Kruskal-Wallis test, the null hypothesis being tested is that all three groups have equal crash rates (i.e., the median difference between all three groups of observations is equal to zero). The alternative hypothesis being tested is that all three groups do not have equal crash rates. In other words, if one group's average (median) crash rate is from either of the other two, the null hypothesis would be rejected. A Wilcoxon rank sum test with continuity correction was then used on the Kruskal-Wallis results to determine if they are significantly different from one another compared to a significance level of 0.05. The results of this testing are shown in Table 4.10. Any crash types or severities that did not have a statistical significance difference between the intersection types are not included in Table 4.10.

Table 4.10 - 2017-2019 Comparative Analysis Significance Testing Results

Crash Type/Severity	RCIs vs Interchanges p-value	RCIs vs Signals p-value	Signals vs Interchanges p-value	Result Interpretation
Total Crashes	**0.003**	0.880	**0.005**	Total Crashes at Interchanges > Total Crashes at RCIs & Total Crashes at Interchanges > Total Crashes at Signals
N Crashes	**0.003**	0.788	**0.003**	N Crashes at Interchanges > N Crashes at RCIs & N Crashes at Interchanges > N Crashes at Signals
Angle Crashes	0.163	**0.092****	0.107	
Sideswipe Crashes	**0.067****	**0.067****	**0.001***	Sideswipe Crashes at Interchanges > Sideswipe Crashes at Signals
Intersection Related Crashes	0.183	**0.014**	**0.001***	Intersection Related Crashes at Signals > Intersection Related Crashes at RCIs & Intersection Related Crashes at Signals > Intersection Related Crashes at Interchanges

*Less than 0.001
**Statistically significant at $\alpha = 0.10$

Reviewing the results from Table 4.10 and comparing them to Figures 4.3 and 4.4, it can be seen that at a significance level of 0.05:

- The average crash rate for total crashes at interchanges is higher than at RCIs and signals.
- The average crash rate for property damage only crashes at interchanges is higher than at RCIs and signals.
- The average crash rate for sideswipe crashes at interchanges is higher than at signals.
- The average crash rate for intersection related crashes at signals is higher than at RCIs and interchanges.

If a significance level of 0.10 were to be used rather than 0.05, the following conclusions could be drawn:

- The average crash rate for angle crashes at signals is higher than at RCIs.
- The average crash rate for sideswipe crashes at interchanges is higher than at RCIs.
- The average crash rate for sideswipe crashes at RCIs is higher than at signals.

With relatively small numbers of K and A crashes at RCIs and rural signals, as shown in Table 4.8, there is not the ability to draw clear distinctions between the intersection types regarding severe crashes.

RCIs tend to have lower crash rates compared to low-volume interchanges when it comes to overall crashes and lower crash rates compared to signals when it comes to angle crashes. The low rate of angle crashes at RCIs is in line with the other results from this study. Though the before-after and cross-sectional analyses showed increases in rear-end crashes at RCIs, they are not statistically significantly different than the other intersection types and Figure 4.4 shows they appear to be less common at RCIs than at signals and interchanges.

Intersection related crashes are crashes that the attending officer determined were located at or impacted by the presence of an intersection. With RCIs, the area included to collect crashes is quite large due to the location of the median U-turns. Similarly, interchanges encompass large areas. Because of that, a portion of the RCI crashes that occur within that large envelope may not be related to the RCI but just happened to occur at that location. That is always the case with any intersection, but the large envelope of the RCI makes it potentially more so. The crash rate results for intersection related crashes show RCIs have lower intersection related crashes than signals, which could indicate even a lower portion of the total crashes occurring at RCIs are related to the RCI itself.

CHAPTER 5: CONCLUSIONS

The results of the before-after and cross-sectional analyses conducted show the RCIs in Minnesota are exhibiting their intended safety benefits. The analyses showed the following impacts of RCIs:

- Reductions in fatal and serious injury crashes
- Reductions in angle crashes
- Reductions in fatal and serious injury angle crashes
- Increases in rear-end crashes
- No changes to sideswipe crashes
- No changes to total crashes

These results are consistent with the safety goals of RCIs as well as with the previous evaluation of RCIs in Minnesota. Even though the RCIs are not causing significant changes in total crashes, there is a severity shift that is resulting in a decrease in high-severity crashes.

