A Study of the Rural Intersection Conflict Warning System (RICWS)

Office of Traffic Engineering

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FINAL REPORT

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Executive Summary

In Minnesota, approximately two-thirds of traffic fatalities occur on roads in rural areas. For more than a decade, the annual totals for fatal crashes in the state's rural areas have outnumbered those in urban areas two to one, despite the fact that approximately 60% of all reported crashes occur within the Twin Cities metro area. Because reducing the number of deadly crashes across the state is a core objective of the Minnesota Department of Transportation's (MnDOT) Strategic Highway Safety Plan, the agency has made targeted investments to reduce these rural roadway fatalities.

The development and testing of intelligent technologies like the Rural Intersection Conflict Warning System (RICWS) is one way in which MnDOT strives to engineer new solutions to this recurring problem. Since 2013, 66 RICWS systems have been installed throughout Minnesota at rural Thru-Stop controlled intersections as a supplemental warning for drivers approaching these intersections. Sites selected for the RIWCS have both major and minor road components and were determined to have a higher-risk of right-angle crashes. This report details the methods utilized to measure the effectiveness of the RICWS by: 1) comparing sites' crash rates before and after the RICWS installation and 2) comparing RICWS sites to a group of control sites with similar characteristics (e.g. risk factors, traffic volumes).

The report's statistical analyses compare crash data for sites with the RICWS installed as well as crash data at a control group of similar intersections. Rates for various crash types, analyzed both before and after the installation of the RICWS, were also examined. The first analysis, which compares the frequency of crashes before and after the RICWS was introduced to an intersection, did not indicate that there were clear reductions in target crash rates after the system had been deployed. The comparison of RICWS and control sites also produced no indication that there were statistically significant differences between the crash rates for the two groups. Despite nominal crash reductions at these rural intersections, minor reductions at RICWS sites for some observed crash rates may suggest that there is some potential for reductions of specific crash types (e.g. right-angle crashes).

Available records from system maintenance personnel highlight multiple instances when issues (such as malfunctioning signal LEDs) were discovered at RICWS sites. The records only contained information on the maintenance of 24 of the RICWS signals that were studied and were only logged from December 2013 – August 2016. A thorough review of the crashes that occurred during the time that the RICWS was not functioning was conducted in order to determine if the crash was a result of the warning system malfunctioning. Contrary to initial expectations, significant mitigation of crashes at RICWS sites was not found during the report's observation period. Factors that may have led to the inconsistent reductions in RICWS's target crash types include technical issues with RICWS signals like those discovered by maintenance workers and the known impacts of a major crash database reporting change in 2016 (which the author addresses in the report, but still affects how any findings are interpreted). Implications for future RICWS planning, utilization, and additional site evaluation options are not explored are in this report.

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Injury Severity of Crash

When a crash occurs, the responding officer files a crash report, detailing the aspects of the crash. Each crash is assigned a level of severity based on the greatest level of injury sustained by all persons involved in a crash. One fatal crash may include one or more person(s) killed and any number of persons who sustained other levels of injury, but it is coded as a *K Injury Crash*.

K-Injury Crash	One or more person involved in the crash died within 30 days due to injuries sustained in the crash
A-Injury Crash	One or more person(s) involved in the crash is suspected to have sustained a serious injury due to the crash
B-Injury Crash	One or more person(s) involved in the crash is suspected to have sustained a minor injury, e.g. broken bones in the crash
C-Injury Crash	One or more person(s) involved in the crash sustained a possible injury in the crash
PDO-Injury Crash	No person(s) involved in the crash sustained an injury, and only vehicular or property damage occurred

Manner of Collision

The assigned crash type or "manner of collision" refers to the way in which one or more vehicles collided with one another.

Right-Angle Crash

When two vehicles collide perpendicular to each other, also known as a T-bone or broadside crash. This type of crash is among the highest risk of death and serious injury.

Rear-End Crash / Front-To-Rear

When two vehicles traveling in the same direction collide with the front of the following vehicle colliding with the rear of the leading vehicle. This is the most common type of crash in Minnesota; however, it is typically of lower risk of death and serious injury.

Head-On Crash / Front-To-Front

Two vehicles collide directly into each other while heading in opposite directions striking at the front of both vehicles. This type of crash is among the highest risk of death and serious injury.

Side-Swipe Crash

Two vehicles collide off-center and scrape the sides of both vehicles. Sideswipes include both crashes where vehicles come into contact while traveling in the same direction, and where the vehicles are traveling in opposing directions. This type of crash is typically at lower risk of death and serious injury.

Other/Not Applicable & Unknown/Blank

These crash types were used when one of the above types or diagrams did not adequately address what had occurred. These four tended to be a catch-all for crashes that did not fit the above descriptions.

List of Acronyms and Terms

AADT	Annual Average Daily Traffic
ADT	Average Daily Traffic
A Rate	Suspected serious injury (A crash) crashes are totaled, multiplied by one million, and divided by the total number of entering vehicles in the same time span.
B Rate	Suspected minor injury (B crash) crashes are totaled, multiplied by one million, and divided by the total number of entering vehicles in the same time span.
CR	County Road
C Rate	Possible injury (C crash) crashes are totaled, multiplied by one million, and divided by the total number of entering vehicles in the same time span.
Crash Rate	Total number of crashes in a given time span, multiplied by one million, and divided by the total number of entering vehicles in the same timespan
CSAH	County State-Aid Highway
ICWS	Intersection Conflict Warning System
MnDOT	Minnesota Department of Transportation
MNTH	Minnesota Trunk Highway
OTE	Office of Traffic Engineering (MnDOT)
PDO Rate	Property damage only (PDO crash) crashes are totaled, multiplied by one million, and divided by the total number of entering vehicles in the same time span.
RICWS	Rural Intersection Conflict Warning System
TH	Trunk Highway
VE	Total number of Vehicles Entering an intersection; the yearly VE was calculated by adding the major road AADT and the minor road AADT and then multiplying that number by 365 days.

Chapter 1: Introduction

1.1 Background

Crashes at rural Thru-Stop controlled intersections make up 65% of all fatal crashes in Minnesota (Department of Public Safety, 2017). However, annual crash statistics have repeatedly indicated that the majority of *all* vehicle crashes occur in the state's urban areas. Notable efforts to reduce traffic crashes, injuries and deaths on Minnesota roads have been coordinated through the state's cornerstone traffic safety program, Towards Zero Deaths (TZD), which has led to substantially fewer traffic-related fatalities around the state (Minnesota TZD, 2013). Launched in 2003, the TZD program's interdisciplinary approaches to making Minnesota roads safer have included new traffic safety legislation, targeted enforcement of impaired and aggressive driving, and public awareness campaigns. Yet even as traffic deaths trend downwards, the proportion of fatalities on rural roads relative to those in urban areas has remained quite similar each year. National and state research on rural highway safety has identified a number of risk factors which are characteristic of many rural areas (e.g. vehicles traveling at higher speeds, intersections where trees/hills obstruct drivers' line-of-sight), but now the challenge has been to determine the best way to prevent these infrequent, but deadly crashes.

A typical Thru-Stop intersection is an intersection where a high volume (major) road intersects with a lower volume (minor) road. The major road is uncontrolled while the minor road is controlled with a stop sign. The Rural Intersection Conflict Warning System (RICWS) was introduced as a potential safety measure to provide drivers with a dynamic warning of other vehicles approaching or entering the intersection. Reducing right angle crashes at these rural intersections is the primary goal of the system. Right angle crashes at high speeds have a higher probability of resulting in fatalities or serious injuries than other intersection crash types. The RICWS alerts drivers on the minor road that a vehicle is approaching in an effort to assist with better gap selection and limited sight distance. On the major road, the RICWS warns cars of entering traffic from the minor road.

Typically, the RICWS consists of three parts: static signing, detection, and dynamic elements. On the minor road, the dynamic warning sign indicates the approach of a vehicle on the major road. When a vehicle from the minor road enters traffic, signs on the major road are activated to warn drivers. The distance away that the RICWS detects an approaching vehicle varies depending on the major road speed limit. The general layout for a RICWS system is shown in Figure 1.

Figure 1 – Concept of a typical RICWS layout taken from MnDOT's System Requirements (2015)

RICWS systems have experienced several maintenance issues following their installation. After the installation of the first 30 RICWS systems, MnDOT recorded a maintenance log from December 20, 2013 – August 5, 2016 detailing when a RICWS was reported not working, what needed fixing, and when the system was fixed. It is unknown if the constant maintenance on the RICWS has any impact on this analysis.

Sixty-six RICWS sites have successfully been installed between 2013 and 2018. The objective of this study is to quantitatively determine the safety benefit of RICWS by comparing crash rates at RICWS (the treatment sites) and control sites before and after RICWS installation. Additionally, the crash rates between RICWS and the control sites were compared.

1.2 Study Locations

To accurately examine the safety impact of the RICWS, a list of 66 sites where RICWS installation occurred was provided by MnDOT. Most of the intersections selected for RICWS implementation were determined to be high risk locations. This means that the selected intersections had either a history of high crash frequency or that the intersection had characteristics that are associated with high crash/high severity frequency. These high-risk characteristics were identified in the 2009-2013 County Road Safety Planning Process and include:

- An intersection skew angle greater than 15 degrees
- The presence of a horizontal curve at or near the intersection
- A railroad crossing located near the intersection
- A commercial development located in one of the intersection quadrants
- The minor leg STOP-controlled approach does not have a STOP sign within five miles prior to the intersection
- The intersection volume
- Prior crash history

The original list of RICWS sites contained information which included the county, the names of the major and minor roads, the intersection configuration, and the turn-on date. Using the database created for the 2016 Minnesota District Safety Plans, the identified sites were matched with the pre-determined intersection ID. If the intersection was not specified in the database, a name was created for it.

A breakdown of the provided RICWS intersections can be found in Appendix A, while a map of the location of each RICWS site can be found in Figure 2.

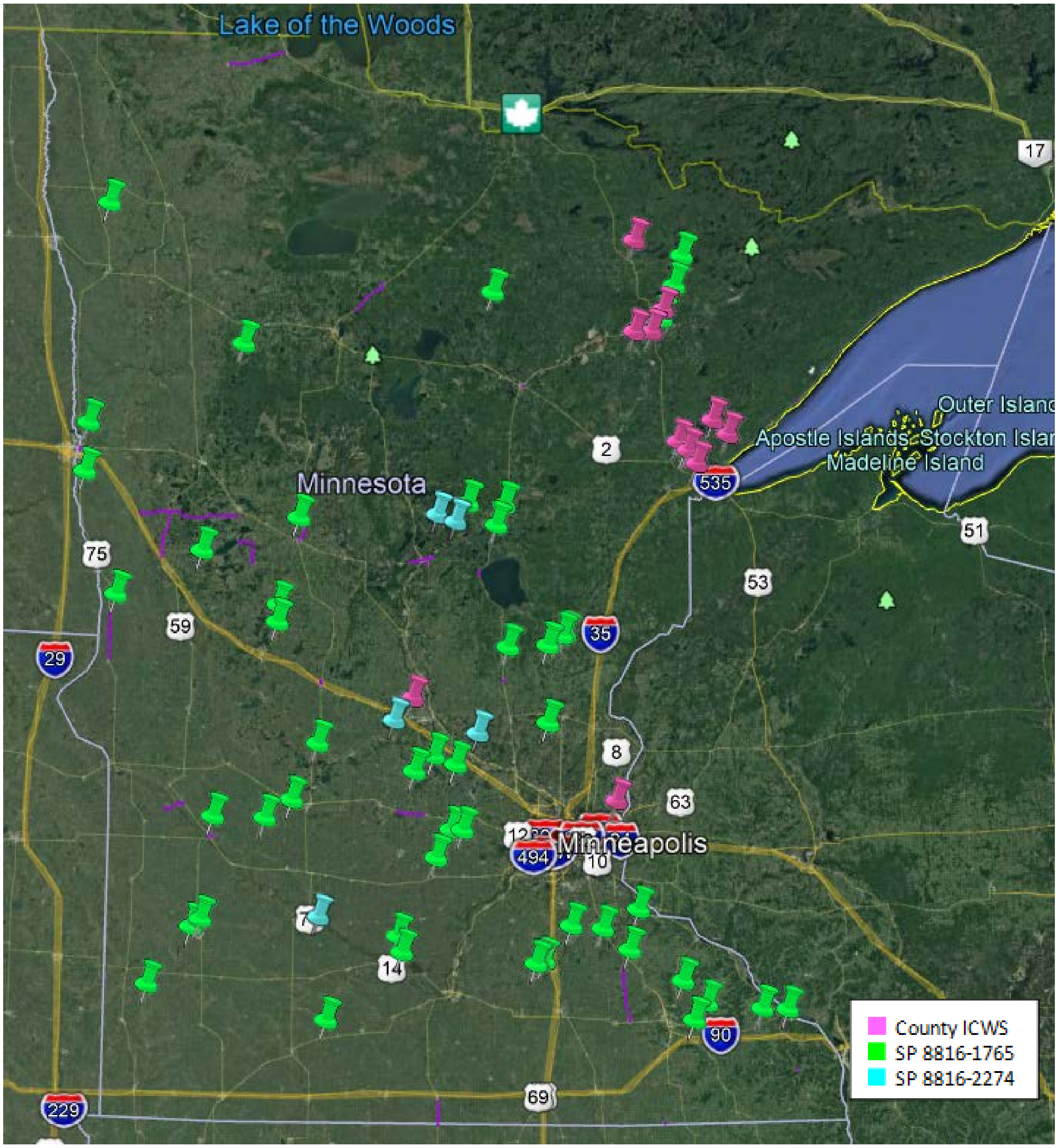

Figure 2 – General depiction of the RICWS locations in this study (n = 66)

1.3 Control Locations

Control intersections were chosen to correspond with each of the provided RICWS sites. MnDOT's Basemap and 2016 District Safety Plan Database were used to help choose control locations. These control locations were chosen based on the following criteria:

- Proximity to RICWS site
- Similar AADT volumes for major and minor legs

- Similar risk factors (near a RR Xing, on/near a curve, in a development, percent skew, previous stop, intersection volume, crash history)
- Same route number (i.e. MNTH 23)
- Same number of legs and intersection configuration (divided/undivided)

Of the 30 control locations from a previous study prepared by the consulting firm CH2M-Hill (2015), 13 were matched up with RICWS sites by matching three out of the five criteria described above and three out of the seven listed risk factors. Of the 17 unmatched control sites, 10 were not a close match to the RICWS sites; these 10 sites were matched (doubled-up) to RICWS sites based on radial proximity. For this reason, there are 76 control sites when there are only 66 RICWS sites. The last 7 unutilized control sites became RICWS sites after the previous study was completed. These 7 intersections, previously used as control locations, were removed from this report's list of control sites:

- St. Louis TH169 & CSAH 21
- Kanabec TH23 & CSAH 12
- Itasca TH6 & TH286
- Pipestone TH23 & CSAH 16
- Clay USTH 75 & CSAH 18
- Meeker MNTH 15 & CSAH 27
- McLeod MNTH 7 & CSAH 1

A breakdown of the selected control sites can be found in Appendix A, and a map of the control locations can be seen in Figure 3.

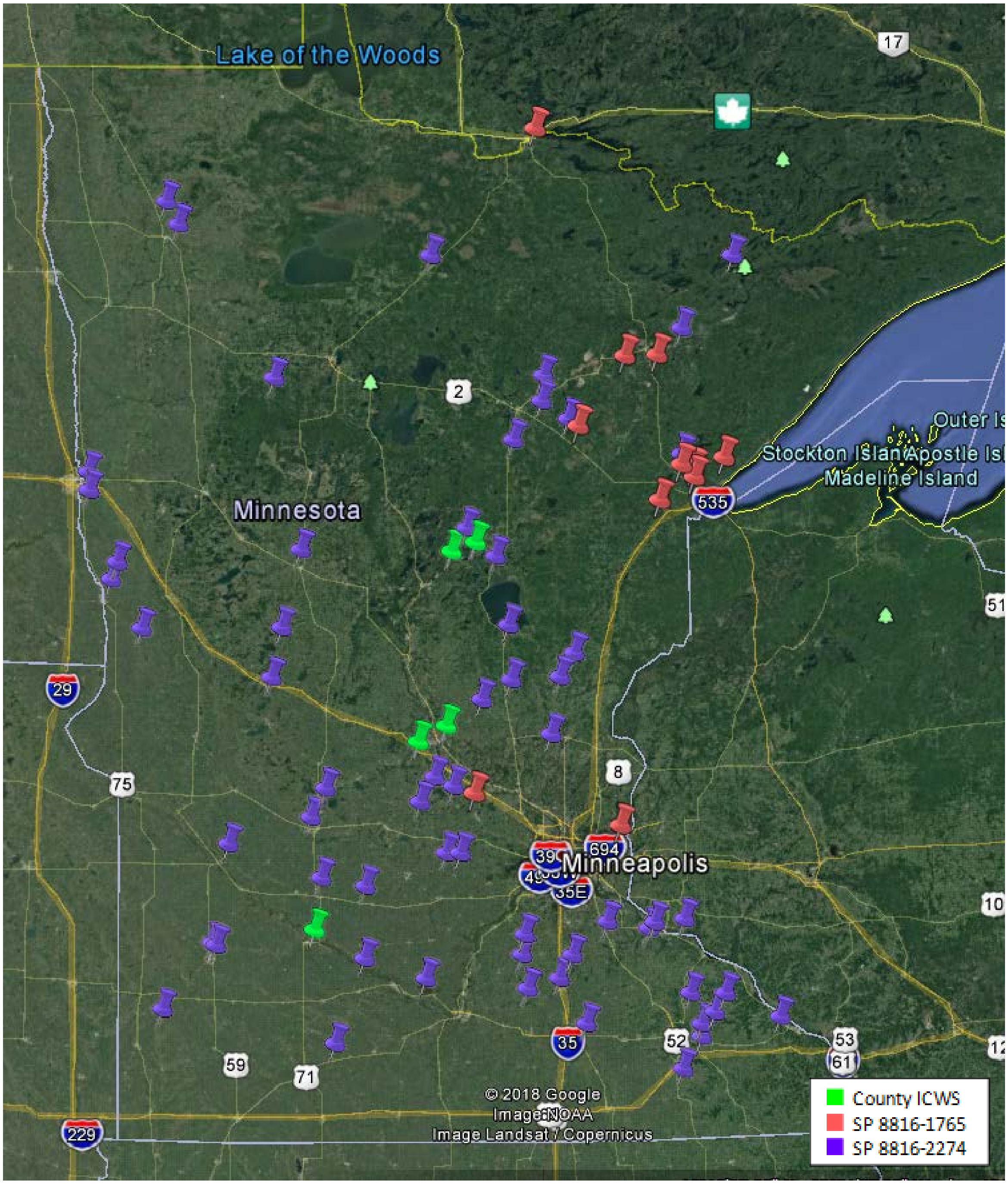

Figure 3 – General depiction of the control locations in this study (*n* = 76)

Chapter 2: Data Methodology

Crashes that occur throughout the state are reported to Minnesota's Department of Public Safety (DPS) and are available for crash analysis. Each crash is assigned a level of severity using the KABCN injury scale[1] based on the greatest level of injury sustained by all persons involved in a crash. Crashes are used to calculate intersection crash rates used in the analysis.

2.1 Crash Data

Starting January 1, 2016, DPS implemented a new crash reporting system. After the deployment of the new crash report, an increase in 'A' crashes were observed system wide. This could be due to the redefinition of crash severities and the easier method of crash reporting. The definitions for an 'A' and 'B' crash now became "suspected" serious injury and "suspected" minor injury. A 'C' crash is now defined as a possible injury. With the use of the term "suspected", it appears that more crashes were being categorized as suspected serious injury. Additionally, more crashes are being reported to the statewide database because the new crash system provided an easier means to report crashes compared with the previous form that was used. To account for the increase in 'A' crashes in the safety analysis presented in this report, the RICWS sites were compared to a set of control sites. The intention was to monitor the 'A' crash rate for the after period for both RICWS and control sites and potentially assess any differences in the crash occurrence that was related to the system performance versus the statewide reporting trends that were observed. Since both RICWS and control sites produced similar results, the change in crash recording is neither washing out nor enhancing the apparent performance of RICWS.

The new system also changed the way the crash diagram was coded. The previous crash data sought to answer two questions when coding crashes as left/right turn and run-off-the-road crashes. The new system removed these as a coding option; however, the old crashes were not updated to this new coding. This leads to a discontinuity in the crash data. In order to account for this change in data (for crashes included in this evaluation only), the crash reports for the old crashes were manually reviewed, and the crash diagram code was updated in accordance with the new coding system.

In order to extract the crash data, ArcMap was used to create a layer of the Google Earth intersection pins. A buffer of 300-feet was placed around each of the intersections, and all crashes from 2006-2015 and 2016 - March 2018 were pulled and assigned to the appropriate intersection. The Minnesota Crash Mapping Analysis Tool (MNCMAT) is an application that plots the location of each crash that occurred through 2015. This tool was used to ensure that all of the crashes were properly pulled. Initially, 1,218 crashes were found for the RICWS sites and 855 crashes for the control sites.

[1] The KABCN injury scale is defined in the Injury Severity of Crash section located at the beginning of the report.

At this time, the maintenance logs were reviewed and cross-referenced with the crashes pulled. There was only one crash that occurred when a RICWS system was recorded to have been not functioning. The crash was not included in the final analysis because it was not intersection-related. Upon further review, the PDO crash occurred due to extremely icy roads.

In order to obtain a better understanding of the impacts of the RICWS, the following crash types were not considered in the analysis of the potential effectiveness of the system because they likely would not be impacted by the performance of the RICWS:

- Relation to Intersection/Junction: Not an Intersection/Junction, and Alley or Driveway Access
- Accident Type/First Harmful Event: Deer, and Other Animal

The officer narrative for each crash report was reviewed for the crashes coded as Blank, Not Applicable, and Other to obtain a deeper understanding of each crash. These crash reports were typically completed by citizens and often were miscoded, so this was a way to determine if the crashes were correctly coded. A short summary of each crash report reviewed was recorded. If these crashes occurred at a driveway, were animal-related, or were not intersection-related, it was noted, and the crashes were removed from the data set used for analysis[2]. After this thorough review of the crash data, the final crash data set contained a total of 482 crashes for RICWS sites and 330 crashes for control sites.

2.2 Traffic Data

Annually, MnDOT's Office of Traffic Forecasting and Analysis is responsible for the traffic counts that are collected on Minnesota's roadways. These counts are then used to calculate the number of vehicles entering intersections (VE) and crash rates. A GIS layer, called a shapefile, is created from these traffic counts. The traffic counts for the specified intersections can then be obtained using the pinned intersections in ArcMap.

Using the shapefiles found on the Traffic Forecasting and Analysis website, the traffic volumes were assigned to the corresponding intersections using ArcMap. AADT data up to 2017 were used. A 300-foot buffer was placed around each pinned intersection. Interpolation and extrapolation were used to estimate AADT for years that had missing data. For missing data that was located between two years that had data, the loss/gain of AADT was averaged over the number of years. For example, if data for 2010-2012 were missing, but there were data for 2009 and 2013, the change between 2009 and 2013 data was calculated and evenly distributed between the three missing years. For more recent years that didn't have data to interpolate between, extrapolation was used. If the given data showed a continuous increase/decrease, the AADT was predicted by calculating the AADT using the current growth/decay rate. If there was no noticeable trend in the AADT data, the last known AADT was used for all

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[2] See the Excel spreadsheet "Crashes Reviewed, Removed, and Recoded" for a complete list of all the crashes reviewed, updated, and deleted is available upon request.

consecutive years. One intersection had no available AADT, so an educated guess was made for this site by an experienced MnDOT engineer.

2.3 Useful Equations

The following section includes the equations used in the analysis.

Equation 1: Equation for the number of years before the RICWS turn-on

$$B = \left(\frac{D_B}{365}\right) + Y_B$$

B = Number of before years

D_B = Number of days before turn-on

Y_B = Number of full years before until 2006 (first year of crash data)

Equation 2: Equation for the number of years after RICWS turn-on

$$A = \left(\frac{D_A + 90^*}{365}\right) + Y_A$$

A = Number of after years

D_A = Number of days after turn-on, includes turn-on day

Y_A = Number of full years after, excludes 2018 because there is only 90 days of available crash data for 2018 (this is the 90* in the formula)

Equation 3: Before RICWS turn-on volume equation

$$VE_B = 365 * \sum_{i\,=\,2006}^{TO-1} AADT_i + D_B * AADT_{TO}$$

VE_B = VE before turn-on

$AADT_i$ = AADT for year [i]

TO = Year of RICWS turn-on

D_B = Number of days before RICWS turn-on

$AADT_{TO}$ = AADT for year of RICWS turn-on

Equation 4: After RICWS turn-on volume equation

$$VE_A = 365 * \sum_{i=TO+1}^{2017} AADT_i + D_A * AADT_{TO} + 90 * AADT_{2018}$$

VE_A = VE after turn-on

D_A = Number of days after RICWS turn-on to December 31 of turn-on year

Equation 5: Three years before RICWS turn-on volume equation

$$VE_{3B} = D_A * AADT_{TO-3} + 365 * (AADT_{TO-2} + AADT_{TO-1}) + D_B * AADT_{TO}$$

VE_{3B} = VE 3 years before RICWS turn-on

Example: Carver MNTH 7 & CSAH 33, turn-on date: 11/26/2013

The date 11/26 is the 329th day of the year, meaning that 36 days remain in the year.

$$B = \left(\frac{329}{365}\right) + 7 = 7.9014\ years$$

$$A = \left(\frac{36 + 90}{365}\right) + 4 = 4.3452\ years$$

$$\mathrm{VE_B} = 365 * (\mathrm{AADT}_{2006} + \cdots + \mathrm{AADT}_{2013-1}) + 329 * (\mathrm{AADT}_{2013})$$

$$\mathrm{VE_A} = 365 * (\mathrm{AADT}_{2013+1} + \mathrm{AADT}_{2015} + \cdots + \mathrm{AADT}_{2017}) + 36 * (\mathrm{AADT}_{2013}) + 90 * (\mathrm{AADT}_{2018})$$

$$\mathrm{VE_{3B}} = 36 * (\mathrm{AADT}_{2013-3}) + 365 * (\mathrm{AADT}_{2013-2} + \mathrm{AADT}_{2013-1}) + 329 * (\mathrm{AADT}_{2013})$$

Before and after crashes were counted by severity and crash type for each intersection. The crash rate was calculated for each intersection in the following manner:

$$Crash\ Rate = \#\ of\ crashes * \frac{1{,}000{,}000}{VE}$$

The crashes for all the intersections were totaled, and the overall crash rate for all RICWS and control sites was determined by severity and crash type. A difference in crash rate was calculated using the following equation:

$$\%\ change = \frac{-(before\ CR - after\ CR)}{before\ CR}$$

Chapter 3: Overview of Crash Data

Before completing any statistical testing, the number of crashes based on crash severity and crash diagram were tabulated and the corresponding crash rates were calculated. These crash rates provided an overview of the crash distributions before and after installation for both RICWS and control sites and were necessary for later statistical testing. The percent difference between before and after crash rates was also calculated for each site. A negative percent difference indicates that the crash rate decreased after the RICWS was installed. Conversely, a positive value would denote a crash rate that increased.

3.1 Crash Rates Based on Severity

Before and after crash rates were calculated based on crash severity for both RICWS and control sites. The crash rates for RICWS sites are shown in Table 1 and the crash rates for control sites is shown in Table 2. From Table 1, it can be seen that the total crash rate, 'K' crash rate, and 'C' crash rate decreased after RICWS was implemented at RICWS sites. In comparison, the total crash rate, 'K' crash rate, and 'C' crash rate increased after the "RICWS turn-on date" at control sites. Only the 'A' crash rate saw a decrease in the after period and is shown in Table 2. This is particularly interesting because it was expected that similar patterns for 'A' crashes would be seen with both RICWS and control sites.