A comparison between RCIs, rural signals, and low-volume interchanges show that RCIs appear to result in lower overall crashes than interchanges as well as lower-angle and intersection-related crashes than signals.

APPENDIX A
RCI LOCATIONS & CHARACTERISTICS

Location	1 - Cook	2 - Twig	3 – Ham Lake
District	1	1	Metro
Intersection	US 53 & MN 1/CR 22	US 53 & CSAH 7/CR 885	MN 65 & 143rd Ave NE
City	Cook	Twig	Ham Lake
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2019	2019	2019
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	Both Sides
Median Condition	Two Lefts	Two Lefts	Two Lefts
Approx. U turn Distance	625'	650'	800'
Other			

Location	4 – Ham Lake	5 – East Bethel	6 – East Bethel
District	Metro	Metro	Metro
Intersection	MN 65 & 153rd Ave NE	MN 65 & 181st Ave NE	MN 65 & Viking Blvd
City	Ham Lake	East Bethel	East Bethel
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2019	2019	2019
Previous Control	Side Street Stop	Side Street Stop	Signal
# of U turns	Both Sides	Both Sides	Both Sides
Median Condition	Two Lefts	Two Lefts	Two Lefts
Approx. U turn Distance	775'	825'	900'
Other			Signalized, Dual U-Turns

Location	7 - Cologne	8 - Cologne	9 - Wabasha
District	Metro	Metro	6
Intersection	US 212 & CR 41	US 212 & CR 36 (E Jct)	US 61 & Shields Ave
City	Cologne	Cologne	Wabasha
Intersection Legs #	4 leg	3 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	55 mph
Construction Year	2019	2019	2019
Previous Control	Side Street Stop	Side Street Stop w/Channelized Right	Side Street Stop
# of U turns	Both Sides	One Side	Both Sides
Median Condition	Two Lefts	Closed	Two Lefts
Approx. U turn Distance	800'	350'	750'
Other			

Location	10 - Wabasha	11 – Heron Lake	12 – Heron Lake
District	6	7	7
Intersection	US 61 & MN 60	MN 60 & CSAH 9/10th St	MN 60 & CSAH 24
City	Wabasha	Heron Lake	Heron Lake
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	55 mph	65 mph	65 mph
Construction Year	2019	2019	2019
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	Both Sides
Median Condition	Two Lefts	Two Lefts	Two Lefts
Approx. U turn Distance	875'	750'	800'
Other			

Location	13 – Heron Lake	14 - Marshall	15 – Cass Lake
District	7	8	2
Intersection	MN 60 & CR 43/1st St	MN 23 & CR 7	US 2 & CR 75
City	Heron Lake	Marshall	Cass Lake
Intersection Legs #	4 leg	4 leg	3 leg
Mainline Speed Limit	65 mph	55 mph	65 mph
Construction Year	2019	2019	2018
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	One Side
Median Condition	Closed	Two Lefts	One Left
Approx. U turn Distance	625'	800'	925'
Other			

Location	16 - Becker	17 – Ham Lake	18 – East Bethel
District	3	Metro	Metro
Intersection	US 10 & CR 23/Sherburne Ave	MN 65 & 157th Ave NE	MN 65 & 187th Ave NE
City	Becker	Ham Lake	East Bethel
Intersection Legs #	3 leg	4 leg	4 leg
Mainline Speed Limit	60 mph	65 mph	65 mph
Construction Year	2018	2018	2018
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	One Side	Both Sides	Both Sides
Median Condition	One Left	Two Lefts	Two Lefts
Approx. U turn Distance	800'	800'	825'
Other	Another access modified to RI/RO		

	between intersection & U-turn		

Location	19 - Jordan	20 - Jordan	21 - Marshall
District	Metro	Metro	8
Intersection	US 169 & CR 59/Delaware Ave	US 169 & Park Blvd & CR 66	MN 23 & Lyon St
City	Jordan	Jordan	Marshall
Intersection Legs #	4 leg	5 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	55 mph
Construction Year	2018	2018	2018
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	Both Sides
Median Condition	Two Lefts	Two Lefts	Two Lefts
Approx. U turn Distance	725' & 1075'	1000'	950'
Other		Two intersections combined into offset Ts with U-turns at Ts	