Table 1 *Before and After Crash Rates for RICWS sites, based on Severity*

Time Period	Metric	K	A	B	C	PDO	Total	VE
Before	Num. of Crashes	9	8	41	60	126	244	447,314,386
Before	Crash Rate	.020	.018	.092	.134	.282	.545	*N/A*
After	Num. of Crashes	8	15	47	37	131	238	450,585,229
After	Crash Rate	.018	.033	.104	.082	.291	.528	*N/A*
	% Increase/Decrease Change in Crash Rate	-11.76%	86.14%	13.80%	-38.78%	3.21%	-3.17%	.73% *VE % Change*

Table 2 *Before and After Crash Rates for Control Sites, based on Severity*

Time Period	Metric	K	A	B	C	PDO	Total	VE
Before	Num. of Crashes	4	7	29	36	78	154	496,194,357
Before	Crash Rate	.008	.014	.058	.073	.157	.310	*N/A*
After	Num. of Crashes	10	4	30	40	92	176	497,437,164
After	Crash Rate	.020	.008	.060	.080	.185	.354	*N/A*
% Increase/Decrease Change in Crash Rate		**149.38%**	**-43.00%**	**10.44%**	**10.83%**	**17.65%**	**14.00%**	.25% *VE % Change*

3.2 Crash Rates Based on Crash Diagram

Similarly, the crash rates for RICWS and control sites were calculated based on crash diagram. The resulting crash rates can be seen in Table 3 for RICWS sites and Table 4 for control sites. Table 3 shows that the angle crash rate decreased in the after period for RICWS sites. However, the angle crashes that were specifically 'K' and 'A' severity saw an increase in crash rate in the after period. For the control sites, both the "K + A only" angle crashes and all angle crashes saw an increase in crash rate in the after period, which can be seen in Table 4.

Table 3 *Before and After Crash Rates for RICWS, based on Manner of Collision*

Time Period	Metric	Angle *K+A only*	Angle *All Severities*	Rear-end	Side-swipe *Same Dir.*	Head-on	Side-swipe *Opp. Dir.*	Other	Unknown
Before	Num. of Crashes	16	156	34	2	8	9	14	21
Before	Crash Rate	.036	.349	.076	.004	.018	.020	.031	.047
After	Num. of Crashes	20	146	36	8	17	10	6	15
After	Crash Rate	.044	.324	.080	.018	.038	.022	.013	.033
% Increase/Decrease Change in Crash Rate		**24.09%**	**-7.09%**	**5.11%**	**297.10%**	**110.96%**	**10.30%**	**-57.45%**	**-29.09%**

Table 4 *Before and After Crash Rates for Control Sites, based on Manner of Collision*

Time Period	Metric	Angle *K+A only*	Angle *All Severities*	Rear-end	Side-swipe Same Dir.	Head-on	Side-swipe Opp. Dir.	Other	Unknown
Before	Num. of Crashes	10	83	27	14	3	8	6	13
Before	Crash Rate	.020	.167	.054	.028	.006	.016	.012	.026
After	Num. of Crashes	14	109	30	6	7	4	5	15
After	Crash Rate	.028	.219	.060	.012	.014	.008	.010	.030
% Increase/Decrease Change in Crash Rate		**39.65%**	**31.00%**	**10.83%**	**-57.25%**	**132.75%**	**-50.12%**	**-16.87%**	**15.10%**

Chapter 4: Before and After RICWS Installation

Locations where a RICWS was installed were analyzed in order to determine the differences in crash rate before and after the device was turned on. Two different before periods were analyzed: all before data and three years of crashes before the turn-on date. The after period consisted of all crashes available after the turn on date until March 31, 2018, as that was the most recent available data. Additionally, the before and after periods for the control sites were analyzed. Since each control site is matched with a RICWS site, the before and after period for each control site are the same as those of its RICWS counterpart.

A few locations underwent major changes either before or after the installation of the RICWS system, which led to alterations to the data. The intersection of TH 55 and CSAH 3/CR 136 in Wright County became signalized on Nov. 15, 2016. Without an exact turn-off date, it was estimated that the RICWS system was removed on Oct. 15, 2016, one month before the new signal was turned on. The intersection of CSAH 2 and Minnesota Street in Saint Joseph was completely reconfigured starting in Fall 2012. January 1, 2013 was defined as the first day that the new road was open and the beginning of the before period. The intersection of US 53 and Landfill Drive near Virginia, MN underwent major road reconstruction in 2017. The project dedication was held on Sept. 15, 2017 and will be used as the beginning of the before period. The RICWS was turned on a month later, starting the after period on Oct. 23, 2017.

4.1 Wilcoxon Signed Rank Test

In order to give an accurate analysis of the before and after data, a Wilcoxon Signed Rank test was used. This test assumes two dependent samples with independent observations. There is also the assumption of symmetry among the data; however, it does not assume normality in the data. Not assuming normality allows for more freedom when working with the data.

A Wilcoxon Signed Rank Test operates under the assumption of a null hypothesis. In this case, the null hypothesis is that the median differences between the distribution of before and after crash rates is equal to zero (i.e. the two distributions are the same). The alternative hypothesis is that the median difference between the before and after crash distributions is not equal to zero (i.e. the two distributions are different). When run, the Wilcoxon Signed Rank Test will provide a p-value which will be compared to a pre-determined significance level. For this study, a significance level of $\alpha = 0.05$ will be used. If the resulting p-value is less than the significance level, then the null hypothesis is rejected in favor of the alternative hypothesis. If the *p*-value is greater than the significance level, the null hypothesis is not rejected, i.e. if the *p*-value is greater than 0.05 sites have similar crash outcomes before and after treatment. The results from the Wilcoxon Signed Rank Test are shown in Table 5.

Table 5 *Results of the Wilcoxon Signed Rank Test*

Intersection Type	Crash Rate Type	*p*-value	Significant
RICWS	Total Crash	0.925	No
	K+A Right-angle Crash	0.530	No
	K+A Crash	0.276	No
	K Crash	0.807	No
	A Crash	0.306	No
	Right-angle Crash	0.648	No
Control	Total Crash	0.989	No
	K+A Right-angle Crash	0.975	No
	K+A Crash	0.865	No
	K Crash	0.110	No
	A Crash	0.260	No
	Right-angle Crash	0.672	No

4.2 Discussion

For both RICWS and control sites, the analysis indicates that there are no significant differences between the before and after crash rates, after the RICWS warning signals were installed. From Table 5, it can be seen that none of the provided *p*-values are less than 0.05. There is also no significant difference between the before and after crash rates for the control sites, which is to be expected because no treatment was applied to those intersections. Since the results between the RICWS and control sites are similar, the change in crash reporting is neither washing out nor enhancing the effect of RICWS. While this does not support the conclusion that RICWS has reduced crashes, it also shows that RICWS is not increasing crash rates.

Chapter 5: Cross-Sectional Study

Control sites were selected and compared to RICWS sites as an additional way to test the effectiveness of the RICWS. The Mann-Whitney U-Test is a way to determine differences in two datasets. This is also a way to control for the increase of serious injury crashes in 2016-2018 crash data. The intended result was to see similar increases in serious injury crash rates.

5.1 Mann-Whitney U-Test

The Mann-Whitney U-Test looks at differences among data sets; in this case, the difference between RICWS and control sites. Specifically, it looks at the treatment effect between two samples, and whether or not it is zero. For this test, the observations need to be assigned to one of two categorical groups: either the RICWS or control group. This test assumes independence within and between the sample as well as continuity. Once again, Mann-Whitney does not assume that the data are normal.

The corresponding null hypothesis for this test is that the distributions for the crash reduction factor at the RICWS and control sites are equal. The alternative hypothesis is that the crash reduction factor distributions for RICWS and control sites are not equal.

Since 2003, fatal and serious injury crashes across the state have trended down. As a result, the expected outcome for control sites would be small decreases. If the installation of RICWS has no effect, the treatment sites should be operating the same as the control sites. If RICWS installation had an effect, the expected result would be a decrease that significantly exceeds the control sites.

Similar outcomes as the Wilcoxon Signed Rank Test were obtained. Again, the provided p-values will be compared to a significance level of $\alpha = 0.05$. If the p-value is greater than 0.05, RICWS and control sites have similar crash outcomes. The results of the Mann-Whitney U-Test are shown in Table 6.

Table 6 *Comparison of RICWS and Control Results for the Mann-Whitney U-Test*

Crash Rate Type % Difference Category	**RICWS** % ∆	**Control** % ∆	***p*-value**	**Significant**
Total Crash	- 3.17%	+ 14.00%	0.775	No
K + A Right-angle Crash	+ 24.09%	+ 39.65%	0.922	No
K + A Crash	+ 34.31%	- 26.95%	0.350	No
K Crash	- 11.76%	+ 149.38%	0.282	No
A Crash	+ 86.14%	- 43.00%	0.056	No*
Right-angle Crash	- 7.09%	+ 31.00%	0.718	No

* Statistically significant at $\alpha = 0.10$

5.2 Discussion

Comparing crash rates for RICWS and control sites before and after RICWS deployment for the six target crash types, no significant differences were identified between RICWS and control sites. From Table 6, it can be seen that all of the *p*-values are greater than 0.05, meaning that none of the target crash types had any significant differences. If the standard for significance is relaxed to 10%, the higher 'A' crash rates at RICWS sites could be significant, which has a *p*-value of 0.056. Several nominally lower crash rates for the RICWS sites may still suggest that RICWS could hold some potential for reducing certain types of crashes (e.g. right-angle crashes), but a distinct or consistent effect on crash rates still remains to be seen. That said, it is worth noting that when evaluated using the less stringent 90% confidence interval ($p = 0.10$), the difference between how much the groups' average 'A' rates would be great enough to be considered statistically significant.

Put another way, the amount that the two groups' 'A' rates changed makes it harder to attribute the changes to chance alone. However, as noted earlier in this report, a known complicating factor that has already been shown to have a significant effect on reported 'A' crash rates statewide is the 2016 change to the crash records database (which added of the word "Suspected" to all "Suspected Serious Injury" crashes). While this difference in the groups' 'A' crash rates may be an apparent one, it still may be difficult to highlight or interpret the practical significance of this difference within the context of the data reporting change for 'A' crashes and an overall lack of distinction between the select RICWS and control sites.

Chapter 6: Summary

The safety benefits of RICWS were analyzed by comparing before and after crash rates at RICWS and control locations. Both a before and after study and a comparative study were completed to assess the effectiveness that RICWS systems have on rural roadway safety. The before and after study yielded no indication that the crash rate at RICWS sites significantly increased or decreased after the implementation of the system. Since both RICWS and control sites produced similar results, the change in crash recording is neither washing out nor enhancing the apparent performance of RICWS. In addition, the comparison test also produced no indication that a difference in crash rate exists between RICWS and control sites. While this study did not produce the expected results, the two tests did not indicate that the installation of RICWS significantly increased crash rates at rural intersections.

The status of the systems was not consistently known throughout the entire duration of deployment. It is unknown if technical issues had an impact on the analysis. After reviewing the maintenance logs, only one crash was found to have occurred while it was known that the RICWS was not working. However, that specific crash was determined to be caused by winter weather conditions and ice on the roadway. Additionally, all fatal and serious injury crashes were reviewed, but none of the crashes' corresponding officer narratives gave any indication that a RICWS signal was malfunctioning when the crash occurred. Not knowing the status of a RICWS system at the time of a crash makes it difficult to fully determine the effectiveness of the system.

The Minnesota Department of Transportation does not see a need to remove existing RICWS due to poor performance. MnDOT will continue to monitor the performance of the system for those remaining in service.

Additional analyses were conducted to determine if subsets of the RICWS analysis produced different effects. The results of these analyses did not produce significant results, so they were not included in the final report. These analyses are included in Appendices C and D merely as an acknowledgement of the analyses attempted.

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Appendix A: List of RICWS and Control Sites

This appendix contains a breakdown of all the RICWS and control sites used in the evaluation. The list includes the project number, intersection ID, county where intersection is located, the names of the major and minor roads, and the date the RICWS was turned on.

Table A-1 List of RICWS Sites

Major SP	Intersection ID	County	Major Road	Minor Road	Turn-On Date
8816-1765	3.023.090	Kanabec	MNTH 23	CSAH 11 (West JCT)	9/1/2015
	6.060.004	Rice	MNTH 60	CSAH 13 T28	5/27/2014
	3.055.028	Wright	MNTH 55	CSAH 3/CR 136	6/18/2014
	1.001.014	St. Louis	MNTH 1/169	CSAH 77	6/6/2014
	8.007.051	Carver	MNTH 7	CSAH 33	11/26/2013
	6.063.025	Olmsted	MNTH 63	CSAH 21/CR 121	6/10/2014
	7.015.063	Nicollet	MNTH 15	CSAH 5	6/11/2014
	8.023.065	Kandiyohi	MNTH 23	CSAH 1	5/21/2014
	3.210.051	Aitkin	MNTH 210	CSAH 12	12/18/2013
	3.023.091	Kanabec	MNTH 23	CSAH 11 (East JCT)	5/16/2014
	3.055.031	Wright	MNTH 55	CSAH 37	6/18/2014
	6.003.013	Rice	MNTH 3	CSAH 20	5/28/2014
	8.023.031	Lyon	MNTH 23	CSAH 30 (North JCT)	6/4/2014
	8.212.050	McLeod	USTH 212	MNTH 22 (E Jct)	6/11/2014
	6.042.003	Olmsted	MNTH 42	CSAH 9	6/10/2014
	6.060.002	Rice	MNTH 60	CSAH 16	5/28/2014
	1.002.030	St. Louis	USTH 2	CSAH 98	12/18/2013
	6.060.003	Rice	MNTH 60	CSAH 44/CR 72	6/9/2014
	4.029.052	Douglas	MNTH 29	CSAH 5	7/6/2015