Location	**22 – Pequot Lakes**	**23 – Pequot Lakes**	**24 - Vermillion**
District	3	3	Metro
Intersection	MN 371 & CR 112	MN 371 & CR 168/107	US 52 & 180th St
City	Pequot Lakes	Pequot Lakes	Vermillion
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2017	2017	2017
Previous Control	New Intersection	New Intersection	Side Street Stop
# of U turns	Both Sides	Both Sides	Both Sides
Median Condition	Two Lefts	Two Lefts	Closed
Approx. U turn Distance	800' & 900'	800' & 1000'	725'

Other	no previous location	no previous location	

Location	25 - Vermillion	26 - Vermillion	27 - Hampton
District	Metro	Metro	Metro
Intersection	US 52 & CR 62 (190th St)	US 52 & CR 66	US 52 & 210th St
City	Vermillion	Vermillion	Hampton
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2017	2014	2017
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	One Side	Both Sides	One Side
Median Condition	One Left (SB)	Two Lefts	Closed
Approx. U turn Distance	725'	950' & 2175'	725'
Other			

Location	28 - Hampton	29 – Mendota Heights	30 – Eagle Lake
District	Metro	Metro	7
Intersection	US 52 & 215th St	MN 62 & Carmen Ln	US 14 & CR 17
City	Hampton	Mendota Heights	Eagle Lake
Intersection Legs #	3 leg	3 leg	4 leg
Mainline Speed Limit	65 mph	55 mph	65 mph
Construction Year	2017	2017	2016
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	One Side	One Side	One Side
Median Condition	Closed	One Left	Two Lefts
Approx. U turn Distance	725'	625'	900'
Other			

Location	31 – Le Sueur	32 - Marshall	33 - Jordan
District	7	8	Metro
Intersection	US 169 & CR 28	MN 23 & Saratoga St	US 169 & Candy Store Access
City	Le Sueur	Marshall	Jordan
Intersection Legs #	4 leg	4 leg	3 leg
Mainline Speed Limit	65 mph	55 mph	65 mph
Construction Year	2015	2015	2012
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	One Side
Median Condition	Two Lefts	Two Lefts	One Left
Approx. U turn Distance	950'	850'	875'
Other			

Location	34 – St. Peter	35 – St. Peter	36 – Lake Elmo
District	7	7	Metro
Intersection	US 169 & MN 22/Dodd Ave	US 169 & St. Julien St	MN 36 & DeMontreville Tr
City	St. Peter	St. Peter	Lake Elmo
Intersection Legs #	4 leg	3 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2014	2014	2013
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	One Side	One Side
Median Condition	Two Lefts	One Left	Two Lefts

Approx. U turn Distance	925'	700'	3825'
Other			

Location	37 - Cotton	38 - Cologne	39 – Ham Lake
District	1	Metro	Metro
Intersection	US 53 & CR 52	US 212 & MN 284/CR 53	MN 65 & 169th Ave
City	Cotton	Cologne	Ham Lake
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2012	2012	2012
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	Both Sides
Median Condition	Two Lefts	Two Lefts	Two Lefts
Approx. U turn Distance	1300'	950'	1675'
Other			

Location	40 - Willmar	41 - Winona	42 - Hampton
District	8	6	Metro
Intersection	MN 994A (Business 71) & CR 24	US 61 & Orin St/Gilmore Ave	US 52 & Fischer Ave
City	Willmar	Winona	Hampton
Intersection Legs #	4 leg	4 leg	3 leg
Mainline Speed Limit	55 mph	45 mph	65 mph
Construction Year	2010	2016	2017
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	One Side (other is EV only)	Both Sides	One Side

Median Condition	Two Lefts	Two Lefts	One Left
Approx. U turn Distance	825'	500' & 700'	750'
Other			

Location	43 - Milaca	44 – Bogus Brook	45 - Princeton
District	3	3	3
Intersection	US 169 & CR 11	US 169 & CR 12	US 169 & CR 13
City	Milaca	Bogus Brook Township	Princeton
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2020	2020	2020
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	Both Sides
Median Condition	Two Lefts	Closed	Closed
Approx. U turn Distance	900'	500'	500'
Other			