Major SP	Intersection ID	County	Major Road	Minor Road	Turn-On Date
	4.210.019	Otter Tail	MNTH 210	CSAH 35	5/28/2015
	4.075.089	Clay	USTH 75	CSAH 2	5/20/2015
	4.200.007	Mahnomen	MNTH 200	CSAH 4	5/18/2015
	2.075.046	Polk	USTH 75	CSAH 21	9/3/2015
	1.169.048	St. Louis	MNTH 169	CSAH 21	10/8/2015
	3.023.084	Kanabec	MNTH 23	CSAH 12	9/30/2015
	8.007.021	Chippewa	MNTH 23	MNTH 7	12/15/2015
	2.006.008	Itasca	MNTH 6	MNTH 286	10/8/2015
	8.071.030	Kandiyohi	USTH 71	MNTH 9	5/21/2014
	N 7.014.561	Nicollet	USTH 14	561st Ave	9/14/2015
	1.053.034	St. Louis	USTH 53	Hat Trick Ave (CSAH 146)	11/4/2014
	8.023.012	Pipestone	MNTH 23	CSAH 16	9/23/2015
	8.023.035	Lyon	MNTH 23	CSAH 7	11/13/2014
	3.169.026	Mille Lacs	USTH 169	CSAH 11	12/5/2014
	6.043.016	Winona	MNTH 43	CSAH 21	9/14/2015
	6.056.066	Goodhue	MNTH 56	CSAH 9	11/26/2014
	4.010.071	Otter Tail	USTH 10	CSAH 75	12/8/2014
	4.029.049	Douglas	MNTH 29	CSAH 20	7/6/2015
	6.052.031	Olmsted	USTH 52	CSAH 19 (W Jct)	9/15/2015
	3.006.009	Crow Wing	MNTH 6	CSAH 30 (North JCT)	11/6/2014
	6.014.056	Winona	USTH 14	CSAH 25	9/14/2015
	3.169.051	Aitkin	USTH 169	CSAH 28	11/6/2014
	3.047.002	Isanti	MNTH 47	CSAH 8	12/4/2014
	4.075.109	Clay	USTH 75	CSAH 18	7/6/2015

Major SP	Intersection ID	County	Major Road	Minor Road	Turn-On Date
	8.007.008	Chippewa	MNTH 7/USTH 59	CSAH 15 (W Jct)	11/13/2014
	7.060.041	Cottonwood	MNTH 60	CSAH 1	11/19/2014
	8.015.029	Meeker	MNTH 15	CSAH 27	12/15/2015
	8.007.049	McLeod	MNTH 7	CSAH 1 (Babcock Ave)	9/30/2015
	6.019.021	Goodhue	MNTH 19	CSAH 7	11/26/2014
	4.075.049	Wilkin	USTH 75	MNTH 55	6/9/2016
	6.060.032	Goodhue	MNTH 60	MNTH 57	6/2/2016
	8.067.024	Redwood	MNTH 67	CSAH 13	12/18/2015
	3.010.065	Sherburne	USTH 10	CR 23	12/8/2015
	3.023.009	Stearns	MNTH 23	CR 158	12/11/2015
	CW 3.004.003	Crow Wing	CSAH 4	CSAH 3	12/15/2015
8816-2274	3.210.035	Crow Wing	MNTH 210	CSAH 59	12/15/2015
	SL 1.053.Land	St. Louis	USTH 53	Landfill Rd	10/23/2017
	S 3.002.Minn	Stearns	CSAH 2	Minnesota St	11/17/2014
	1.002.028	St. Louis	USTH 2/MNTH 194	CSAH 46	12/1/2016
	SL 1.002.223	St. Louis	USTH 2	CR 223	12/1/2016
6918-86	1.053.047	St. Louis	USTH 53	CSAH 115	12/1/2016
County ICWS	1.037.015	St. Louis	MNTH 37	CSAH 7	12/1/2016
	1.037.011	St. Louis	MNTH 37	CSAH 25 (W Jct)	12/1/2016
	SL 1.004.043	St. Louis	CSAH 4	CSAH 43	12/1/2016
	SL 1.037.002	St. Louis	CSAH 37	CSAH 2	12/1/2016
	M.017.069	Washington	CSAH 17	69th Street North	5/29/2015

Major SP	Intersection ID	County	Major Road	Minor Road	Turn-On Date
	SL 1.013.045	St. Louis	CSAH 13	CSAH 45/N Cloquet Rd	10/1/2017

Table A-2 *List of Control Sites*

Intersection ID	District	County	Major Road	Minor Road	"Turn On Date"
3.023.056	3	Benton	MNTH 23	CSAH 6	9/1/2015
6.060.006	6	Rice	MNTH 60	CSAH 17 (Dalton Ave)	5/27/2014
6.218.030	6	Steele	USTH 14	CSAH 6 (N Jct)/CR 159	5/27/2014
3.055.027	3	Wright	MNTH 55	CSAH 2 (E Jct)/M8	6/18/2014
1.001.022	1	St. Louis	MNTH 1	CSAH 88 (W Jct)	6/6/2014
8.007.050	8	McLeod	MNTH 7	CSAH 9	11/26/2013
6.042.010	6	Wabasha	MNTH 42	CSAH 4/56	6/10/2014
6.061.053	6	Goodhue	USTH 61	CSAH 21	6/10/2014
8.212.036	8	Renville	USTH 212	MNTH 4	6/11/2014
8.023.066	8	Kandiyohi	MNTH 23	CSAH 5	5/21/2014
1.169.001	1	Aitkin	USTH 169	MNTH 200	12/18/2013
3.023.094	3	Kanabec	MNTH 23	CSAH 5	5/16/2014
3.055.030	3	Wright	MNTH 55	CSAH 6	6/18/2014
6.003.009	6	Rice	MNTH 3	CR 75/T-40	5/28/2014
8.019.012	8	Lyon	MNTH 19	CSAH 7	6/4/2014
8.071.015	8	Renville	USTH 71	USTH 212	6/11/2014
6.042.004	6	Olmsted	MNTH 42	CSAH 2 (W Jct)/Viola Rd	6/10/2014
7.060.091	7	Le Sueur	MNTH 60	CSAH 3 (Reed St)	5/28/2014
7.013.048	7	Le Sueur	MNTH 21/13	CSAH 28	5/28/2014
1.002.018	1	St. Louis	USTH 2	MNTH 65	12/18/2013

Intersection ID	District	County	Major Road	Minor Road	"Turn On Date"
1.002.013	1	Itasca	USTH 2	CSAH 71	12/18/2013
6.063.011	6	Mower	MNTH 63	CSAH 1	6/9/2014
4.029.020	4	Douglas	MNTH 29	CSAH 4	7/6/2015
4.210.001	4	Wilkin	MNTH 210	MNTH 9/CSAH 16	5/28/2015
4.075.091	4	Clay	USTH 75	CSAH 8	5/20/2015
2.200.049	2	Clearwater	MNTH 200	MNTH 92/CSAH 37	5/18/2015
2.059.053	2	Marshall	USTH 59	CSAH 2	9/3/2015
2.059.029	2	Pennington	USTH 59	CSAH 8	9/3/2015
1.135.004	1	St. Louis	MNTH 135	CSAH 4	10/8/2015
1.169.015	1	Itasca	USTH 169	CSAH 15	10/8/2015
3.065.023	3	Kanabec	MNTH 65	MNTH 70/CR 47	9/30/2015
8.007.013	8	Chippewa	MNTH 7	CSAH 15 (E Jct)	12/15/2015
2.071.069	2	Koochiching	USTH 71	CSAH 36	10/8/2015
8.071.026	8	Kandiyohi	USTH 71	CSAH 10	5/21/2014
7.014.040	7	Nicollet	USTH 14	CSAH 21	9/14/2015
1.053.018	1	St. Louis	USTH 53	CSAH 15/CR 223	11/4/2014
8.023.013	8	Pipestone	MNTH 23	CSAH 8	9/23/2015
8.023.037	8	Lyon	MNTH 23	CSAH 67 (S Saratoga St)	11/13/2014
3.169.034	3	Mille Lacs	USTH 169	CSAH 22	12/5/2014
ML 3.169.009	3	Mille Lacs	USTH 169	CSAH 9	12/5/2014
6.014.041	6	Olmsted	USTH 14	CSAH 19	9/14/2015
M.056.086	M	Dakota	MNTH 56	CSAH 86	11/26/2014
4.029.075	4	Otter Tail	MNTH 29	CSAH 75	12/8/2014
4.029.054	4	Douglas	MNTH 29	CSAH 14	7/6/2015
6.052.032	6	Olmsted	USTH 52	CSAH 16	9/15/2015

Intersection ID	District	County	Major Road	Minor Road	"Turn On Date"
3.006.010	3	Crow Wing	MNTH 6	CSAH 11	11/6/2014
6.063.026	6	Olmsted	USTH 63	MNTH 247	9/14/2015
6.014.058	6	Winona	USTH 14	CSAH 20	9/14/2015
3.169.050	3	Aitkin	USTH 169	CSAH 11	11/6/2014
3.047.005	3	Isanti	MNTH 47	CSAH 5	12/4/2014
4.075.098	4	Clay	USTH 75	CSAH 76 (MSAS 137)	7/6/2015
7.004.049	7	Brown	MNTH 4	CSAH 29	11/13/2014
7.060.040	7	Cottonwood	MNTH 60	570th Ave (CSAH 27)	11/19/2014
8.015.028	8	Meeker	MNTH 15	CSAH 21	12/15/2015
8.007.048	8	McLeod	MNTH 7	CSAH 15/CR 88 (Falcon Ave)	9/30/2015
6.019.022	6	Goodhue	MNTH 19	CSAH 51	11/26/2014
6.019.023	6	Goodhue	MNTH 19	CSAH 6	11/26/2014
4.009.054	4	Wilkin	MNTH 55	MNTH 9	6/9/2016
4.009.065	4	Wilkin	MNTH 9	CSAH 18	6/9/2016
7.013.037	7	Le Sueur	MNTH 13	MNTH 99	6/2/2016
8.067.021	8	Redwood	MNTH 67	CSAH 1/CR 53	12/18/2015
3.010.049	3	Sherburne	USTH 10	CSAH 7	12/8/2015
3.023.016	3	Stearns	MNTH 23	CSAH 47	12/11/2015
3.210.046	8	Crow Wing	MNTH 210	MNTH 6/Front St.	12/15/2015
3.210.034	8	Crow Wing	MNTH 210	CR 147	12/15/2015
SL 1.053.950	1	St. Louis	USTH 53	CR 950/Bodas Rd	10/23/2017
3.055.035	3	Wright	MNTH 55	CR 109	11/17/2014
1.002.032	1	St. Louis	USTH 2	CSAH 56	12/1/2016
1.002.019	1	Itasca	USTH 2	CSAH 25/CR 429	12/1/2016
1.053.060	1	St. Louis	USTH 53	CSAH 24/2nd Ave E	12/1/2016

Intersection ID	District	County	Major Road	Minor Road	“Turn On Date”
1.194.001	1	St. Louis	USTH 2	CSAH 98/Canosia Rd	12/1/2016
1.037.010	1	St. Louis	MNTH 37	CR 453	12/1/2016
1.210.010	1	Carlton	MNTH 210	CSAH 5	12/1/2016
SL 1.037.280	1	St. Louis	CSAH 37	CR 280 (Riley Rd)	12/1/2016
M.017.057	M	Washington	CSAH 17	57th Street North	5/29/2015
SL 1.013.104	1	St. Louis	CSAH 13	MSAS 104 (Arrowhead Rd)	10/1/2017

Appendix B: Fatal and Severe Injury Crash Summary

This appendix provides a summary of the all the fatal and severe injury crashes that occurred at RICWS sites in the after period. Each summary contains the date and time of the crash, details from the crash narrative, and pertinent road characteristics.

Crash 143290036 (11012670) – November 3, 2014, 7:07 AM, Intersection of TH 55 and CSAH 3 southeast of South Haven

K crash. Vehicle 1 was heading eastbound on TH 55. Vehicle 2 was northbound on CR 3 and failed to stop at the stop sign. The two cars collided in the intersection and ended up in the ditch. Driver 2 was deceased on the scene. The weather was cloudy and the posted speed limit was 55 miles per hour. The roadway was curved and level, and the surface was dry. One lane of traffic in each direction. The RICWS system was working properly.

Crash 151530193 (11057900) – May 31, 2015, 4:16 PM, Intersection of TH 212 and TH 22 in Glencoe

A crash. Vehicle 1 was eastbound on US 212 and intended to make a left turn to go north onto TH 22. Vehicle 2 was in the left lane, heading westbound. V1 thought V2 was also turning onto TH 22. V1 turned in front of V2. Driver 1 veered to the left after the collision and ended up in the ditch. Driver of vehicle 2 was not wearing a seat belt. The intersection was a divided highway, straight and level. The road surface was dry and the weather was clear. The posted speed limit was 55 miles per hour. The signal was working properly.

Crash 151630199 (11058647) – June 9, 2015, 7:01 PM, Intersection of TH 42 and CR 9 north of Eyota

A crash. Vehicle 1 was westbound on CR 9. Vehicle 2 was northbound on TH 42. Vehicle 3 was southbound on TH 42, slowing to turn right onto CR 9. Vehicle 1 failed to yield the right of way and continued into the intersection and was hit by vehicle 2. Vehicle 1 was pushed into vehicle 3, which rolled down into the ditch. There was a detour going on at the time of the crash. Road Closed sign posted on south side of TH 42. There was one lane of traffic in each direction and the road was straight and level. The road surface was dry and the weather was clear. The posted speed limit was 55 miles per hour. Traffic signal working was coded as not applicable.

Crash 151730179 (11059304) – June 18, 2015, 3:04 PM, Intersection of TH 42 and CR 9 north of Eyota

K crash. Vehicle 1 was eastbound on CR 9. He stopped at the stop sign then started making a left turn to go northbound on TH 42. Vehicle 2 was heading southbound on TH 42, when he collided with vehicle 1. USTH 14/MNTH 42 is under construction. CR 9 is the detour route. LED traffic control devices at the location. Traffic signal working was coded as not applicable, so unsure if working. There was one lane of traffic in each direction and the road was straight and level. The road surface was dry and the weather was clear. The posted speed limit was 55 miles per hour.

Crash 152510308 (11066488) – September 6, 2015, 2:32 PM, Intersection of TH 169 and CSAH 11 north of Milaca

K crash. Vehicle 1 was eastbound on CR 11, crossing southbound TH 169. Vehicle 2 was southbound in the left lane of TH 169. Vehicle 1 pulled out to cross and vehicle 2 hit vehicle 1. Vehicle 1 rolled into the median. Passenger 1 was deceased on scene. Driver 1 had serious injuries. Both had been belted. The intersection was a two-lane divided highway and the road was curved and level. The road surface was dry and the weather was cloudy. The posted speed limit was 65 miles per hour. The RICWS system was reported working properly.

Crash 152090271 (11061716) – July 26, 2015, 4:14 PM, Intersection of TH 47 and CSAH 8 north of St. Francis

K crash. Vehicle 1 was westbound on CR 8 and stopped at the intersection waiting to turn left to go southbound on TH 47. Vehicle 2, a motorcycle, was northbound on TH 47. Vehicle 1 turned in front of vehicle 2 and was hit. Both people on the motorcycle were not wearing helmets and were ejected from the vehicle. Driver 2 died in the hospital. There was one lane of traffic in each direction and the road was straight and level. The surface was dry and the weather was clear. The posted speed limit was 60 miles per hour. Traffic signal working coded as not applicable.