Location	46 - Isanti	47 – St. Cloud	48 - Milaca
District	3	3	3
Intersection	MN 65 & Cajima St NE	MN 23 & CR 8	US 169 & Pit Entrance
City	Isanti	St. Cloud	Milaca
Intersection Legs #	4 leg	4 leg	4 leg
Mainline Speed Limit	65 mph	65 mph	65 mph
Construction Year	2020	2020	2020
Previous Control	Side Street Stop	Side Street Stop	Side Street Stop
# of U turns	Both Sides	Both Sides	One Side

Median Condition	Two Lefts	Two Lefts	One Left
Approx. U turn Distance	1000'	800'	800'
Other			

Location	49 – Norwood Young America
District	Metro
Intersection	US 212 & CSAH 34/Tacoma Ave
City	Norwood Young America
Intersection Legs #	4 leg
Mainline Speed Limit	60 mph
Construction Year	2020
Previous Control	Side Street Stop
# of U turns	One Side
Median Condition	One Left
Approx. U turn Distance	625'
Other	South leg still full movement

APPENDIX B
RCI CRASH DATA BY SEVERITY AND TYPE PER YEAR

Location: 40 - Willmar
Construction Year: 2010
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2001					1		1		
2002		1			1		2		
2003				1		1	1		
2004					1	1	1		
2005			1	2	1	3	4		
2006			1		1	1	2	1	
2007			1	1	1	1	3	1	
2008			1		1	1	2	1	
2009		1		2	3	3	4		

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2011									
2012					1		1	1	
2013					1		1	1	
2014				1					
2015									
2016				1	1				1
2017					1		1	1	
2018									
2019					1		1	1	

Location: 33 - Jordan

Construction Year: 2012

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2005									
2006			1	1	1	1	1		
2007				1	2		1	1	1
2008				2	2		1	1	2
2009					2		1	1	
2010				1	1			1	
2011			2	3	1	1	2	2	

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2013					1		1		
2014				1	2		1	2	
2015				1	3			1	2
2016				2	3		1	5	
2017				2	1			1	
2018			1	3	4			3	3
2019					1				

Location: 37 - Cotton

Construction Year: 2012

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2005					2	1	1		
2006				2		1	2		
2007	1	1	1	2	1	4	5	1	
2008	1				1	1	1	1	
2009			1	2	1	2	1		
2010			1	2	1	3	2		
2011									

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2013			1		4	1	1		2
2014			1	1	2		2	1	1
2015				1	3		2		
2016				1	3		1		
2017				1			1	1	
2018			1	1				1	
2019									

Location: 38 - Cologne

Construction Year: 2012

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2005	1			2	3	3	6	1	1
2006					1	1	1		
2007	1		1	2	2	3	6		1
2008				2	3	2	4		
2009	1			1	2	1	4		2
2010					3	1	3		1
2011	2		2	3	2	5	9		

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2013			1	1	5	1	5		2
2014				1	7		5	3	1
2015					2				1
2016			1	1	3	1	3	2	1
2017		1			6	2	4	2	1
2018				1	3		1	3	1
2019				1	8	3	1	1	

Location: 39 – Ham Lake

Construction Year: 2012

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2005		2	4	2		4	5		1
2006	1		1	1	4	4	4	1	1
2007			3		2	3	4		
2008			1		1		2	1	
2009				1	4	3	4	1	
2010		1	4		1	2	1	1	1
2011			3	2	2	1	4	3	2

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2013									
2014					1		1		
2015			1	1	1	2	3		
2016			1		1		1		1
2017			1	1			1	1	
2018			1	1		1	2		
2019				3		2	2		

Location: 36 – Lake Elmo

Construction Year: 2013

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2007				3	9	1	3	2	4
2008				1	3	2	1		
2009			1	2	4	3	3	1	
2010		1		1	6	1	3	1	
2011			3		3	1	1	2	1
2012				1	3			2	1

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2014				1	4	1	2		2
2015			2	2	5	3	6	2	1
2016					5	1	2	2	1
2017				1	4			1	
2018			1	1	7		1	4	2
2019				1	3	1			1

Location: 26 - Vermillion
Construction Year: 2014
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2009			2	2	6	2	4	3	1
2010				2	3	4	5		
2011					2				
2012			1	4	10	8	12	1	1
2013		1	3	2	4	1	2	2	1

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2015		1	1	3	3	1	2		4
2016					7	1	1	2	2
2017		1		1	8		2	8	1
2018		1		1	3	1	1	1	1
2019				1	10	1	6	5	

Location: 34 – St. Peter

Construction Year: 2014

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2009			1	2	1	1	4	3	
2010			1		7	1	3	1	
2011			1		4	1	4		2
2012				1	1		1		
2013					2		1		1

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2015			1	3	5	1	5	6	
2016			1		3		3	4	
2017		1	1		5		4	5	
2018					6		3	4	1
2019				1			1	1	

Location: 35 – St. Peter

Construction Year: 2014

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2009					1				
2010					4		2	2	
2011					6	2	4	2	1
2012					2	1	1		1
2013			1	1	1	1	2	1	

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2015				3	3	2	5	3	1
2016			1		6	1	4	5	
2017			2		2	1	3	2	1
2018					6		4	4	1
2019				1	4	1	5	3	1

Location: 31 – Le Sueur

Construction Year: 2015

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2011					2	1		1	
2012									
2013					1		1		
2014					1				

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2016					4	1	2		1
2017					3				
2018				2	3			2	
2019				1	3			1	

Location: 32 - Marshall
Construction Year: 2015
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2011				1	2	2	3		1
2012				2	4	2	6	1	2
2013				1	3	2	4		
2014		1	2	1	1	4	5		

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2016			1						
2017									
2018			1		1			1	
2019									

Location: 30 – Eagle Lake
Construction Year: 2016
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2013			1	1			1		
2014			1	2		2	3	1	
2015	1		1			1	1	1	

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017				1	1	1	1	1	
2018			1	1	3	2	3		
2019			1		4	2	3	2	

Location: 41 - Winona
Construction Year: 2016
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2013				1	4	1	4		2
2014		1	2	1		2	4		
2015			2		3	3	5	1	

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017					1				1
2018				1			1	1	
2019	1				2		3		

Location: 24 - Vermillion
Construction Year: 2017
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2015					1		1		
2016					1	1	1		

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2018					3		2	2	
2019					1				1

Location: 25 - Vermillion
Construction Year: 2017
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2015				2	3	1	3	2	
2016			1		1	1	1		

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2018			1		12	2	3	1	2
2019				1	6	1	3	3	1

Location: 27 - Hampton

Construction Year: 2017

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2015					1			1	
2016			1	1	3	1	1		1

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2018					5				2
2019					3				

Location: 28 - Hampton

Construction Year: 2017

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2015				1					
2016									

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear - End Crashes	Sideswipe Crashes
2018				1	3			2	
2019					1				

Location: 43 - Hampton

Construction Year: 2017

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2015				1	1				
2016				1	2				

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2018					3		1		1
2019					1			1	

Location: 15 – Cass Lake

Construction Year: 2018

Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017			1		3	3	3		

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2019					1		1		

Location: 16 - Becker
Construction Year: 2018
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017			2	1	6	3	4	4	2

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2019					2		1		1

Location: 17 – Ham Lake
Construction Year: 2018
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017		1	1	1		3	3		

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2019					3		1	1	1

Location: 18 – East Bethel
Construction Year: 2018
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017	1		1		2	3			

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2019					2		2	1	

Location: 19 - Jordan
Construction Year: 2018
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017		1		1	4	3	4	2	

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2019			1	1	1			3	

Location: 20 - Jordan
Construction Year: 2018
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017									

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2019		1			4	1	2	2	

Location: 21 - Marshall
Construction Year: 2018
Before Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2017									

After Crashes

Year	K Crashes	A Crashes	B Crashes	C Crashes	N Crashes	Angle Crashes	Intersection Related Crashes	Rear-End Crashes	Sideswipe Crashes
2019					1		1	1	

APPENDIX C
RCI SEVERE CRASH DETAILS

As seen in the before-after analysis, the locations with RCIs saw a decrease in K and A severity crashes after installation of the RCIs. However, there have still been six A severity crashes and one K severity crash at these locations. Details about those crashes are included in Table C.1.