Crash 152440187 (11033098) – August 28, 2015, 7:49 PM, Intersection of TH 75 and CSAH 18 in Moorhead

A crash. Vehicle 1 was westbound on CSAH 18, slowing for the stop sign. Vehicle 2 was northbound on US 75. Vehicle 1 almost came to a stop, but then quickly accelerated in front of vehicle 2. Vehicle 2 attempted to turn to the left to avoid vehicle 1 but hit it anyways. Driver 1 smelled of alcohol and had bloodshot eyes and slurred speech. There was one lane of traffic in each direction and the road was straight and level. The surface was dry and the weather was clear. The posted speed limit was 60 miles per hour. The RICWS signal was working properly.

Crash 418707 – January 15, 2017, 11:21 AM, Intersection of TH 169 and CR 77 in Peyla

A crash. Vehicle 1 was traveling eastbound on CR 77 and vehicle 2 was traveling northbound on US 169. Vehicle 1 went through the stop sign and, upon seeing vehicle 2, swerved to avoid it, but hit it anyways. Driver 1 was not wearing a seat belt. Unclear if driver 1 was distracted. The stop sign was operational and visible. The posted speed limit was 55 miles per hour and the weather was clear. The road surface was wet and the road alignment was straight and level. There was one lane of traffic in each direction.

Crash 508392 – October 11, 2017, 6:49 AM, Intersection of TH 212 and Chandler Ave in Glencoe

A crash. Vehicle 1 traveling westbound on TH 212 and vehicle 2 traveling eastbound on TH 212, attempting to turn left to go north on Chandler Ave. Vehicle 2 took the turn in front of vehicle 1 and was stuck by vehicle 1. The weather was clear and the road surface was dry. The roadway curved left and was level. It was a two-way, divided intersection with an unprotected median. Both cars were on the major road; therefore, the RICWS was ineffective. The posted speed limit was 55 miles per hour.

Crash 386996 – October 6, 2016, 10:52 AM, Intersection of TH 75 and CR 21 near Euclid

K crash. Vehicle 1 was traveling eastbound on CR 21 and failed to yield the right of way to vehicle 2, which was northbound on US 75. The road alignment was straight and level. The roadway was two-way, undivided. The weather was clear and the road surface was dry. The posted speed limit was 55 miles per hour.

Crash 374476 – August 26, 2016, 12:45 PM, Intersection of TH 286 and TH 6 in Talmoon

A crash. Vehicle 1 was traveling westbound on TH 286. Driver 1 did not see the stop sign and proceeded through the intersection, colliding with vehicle 2, which was southbound on TH 6. No signs of impairment. The road was straight and level. The roadway is two-way, undivided. The weather was clear and the road surface was dry. The posted speed limit was 55 miles per hour.

Crash 520516 – November 29, 2017, 12:34 PM, Intersection of TH 71 and TH 9 west of New London

A crash. Vehicle 1 was southbound on USTH 71 and attempted to turn left (to go eastbound) in front of a northbound vehicle. The two cars collided and vehicle 2 rolled onto its roof. Both vehicles were on the major road, so the RICWS not helpful. The weather was cloudy and the surface was dry. The posted speed limit was 60 miles per hour.

Crash 384957 – October 7, 2016, 5:04 PM, Intersection of TH 23 and CR 7 in Marshall

A crash. Vehicle 1 traveling westbound on MNTH 23 and vehicle 2 traveling southbound on CR 7. Vehicle 2 stopped at the stop sign, then pulled out to turn left onto TH 23 and was hit by vehicle 1. Vehicle 2 failed to yield right-of-way. No mention of RICWS in the report. The weather was clear and the surface was dry. The posted speed limit was 55 miles per hour.

Crash 411381 – January 4, 2017, 4:46 PM, Intersection of TH 169 and CSAH 11 north of Milaca

K crash. Vehicle 1 was eastbound on CSAH 11 and vehicle 2 (a truck) was southbound on USTH 169. Vehicle 1 did not see vehicle 2 and pulled out into the intersection. Vehicle 2 attempted to brake and avoid the crash but was unable to. Driver 1 was pronounced dead on the scene. Vehicle 1 failed to yield right-of-way. No mention of RICWS in the report. The weather was clear and the road surface was dry. The posted speed limit was 65 miles per hour.

Crash 342793 – April 16, 2016, 8:37 AM, Intersection of TH 56 and CR 9

A crash. Vehicle 1 was westbound on CR 9 and vehicle 2 was northbound on MNTH 56. Vehicle 1 stopped at the stop sign and then proceeded into the intersection in front of vehicle 2. Vehicle 2 struck vehicle 1 in the side and both cars ended up in the ditch. Vehicle 1 failed to yield right-of-way. No mention of RICWS in the report. The weather was clear and the road surface was dry. The posted speed limit was 55 miles per hour.

Crash 360245 – June 23, 2016, 10:23 AM, Intersection of TH 47 and CSAH 8 north of St. Francis

K crash. Vehicle 1 was westbound on CSAH 8 and vehicle 2 (a motorcycle) was northbound on MNTH 47. Vehicle 1 saw the motorcycle and thought the intersection was a 4-way stop and did not see the RICWS warning of an oncoming vehicle. After coming to a stop, vehicle 1 proceeded to turn left (to go southbound) onto MNTH 47 and was hit by vehicle 2. The weather was clear and the road was dry. The posted speed limit was 60 miles per hour.

Crash 389240 – October 25, 2016, 8:45 AM, Intersection of TH 75 and 28th Ave in Moorhead

A crash. Vehicle 1 was heading westbound on 28th Avenue N and vehicle 2 (A bus) was northbound on USTH 75. Vehicle 1 stopped at stop sign and then proceeded into intersection. The vehicles collide in the intersection. Vehicle 1 failed to yield right-of-way. No mention of RICWS in crash report. The weather was clear and the road surface was dry. The posted speed limit was 40 miles per hour.

Crash 353019 – May 21, 2016, 5:14 PM, Intersection of TH 7 and CSAH 1 north of Lester Prairie

A crash. Vehicle 1 (a motorcycle) was northbound on CSAH 1 and vehicle 2 was eastbound on MNTH 7. It is unknown if vehicle 1 stopped at the stop sign. Driver was charged with failure to yield right-of-way. Driver 1 has early onset Alzheimer's/Dementia and memory issues and also takes medication to control seizures. The posted speed limit was 55 miles per hour.

Crash 525438 – December 15, 2017, 7:34 PM, Intersection of TH 7 and CSAH 1 north of Lester Prairie

A crash. Vehicle 1 was southbound on CSAH 1 and vehicle 2 was westbound on MNTH 7. Witnesses say vehicle 1 had been "weaving all over the road." Driver 1 was distracted by a text on her cell phone and did not stop for the stop sign. The posted speed limit was 55 miles per hour.

Crash 381910 – September 18, 2016, 11:15 AM, Intersection of CSAH 2 and Minnesota St in St. Joseph

A crash. Vehicle 1 was southbound on CSAH 2 and vehicle 2 (a motorcycle) was northbound on CSAH 2. Vehicle 1 turned on left-turn blinker and started slowing down. Vehicle 1 started making left turn in front on vehicle 2. Vehicles collided and driver 2 was ejected from the motorcycle. Unsure if driver 1 misjudged northbound vehicles or if driver 1 did not see vehicle 2 until last minute due to medical/eye issues. Both vehicles on major road; therefore, RICWS was ineffective. The posted speed limit was 55 miles per hour.

Crash 497934 – August 29, 2017, 1:58 PM, Intersection of TH 37 and CR 7 in Iron

K crash. Vehicle 1 was heading eastbound on MNTH 37 and vehicle 2 (a motorcycle) was westbound on MNTH 37. Vehicle 1 attempted to turn left on CR 7 but failed to yield right-of-way to vehicle 2. Driver 2 attempted to swerve to miss the crash, but the cars collided in the intersection. Driver 2 was thrown from the vehicle and pronounced dead at the hospital. Driver 1 thought vehicle 2 had its left turning blinker on, so they thought it was safe to turn. Both vehicles were on the major road; therefore, RICWS was ineffective. The weather was clear and the road surface was dry. The posted speed limit was 55 miles per hour.

Crash 429441 – March 14, 2017, 3:55 PM, Intersection of West Tischer Rd and Jean Duluth Rd north of Duluth

A crash. Vehicle 1 was traveling eastbound on West Tischer Rd and vehicle 2 was traveling northbound on Jean Duluth Rd. Vehicle 1 came to a stop at the stop sign, looked for cars and then entered the intersection. Driver 1 saw a vehicle approaching but felt that he had enough time to cross. The vehicles collided in the intersection. Driver 1 failed to yield after coming to a stop at the stop sign. The weather was clear and the road was dry. No mention of the RICWS system aiding in decision to cross. The posted speed limit was 55 miles per hour.

Appendix C: Additional Analyses Considered

This appendix contains an explanation and summary of all the tests that were completed for this evaluation. A lot of the same statistical tests were completed on varying datasets in an attempt to learn how changing different aspects of the study would affect the results. The changes in datasets included looking at all available crashes, looking at only intersection-specific crashes, varying the control sites turn-on date, and varying the before period.

Preliminary Findings

Some preliminary crash rates were calculated in order to obtain an idea of the expected results from the analysis. Two different periods of crash data were used in this analysis.

Section C.1: All Available Crashes

An initial look at the data was completed in order to obtain a brief overview of the potential results. All available crashes were used in this analysis. No attempt was yet made to update old crashes into the new coding format. The average turn-on date of the RICWS sites was May 21, 2015, and it was used for the turn-on date for all the control sites. The calculated crash rates for RICWS and control sites are broken down by severity and crash diagram and can be seen in Tables C-1, C-2, C-3, and C-4. The results from this section were not used in the full report because the crash data had not yet been reviewed to ensure that crashes included in the analysis actually occurred at the intersection and not a nearby parking lot or driveway.

From the tables, the total crash rate appears to be decreasing for both control and RICWS sites, which is expected. However, when looking at the K, A, and angle crash rates, there are contrasting results between the RICWS and control sites. RICWS intersections saw a decrease in K crash rate, while control intersections saw an increase in K crash rate. For A crashes, control sites saw a decrease in crash rate, while RICWS sites saw an increase. For angle crashes, RICWS sites saw a decrease in crash rate, while control sites saw an increase. Finding this trend was a surprise because even though it had been assumed that individual sites could certainly vary in crash rates, the expectation was that when aggregated, the RICWS and control sites would at least see trends in the same general direction. That said, without manually validating all of the available crashes (as described above), it would not be accurate to automatically attribute the crash rate differences in these tables to a safety impact of the RICWS.

Table C-1 *Crash Rates Based on Severity [All Crashes, RICWS Locations]*

Description	VE	Total	K+A	K	A	B	C	PDO
Before Crashes	1,381,609,130	949	65	32	33	136	223	525
Before Crash Rate	NA	0.687	0.047	0.023	0.024	0.098	0.161	0.380
After Crashes	450,585,229	270	23	8	15	50	39	158
After Crash Rate	NA	0.599	0.051	0.018	0.033	0.111	0.087	0.351
Percent Increase/Decrease (By Rate)	NA	**-12.76%**	**8.50%**	**-23.34%**	**39.38%**	**12.73%**	**-46.37%**	**-7.72%**

Table C-2 *Crash Rates Based on Severity [All Crashes, Control Locations]*

Description	VE	Total	K+A	K	A	B	C	PDO
Before Crashes	1,590,262,793	675	39	18	21	98	177	361
Before Crash Rate	NA	0.424	0.025	0.011	0.013	0.062	0.111	0.227
After Crashes	499,024,633	183	13	7	6	37	38	95
After Crash Rate	NA	0.367	0.026	0.014	0.012	0.074	0.076	0.190
Percent Increase/Decrease (By Rate)	NA	**-13.60%**	**6.22%**	**23.93%**	**-8.95%**	**20.32%**	**-31.58%**	**-16.14%**

Table C-3 *Crash Rates Based on Crash Diagram [All Crashes, RICWS Locations]*

Description	VE	Rear-end	Sideswipe Same Dir	Right-angle	Head On	Sideswipe Opp
Before Crashes	1,381,609,130	141	48	471	47	26
Before Crash Rate	NA	0.102	0.035	0.341	0.034	0.019
After Crashes	450,585,229	39	12	138	19	10
After Crash Rate	NA	0.087	0.027	0.306	0.042	0.022
Percent Increase/Decrease (By Rate)	NA	**-15.19%**	**-23.34%**	**-10.16%**	**23.95%**	**17.93%**

Table C-4 *Crash Rates Based on Crash Diagram [All Crashes, Control Locations]*

Description	VE	Rear-end	Sideswipe Same Dir	Right-angle	Head On	Sideswipe Opp
Before Crashes	1,590,262,793	106	46	276	41	35
Before Crash Rate	NA	0.067	0.029	0.174	0.026	0.022
After Crashes	499,024,633	37	7	90	9	7
After Crash Rate	NA	0.074	0.014	0.180	0.018	0.014
Percent Increase/Decrease (By Rate)	NA	**11.24%**	**-51.51%**	**3.92%**	**-30.05%**	**-36.27%**

Section C.2: Intersection-Specific Crashes - Part I

All crashes that were coded as non-intersection-related - crashes in an alley or a driveway, or animal-related crashes—were removed from the study. All 2006-2015 crashes used in the study were updated in accordance with the 2016 coding system. The turn-on date for all of the control sites was kept as the average turn-on date, May 21, 2015. At this stage, only crash rates were calculated and no further statistical analysis was completed. All calculated crash rates can be found in Tables C-5, C-6, C-7, and C-8. The results in this section were not used because it was determined that the results would be more accurate if a control site used the turn-on date of its matching RICWS site instead of an average turn-on date.

Similar results to those found in the previous section were seen, but on a smaller scale. The total crash rate for both RICWS and control sites decreased by approximately 5% and 7%, respectively. This is about half the decrease seen in the previous section. Additionally, RICWS sites saw a decrease in K and right-angle crash rates, but an increase in A crash rate. On the other hand, control sites saw a decrease in A crash rate and an increase in K and right-angle crash rates.

Table C-5 *Crash Rates Based on Severity [Intersection-Specific Crashes I, RICWS Locations]*

Description	VE	Total	K	A	B	C	PDO
Before Crashes	1,380,514,330	771	31	28	117	193	402
Before Crash Rate	NA	0.558	0.022	0.020	0.085	0.140	0.291
After Crashes	450,585,229	238	8	15	47	37	131
After Crash Rate	NA	0.528	0.018	0.033	0.104	0.082	0.291
Percent Increase/Decrease (By Rate)	**-67.36%**	**-5.42%**	**-20.93%**	**64.13%**	**23.08%**	**-41.26%**	**-0.16%**

Table C-6 *Crash Rates Based on Severity [Intersection-Specific Crashes I, Control Locations]*

Description	VE	Total	K	A	B	C	PDO
Before Crashes	1,590,262,793	519	14	15	86	135	269
Before Crash Rate	NA	0.326	0.009	0.009	0.054	0.085	0.169
After Crashes	499,024,633	152	7	3	33	31	78
After Crash Rate	NA	0.305	0.014	0.006	0.066	0.062	0.156
Percent Increase/Decrease (By Rate)	**-68.62%**	**-6.67%**	**59.34%**	**-36.27%**	**22.28%**	**-26.82%**	**-7.60%**

Table C-7 *Crash Rates Based on Crash Diagram [Intersection-Specific Crashes I, RICWS Locations]*

Description	Rear End	Sideswipe Same Dir	Angle	Head On	Sideswipe Opp	Other/Not App	Unknown/ Blank	K+A w/ Angle
Before Crashes	119	34	477	20	18	49	54	54
Before Crash Rate	0.086	0.025	0.346	0.014	0.013	0.035	0.039	0.039
After Crashes	36	8	146	17	10	6	15	20
After Crash Rate	0.080	0.018	0.324	0.038	0.022	0.013	0.033	0.044
Percent Increase/Decrease (By Rate)	**-7.31%**	**-27.91%**	**-6.22%**	**160.43%**	**70.21%**	**-62.48%**	**-14.89%**	**13.48%**

Table C-8 *Crash Rates Based on Crash Diagram [Intersection-Specific Crashes I, Control Locations]*

Description	Rear End	Sideswipe Same Dir	Angle	Head On	Sideswipe Opp	Other/Not App	Unknown/ Blank	K+A w/ Angle
Before Crashes	97	38	282	14	23	25	40	25
Before Crash Rate	0.061	0.024	0.177	0.009	0.014	0.016	0.025	0.016
After Crashes	32	6	89	6	4	1	14	10
After Crash Rate	0.064	0.012	0.178	0.012	0.008	0.002	0.028	0.020
Percent Increase/Decrease (By Rate)	**5.13%**	**-49.68%**	**0.57%**	**36.57%**	**-44.58%**	**-87.25%**	**11.54%**	**27.47%**

Section C.3: Intersection-Specific Crashes - Part II

Since control sites were selected based on specific RICWS sites, it made sense to assign the corresponding RICWS turn-on date to its matching control site. The same data from Section C.2 was used, but now with updated crashes to match turn-on dates for RICWS sites. In this section the crash data is heavily weighted towards the before data. Therefore, it was determined that three years of before crashes would provide a better representation of the crashes that occur at these intersections within the most recent years. This is a relatively standard before period that has been followed by previous studies.

The crash rates for the RICWS sites are the same as Section C.2. Only the results for the control sites have changed. The updated crash rates for control sites can be found in Tables C-9, and C-10. From the tables, it can be seen that control sites now see an 11% increase in total crash rate compared to the 7% decrease seen in Section C.2. However, the control sites still see an increase in K and right angle crash rates and a decrease in 'A' crash rate.

To further investigate the significance of the differences in crash rates, two statistical tests were run: the Mann-Whitney U-Test and the Wilcoxon Signed Rank Test. The Mann-Whitney U-Test looks at the differences between the RICWS and control sites crash rates. The results of the test done in SPSS are shown in Table C-13. At a 5% level, fatal crash rates are significantly lower at RICWS than control sites. From Table C-11, RICWS sites saw a 21% decrease in crash rates. If the significance level was relaxed to 10%, K and A right angle crashes are also significantly lower at RICWS than control sites. From Table C-12, RICWS sites saw a smaller positive percent difference compared to control sites.

On the other hand, the Wilcoxon Signed Rank Test compares the differences between before and after crashes for RICWS and control sites separately. The control sites were tested here with the intent that there would be similar results for both RICWS and control sites. The statistical results can be found in Table C-14. From the table, it can be seen that none of the tested crash types for RICWS sites were found to be significant. This indicates that there is not a difference in crash rates after RICWS was installed. While these results do not verify the expected results, they also do not show that RICWS is increasing crash rates at rural intersections.

Table C-9 *Crash Rates Based on Severity [Intersection-Specific Crashes II, Control Locations]*

Description	VE	Total	K	A	B	C	PDO
Before Crashes	1,514,811,362	482	10	14	85	125	248
Before Crash Rate	NA	0.318	0.007	0.009	0.056	0.083	0.164
After Crashes	497,437,164	176	10	4	30	40	92
After Crash Rate	NA	0.354	0.020	0.008	0.060	0.080	0.185
Percent Increase/Decrease (By Rate)	**-67.16%**	**11.20%**	**204.52%**	**-12.99%**	**7.48%**	**-2.55%**	**12.97%**

Table C-10 *Crash Rates Based on Severity [Intersection-Specific Crashes II, Control Locations]*

Description	Rear End	Sideswipe Same Dir	Angle	Head On	Sideswipe Opp	Other/Not App	Unknown/ Blank	K+A w/ Angle
Before Crashes	98	36	256	12	23	21	36	20
Before Crash Rate	0.065	0.024	0.169	0.008	0.015	0.014	0.024	0.013
After Crashes	30	6	109	7	4	5	15	14
After Crash Rate	0.060	0.012	0.219	0.014	0.008	0.010	0.030	0.028
Percent Increase/Decrease (By Rate)	**-6.78%**	**-49.25%**	**29.66%**	**77.64%**	**-47.04%**	**-27.49%**	**26.88%**	**113.17%**

Table C-11 *Comparing RICWS and Control Percent Differences Based on Severity [Intersection-Specific Crashes II]*

	Total	K	A	B	C	PDO
RICWS Percent Difference	-5.42%	-20.93%	64.13%	23.08%	-41.26%	-0.16%
Control Percent Difference	11.20%	204.52%	-12.99%	7.48%	-2.55%	12.97%

Table C-12 *Comparing RICWS and Control Percent Differences Based on Crash Diagram [Intersection-Specific Crashes II]*

	Rear End	Sideswipe Same Dir	Angle	Head On	Sideswipe Opp	Other/Not App	Unknown/ Blank	K+A w/ Angle
RICWS Percent Difference	-7.31%	-27.91%	-6.22%	160.43%	70.21%	-62.48%	-14.89%	13.48%
Control Percent Difference	-6.78%	-49.25%	29.66%	77.64%	-47.04%	-27.49%	26.88%	113.17%

Table C-13 *Mann-Whitney U-Test SPSS Results [Intersection-Specific Crashes II]*

Crash Rate % Difference Category	Z Statistic	P-value	Significant
Total Crash	-0.777	0.437	No
K+A Right Angle Crash	-1.874	0.061	Yes**
K+A Crash	-1.347	0.178	No
K Crash	-2.560	0.010	Yes*
A Crash	-0.813	0.416	No
Right Angle Crash	-0.201	0.841	No

*Significant at 5% significance level

**Significant at 10% significance level

Table C-14 *Wilcoxon Signed Rank Test SPSS Results [Intersection-Specific Crashes II]*

Intersection Type	Crash Rate Type	Z Statistic	P-value	Significant?
RICWS	Total Crash	-1.199	0.230	No
	K+A Right Angle Crash	-0.500	0.617	No
	K+A Crash	-0.256	0.798	No
	K Crash	-1.486	0.137	No
	A Crash	-0.686	0.493	No
	Right Angle Crash	-0.445	0.656	No
Control	Total Crash	-1.060	0.289	No
	K+A Right Angle Crash	-1.154	0.248	No
	K+A Crash	-0.713	0.476	No
	K Crash	-1.818	0.069	Yes*
	A Crash	-0.628	0.530	No
	Right Angle Crash	-0.056	0.955	No

*Significant at 10% significance level

Regression Testing

A secondary interest in the study was to develop an equation to predict crashes. Further analysis was completed on the data with the goal that a multivariate logistic regression could be fitted to the data. The regression equation would estimate the number of crashes at an intersection based on pre-defined risk characteristics of the intersection. Twelve predictor variables were used including:

- Treatment type (RICWS/Control)

- Major and minor road AADT
- Number of years before/after turn-on date
- Number of intersection legs
- If the major road was divided or undivided
- Presence of a horizontal or vertical curve
- Proximity to a railroad crossing
- Skew of the road
- A commercial development located in one of the intersection’s quadrants
- Speed limit
- Presence of lighting.

Multivariate Regression

Multivariate regression was chosen as the method of creating a regression model. Eight assumptions are associated with this model and needed to be verified before creating the model. Pre-screening the data is important because it determines how statistically sound the determined results are. Without testing the assumptions, a regression model could be created; however, the results would not be correct. The eight assumptions tested were:

- Assumption 1: The dependent variable must be a continuous variable.
    - In this case, the number of crashes is the dependent variable. There can be an infinite amount of crashes that could occur at an intersection. Therefore, it is a continuous variable.
    - Verified
- Assumption 2: There must be two or more independent variables, which can either be continuous or ordinal.
    - The twelve road characteristics listed above are the independent variables. Each variable is either continuous or ordinal (has some kind of order to it).
    - Verified
- Assumption 3: The observations must be independent.
    - The Durbin-Watson test statistic is equal to 1.638 and was found from the model summary shown in Table C-15. Since it falls between 1.5 and 2.5, this indicated that the observations are independent.
    - Verified

Table C-15 *SPSS Multivariate Regression Model Summary Depicting the Durbin-Watson Statistic*

Model Summary[b]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.483[a]	.233	.228	1.146	1.638

a. Predictors: (Constant), LIGHTING, OP_YEAR, NUM_LEGS, SPEED, DVLPMNT, SKEW, TX, RR_XING, MAJ_VOL, CURVE, MIN_VOL, NUM_LANE

b. Dependent Variable: CRASH

- Assumption 4: There must be a linear relationship between a.) the dependent variable and each of the independent variables and b.) the dependent variable and all the independent variables collectively.
  - The twelve road characteristics were graphed along with the crashes. Since ordinal variables only result a vertical line, these graphs are not shown in the matrix scatterplot. Only the continuous variables are shown in Figure C-1. The first row of the matrix scatterplot shows the relationship between crashes and each of the road characteristics. A linear relationship would be indicated by a single straight, diagonal line. Since none of the scatterplots show any kind of line, linearity cannot be assumed.
  - Assumption violated

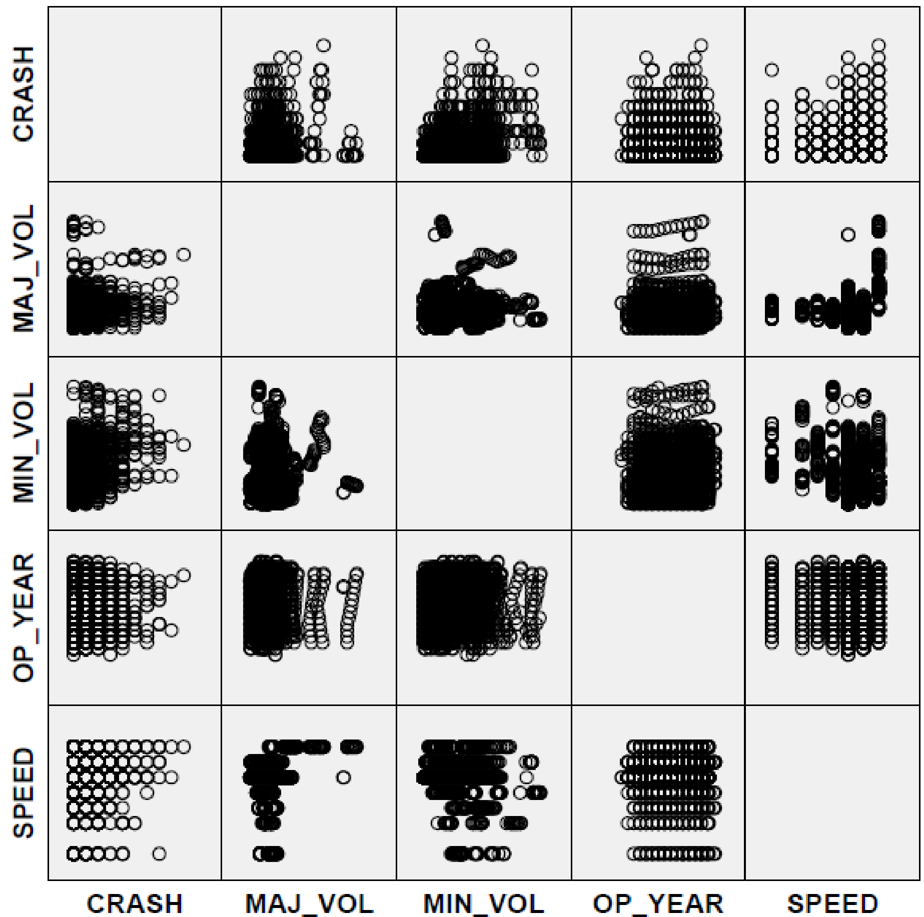

Figure C-1: Matrix Plot of the Road Characteristics Used in the Multivariate Regression Model

- Assumption 5: The data need to be homoscedasticity.
  - A residual plot, shown in Figure C-2, was created to determine homoscedasticity. The residuals plot does not show an even clustering of data points throughout the plot. Therefore, the data is heteroscedasticity.
  - Assumption violated