Table C.1: K & A Severity Crashes at RCI Locations After Construction Year

Location	City	RCI Construction Year	Crash Year	Crash Severity	Description
US 212 & MN 284/CR 53	Cologne	2012	2017	A	Rear end on US 212
US 52 & CR 66	Vermillion	2014	2015	A	Sideswipe on US 52
US 52 & CR 66	Vermillion	2014	2017	A	Rear end on US 52 (lane closure)
US 52 & CR 66	Vermillion	2014	2018	A	Rear end on US 52 (ice)
US 169 & MN 22/Dodd Ave	St. Peter	2014	2017	A	Run off road on TH 169
US 61 & Orin St/Gilmore Ave	Winona	2016	2019	K	Run off road on TH 61
US 169 & Park Blvd & CR 66	Jordan	2018	2019	A	Rear end into snowplow on US 169

Of these seven crashes, six of them (the four rear ends and the two run-off roads) do not appear to be directly related to the RCI itself. The sideswipe crash at US 52 & CR 66 may have been RCI related.

APPENDIX D
RCI CONSTRUCTION YEAR SEVERE CRASHES

As mentioned, crashes during the construction years were not included in the analysis. There were nine K and A severity crashes at RCI locations during those construction years. Six of those occurred before the RCI was constructed, but Table D.1 lists each of those nine with descriptions for the three that occurred after the RCI installation.

Table D.1: K & A Severity Crashes at RCI Locations After Construction Year

Location	City	Construction/ Crash Year	Crash Severity	Before or After Construction of RCI	Description
MN 23 & Saratoga St	Marshall	2015	K	Before	
MN 23 & Saratoga St	Marshall	2015	K	Before	
US 10 & CR 23/Sherburne Ave	Becker	2018	K	After	Pedestrian on US 10
MN 65 & 157th Ave	Ham Lake	2018	K	Before	
MN 65 & 187th Ave	East Bethel	2018	A	Before	
MN 65 & 153rd Ave	Ham Lake	2019	A	Before	
MN 65 & 181st Ave	East Bethel	2019	A	After	Sideswipe heading to U-turn in RCI on MN 65
MN 65 & Viking Blvd (signalized RCI)	East Bethel	2019	A	Before	
MN 65 & Viking Blvd (signalized RCI)	East Bethel	2019	K	After	Run off road on MN 65

Of the three crashes that occurred after the RCIs were constructed, one of them (the run-off road crash) at MN 65 & Viking Blvd does not appear to be directly related to the RCI itself. The sideswipe crash at MN 65 & 181st Ave was RCI-related. The details of the pedestrian crash at US 10 & CR 23/Sherburne Ave leave it unclear if it is related to a pedestrian crossing the roadway at the intersection or walking along the shoulder/lane of the roadway near the intersection.

APPENDIX E
RCI TARGET CRASH TYPE BREAKDOWNS

Figures E.1 through E.3 show a breakdown of how and where rear end, angle, and sideswipe crashes are occurring at RCIs. The crash numbers shown in these figures are from the after portion of the Before-After analysis when RCIs were fully in place.