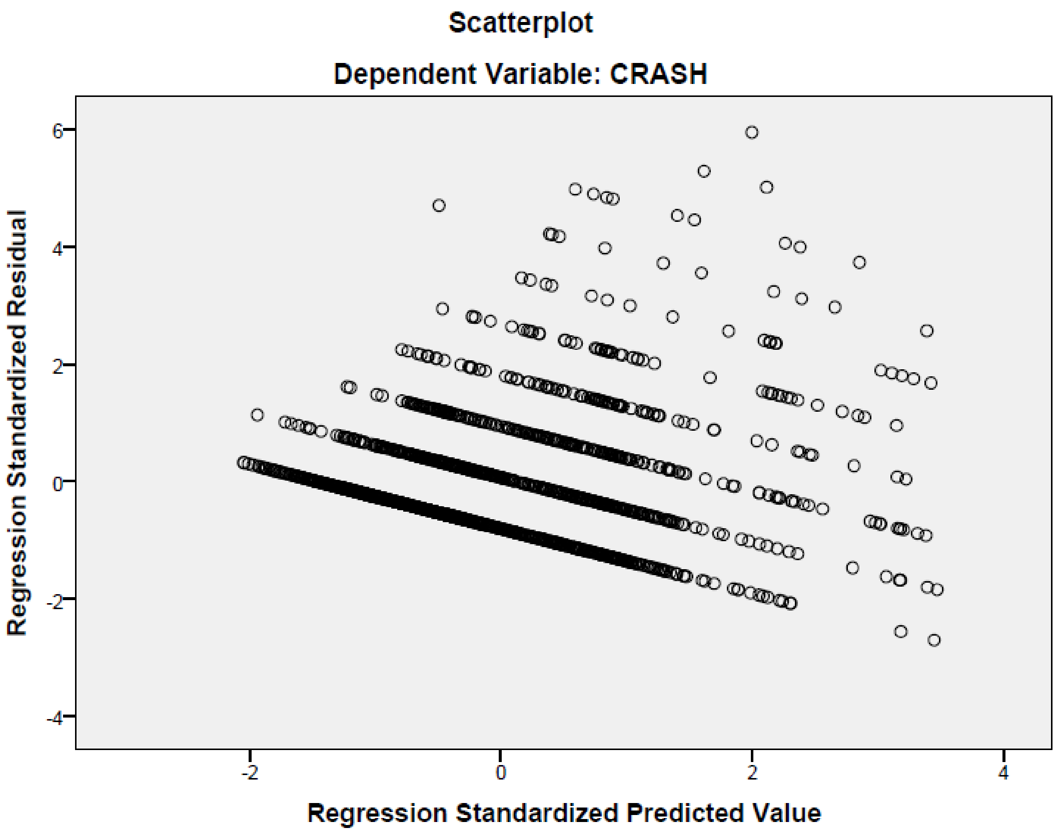

Figure C-2: Scatterplot of Crash Data

- Assumption 6: The data must not show multicollinearity.
  - Using a summary of the coefficients from the regression model shown in Table C-16, the Pearson correlation, VIF score, and the tolerance were looked at. To meet the assumption conditions, the Pearson correlation needs to be greater than 0.8, the VIF needs to be less than 10, and the tolerance needs to be greater than 0.2. All of the independent variables meet this criteria.
  - Verified

Table C-16 *Multivariate Regression Model Coefficients and Collinearity Statistics for the Independent Variables*

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	Collinearity ...
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-1.652	.389		-4.246	.000		
	TX	.267	.058	.102	4.614	.000	.873	1.145
	MAJ_VOL	3.961E-005	.000	.099	3.913	.000	.672	1.489
	MIN_VOL	.001	.000	.397	16.549	.000	.745	1.343
	OP_YEAR	-.030	.007	-.085	-4.063	.000	.984	1.016
	NUM_LEGS	.209	.075	.061	2.771	.006	.891	1.123
	NUM_LANE	.210	.054	.104	3.862	.000	.592	1.690
	CURVE	.105	.059	.040	1.770	.077	.833	1.200
	RR_XING	.239	.079	.066	3.041	.002	.907	1.102
	SKEW	.115	.060	.043	1.910	.056	.838	1.193
	DVLPMNT	-.014	.064	-.005	-.224	.823	.904	1.106
	SPEED	.002	.005	.009	.393	.694	.733	1.365
	LIGHTING	-.182	.061	-.070	-3.006	.003	.795	1.258

- Assumption 7: There must be no significant outliers, high leverage points, or highly influential points.
  - Cook's distance is a method that is used to determine if there are outliers in a dataset. If Cook's distance is greater than 1, it would indicate that the data point is an outlier. All of the Cook's distance were less than 1, meaning that there are no outliers.
  - Verified
- Assumption 8: The residuals must be approximately normal.
  - A Normal P-P plot was created to show the residuals. The plot is shown in Figure C-3. If all the plotted residuals fall on the line shown, then it can be concluded that the residuals are normal. From the plot, it can be seen that the crash residual do not fall along the plotted line, meaning that they are not normal.
  - Assumption violated

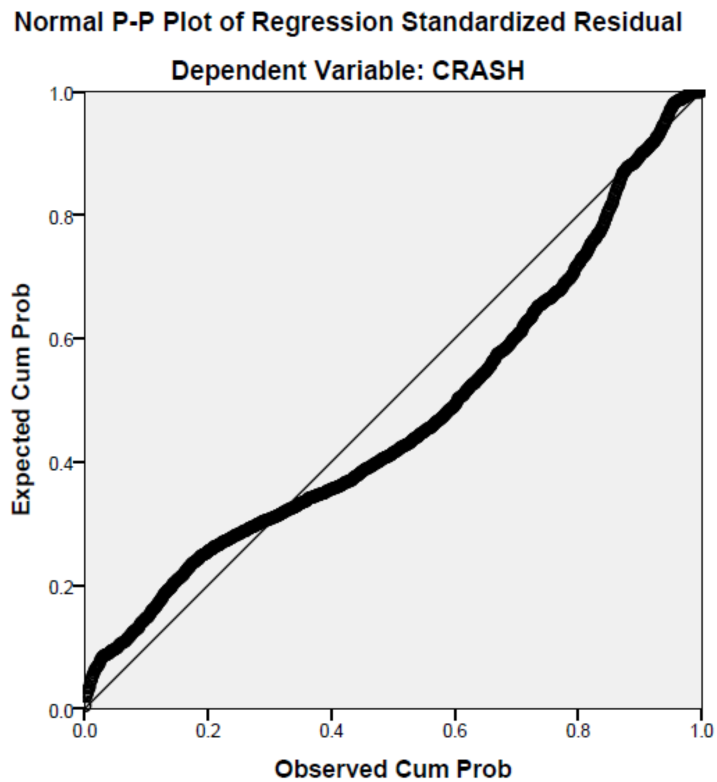

Figure C-3: Normal P-P Plot of Regression Standardized Residual for Crash Data

Since the assumptions of normality, homoscedasticity, and linearity are violated, the resulting model may not be the best choice for the data. After further consideration, a Poisson regression model was determined to be a better fit for the data.

Poisson Regression

The Poisson regression model is a better option for creating a model for count data. Since the desired model predicts a crash count, this is a more appropriate regression model. The Poisson regression model has only five assumptions associated with it:

- Assumption 1: The dependent variable is count data.
  - Count data means that all data points are positive integers. Crash data is considered count data.
  - Verified
- Assumption 2: There must be one or more independent variables, which can either be continuous, nominal, or ordinal.
  - All twelve road characteristics are either continuous, nominal, or ordinal variables.
  - Verified

- Assumption 3: There must be independence of observations.
    - All crashes are independent of one another, so therefore, the observations are independent.
    - Verified
- Assumption 4: The counted data given the model must follow a Poisson distribution.
    - The expected number of crashes were calculated using a Poisson distribution and then compared to the observed number of crashes from the dataset.
    - From Figure C-4, it can be seen that the number of observed zero crashes is higher than the expected number of zero crashes. Also, the observed number of single crashes is lower than the expected number of single crashes.
    - Assumption violated

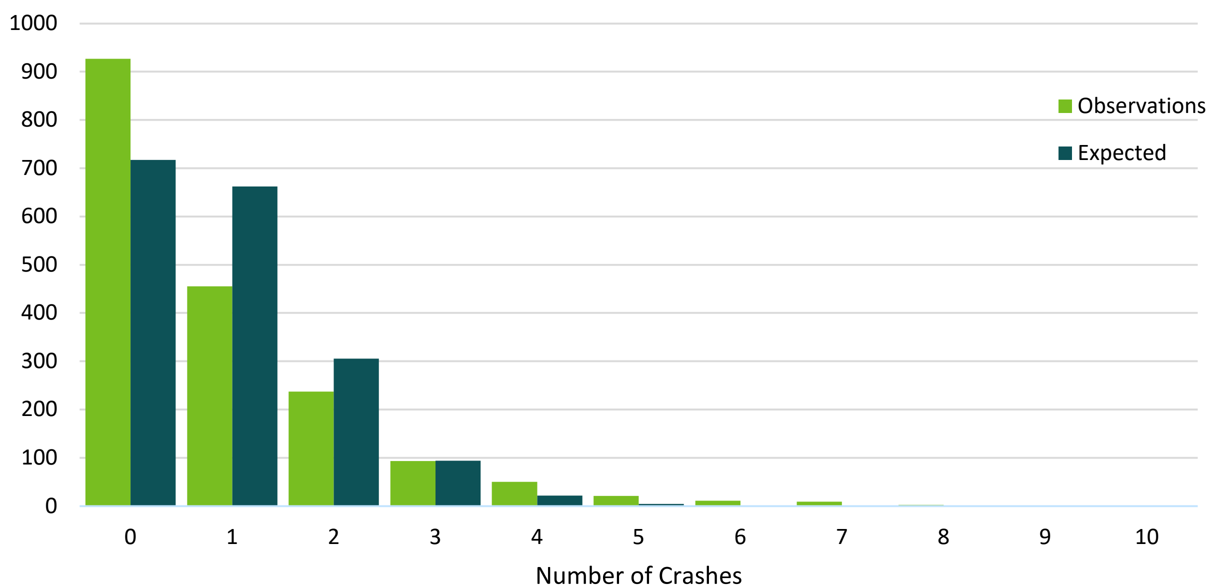

Figure C-4: Histogram of Observed and Expected Number of Crashes for Poisson Distribution

- Assumption 5: The mean and the variance of the model must be the same.
    - The mean and variance were calculated and are shown in Table C-17. From the table, the mean and variance are shown to be different. Since the variance is larger than the mean, this indicates that there is multicollinearity among the crash data.
    - Assumption violated

Table C-17 *The Mean and Variance of the Crash Data*

Descriptive Statistics

	N	Mean	Variance
CRASH	1806	.92	1.702
Valid N (listwise)	1806		

Since the assumptions for both regression models were not fully met, a Poisson regression model was not created because the resulting model may not be reliable.

Appendix D: Effects of Road Characteristics

This appendix analyzes the effects of various road characteristics on before and after crash rates at RICWS and control sites. These characteristics include cross product, major road volume, minor road volume, the presence of a horizontal or vertical curve, the skew of the minor road in relation to the major road, the proximity to development, the presence of a railroad crossing, the presence of lighting, speed limit, and the configuration of the intersection – four-lane versus three-lane intersections and divided versus undivided intersections.

RICWS Locations – Observed Trends in the Before and After Periods

Figure D-1: Cross Product

In the after period, intersections with a cross product of 2 – 8 million entering vehicles and 12 – 18+ million entering vehicles saw increases in crashes. Only intersections with a cross product of 8-12 million entering vehicles saw a decrease in crashes. It is hard to find a consistent trend with cross product.

Figure D-2: Major Road AADT

In the after period, there appears to be no pattern when comparing AADT and increasing/decreasing crash percentages.

Figure D-3: Minor Road AADT

In the after period, on average there is a decrease in crashes for minor roads that have AADTs of less than 2,500, except for AADTs between 1,500 – 2,000 daily entering vehicles. Intersections that had a minor road AADT of greater than 2,500 saw increases in crashes.

Figure D-4: Located On/Near A Curve

Intersections that are not located on or near a curve make up the majority of intersections used in the study. In the after period, intersections located on/near a curve saw an increase in crashes, while those not located on/near a curve saw a decrease in crashes. This suggests that the presence of a horizontal or vertical curve influences the performance of RICWS.

Figure D-5: Skew

Intersections with perpendicular legs (i.e. a skew of zero) saw the most crashes compared to intersections with any amount of skew. In the after period, it is hard to determine a trend based on skew.

Figure D-6: Development In A Quadrant

Intersections with commercial development located in one of the intersection’s quadrants make up more than half of the intersections studied. Intersections that are located in a commercial development saw a small, but noticeable decrease in crashes in the after period, and intersections not located in a development saw a small increase in crash frequency. This is interesting because it means that the performance of RICWS is influenced by the lack of commercial development.

Figure D-7: Railroad Crossing

Approximately 80% of intersections used in this study are not located near a railroad crossing. In the after period, there was almost no change in the crashes that occurred both at intersections located near a railroad crossing and those that were not located near a railroad crossing. This suggests that the installation of RICWS had no effect at these locations.

Figure D-8: Presence of Lighting

Intersections that have street lighting present make up a large portion of the intersections used in the study. When comparing the before and after periods for intersections with lighting present, there was very little change in the number of crashes that occurred. The same can be said for intersections that do not have lighting present. This suggests that the installation of RICWS had little to no effect at these locations.

Figure D-9: Speed Limit

In the before period, crashes were proportional to the distribution of the intersections by speed limit. Approximately 85% of intersections have a speed limit of 55 – 65 MPH. In the after period, it is difficult to discern a trend. However, intersections that have a speed limit of 55 MPH, which make up the largest portion of intersections in the study, saw a decrease in crashes.

Figure D-10: Intersection Configuration I (3-Legged or 4-Legged)

Four-legged intersections make up approximately 70% of the intersections used in the study. For both T-intersections and four-legged intersections, there was very little change in the number of crashes observed in the after period. This suggests that the installation of RICWS had little to no effect at these locations.

Figure D-11: Intersection Configuration II (Divided or Undivided)

Two-lane intersections on an undivided highway are over represented in the figure. In the after period for both divided and undivided intersections, there was very little change in crashes observed. This suggests that RICWS has little to no effect at these locations.