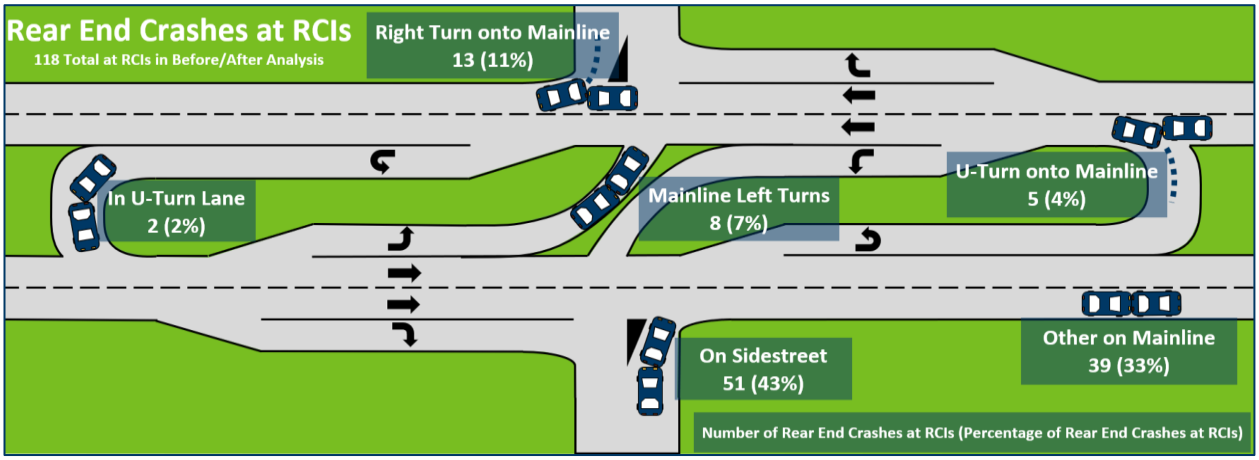

Figure E.1 - Breakdown of Rear-End Crashes at RCIs

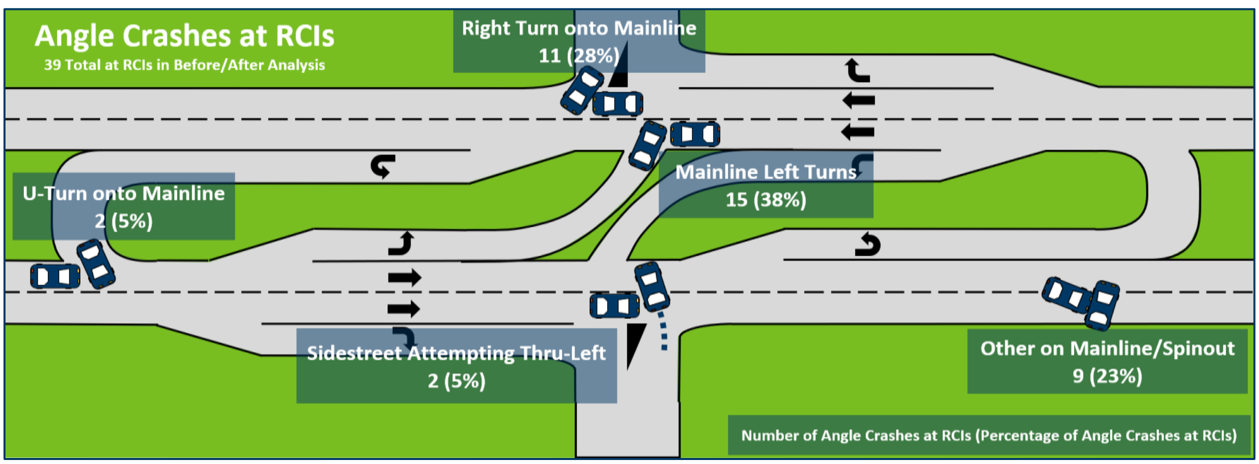

Figure E.2 - Breakdown of Angle Crashes at RCIs

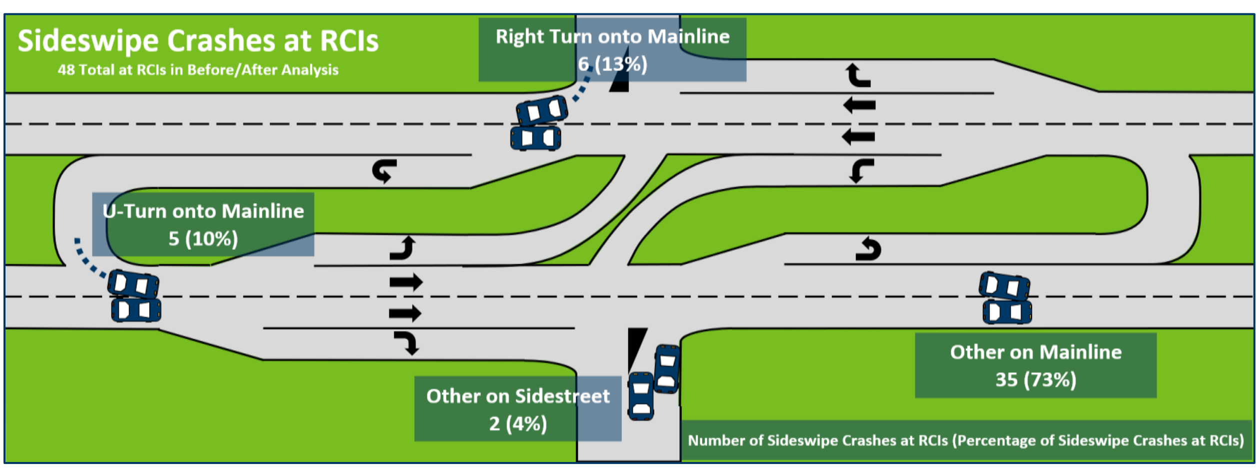

Figure E.3 - Breakdown of Sideswipe Crashes at RCIs