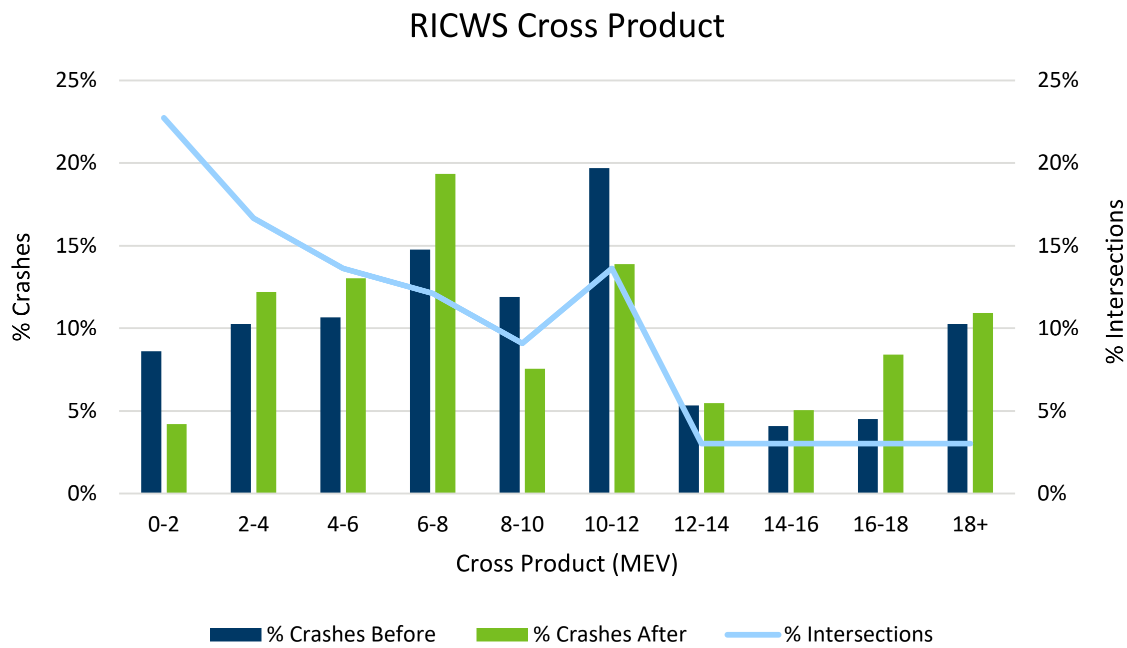

Figure D-1: Cross Product [RICWS Locations]

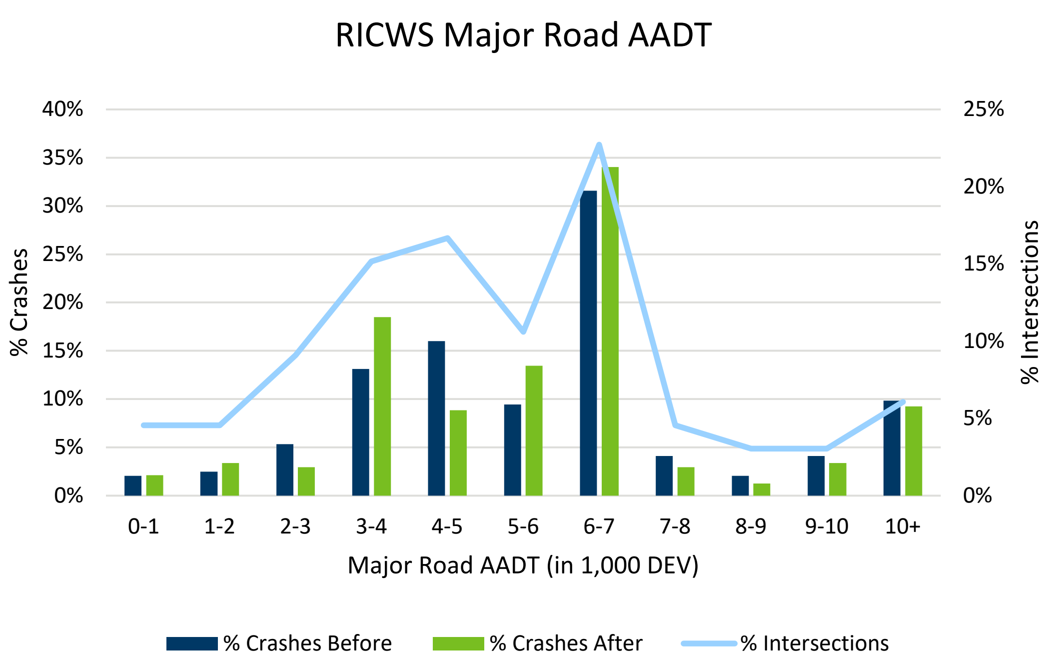

Figure D-2: Major Road AADT [RICWS Locations]

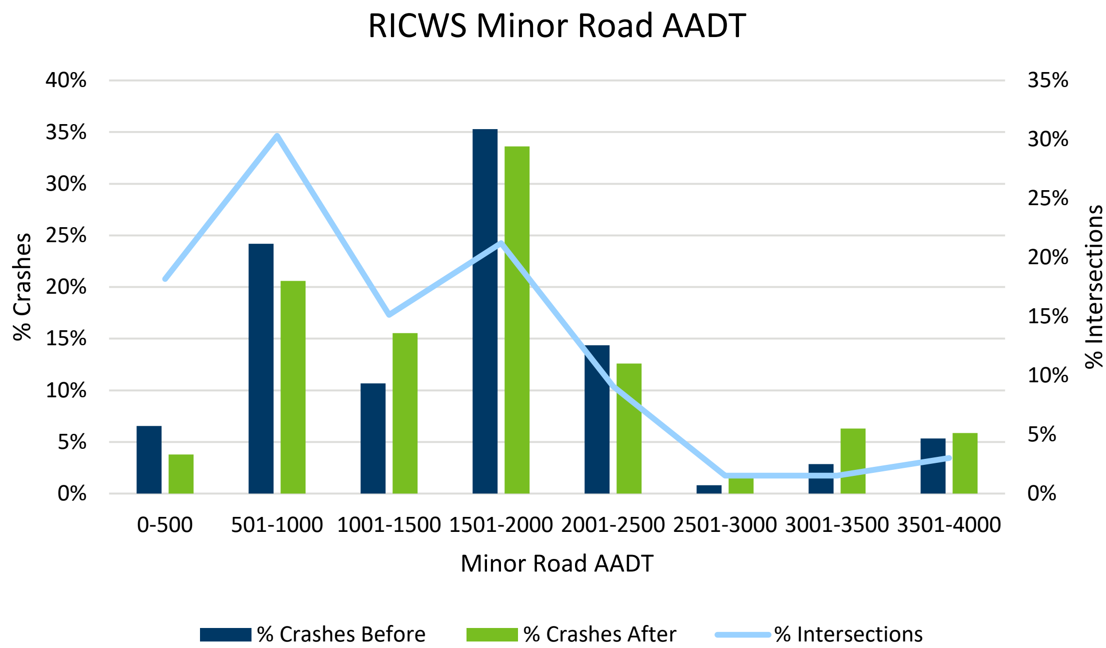

Figure D-3: Minor Road AADT [RICWS Locations]

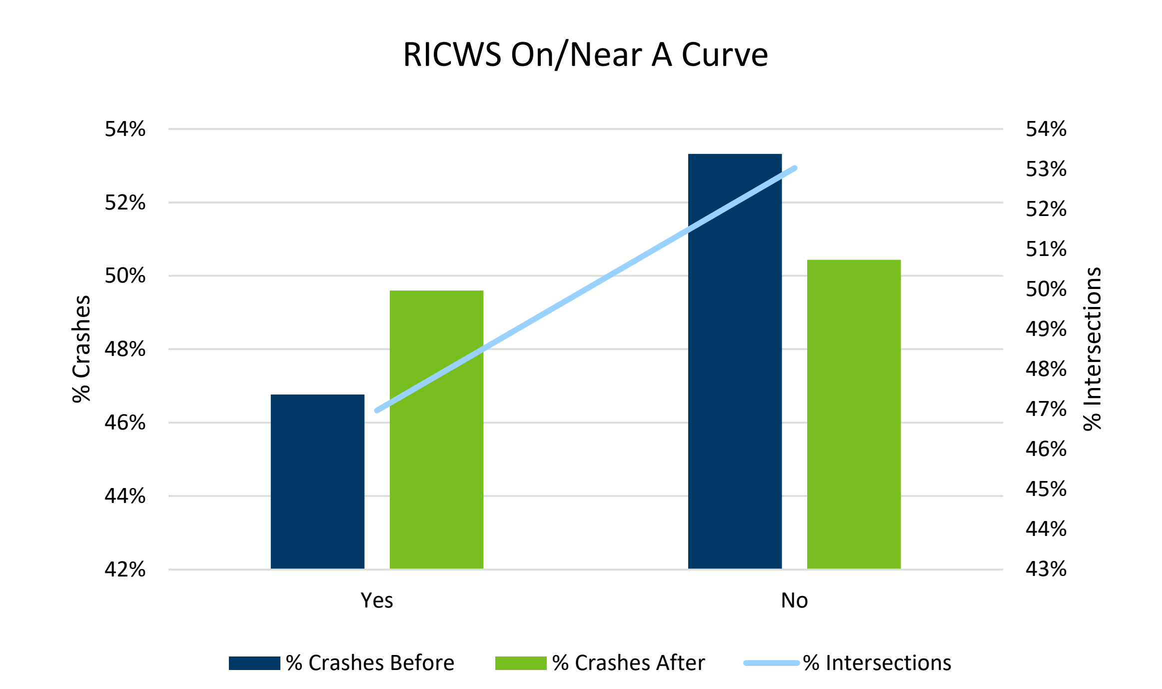

Figure D-4: Located On/Near a Curve [RICWS Locations]

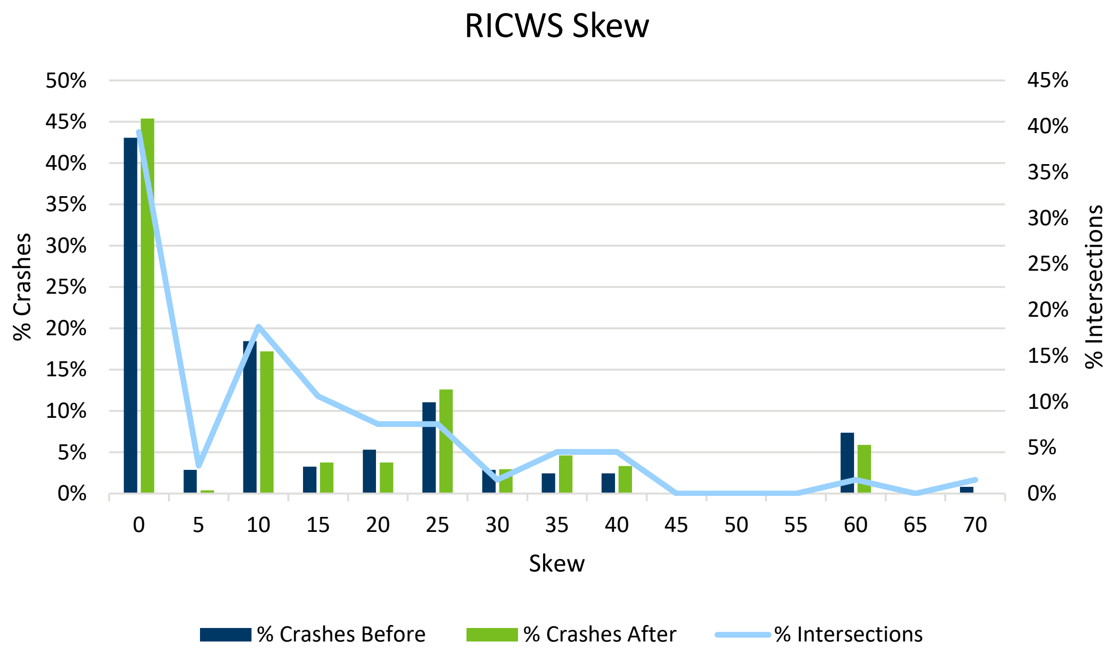

Figure D-5: Skew [RICWS Locations]

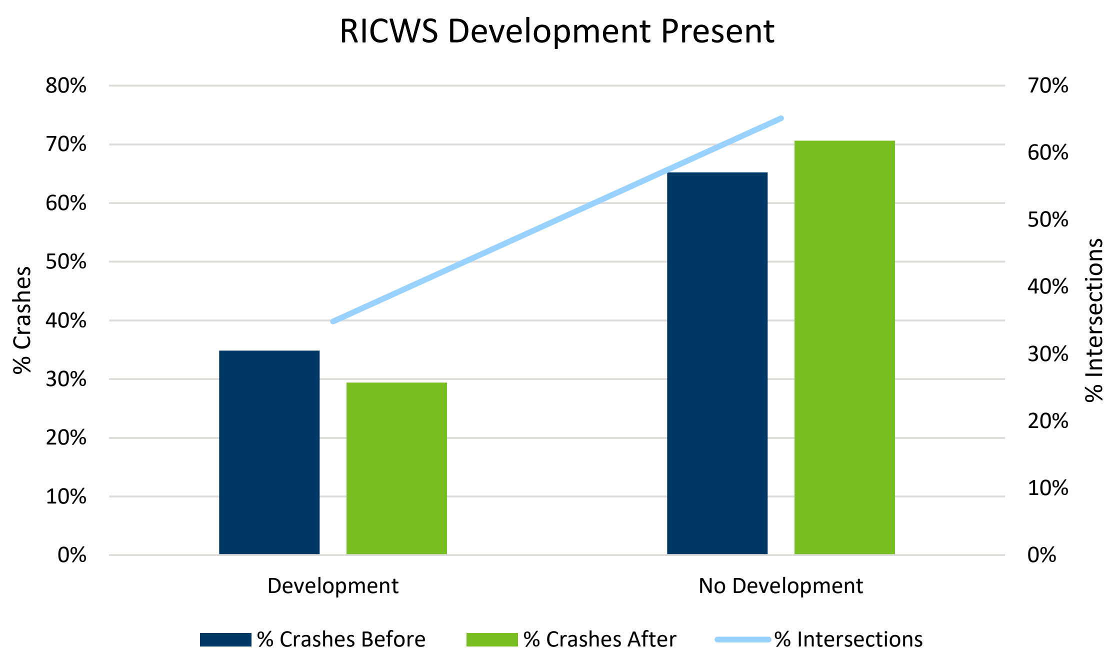

Figure D-6: Development in a Quadrant [RICWS Locations]

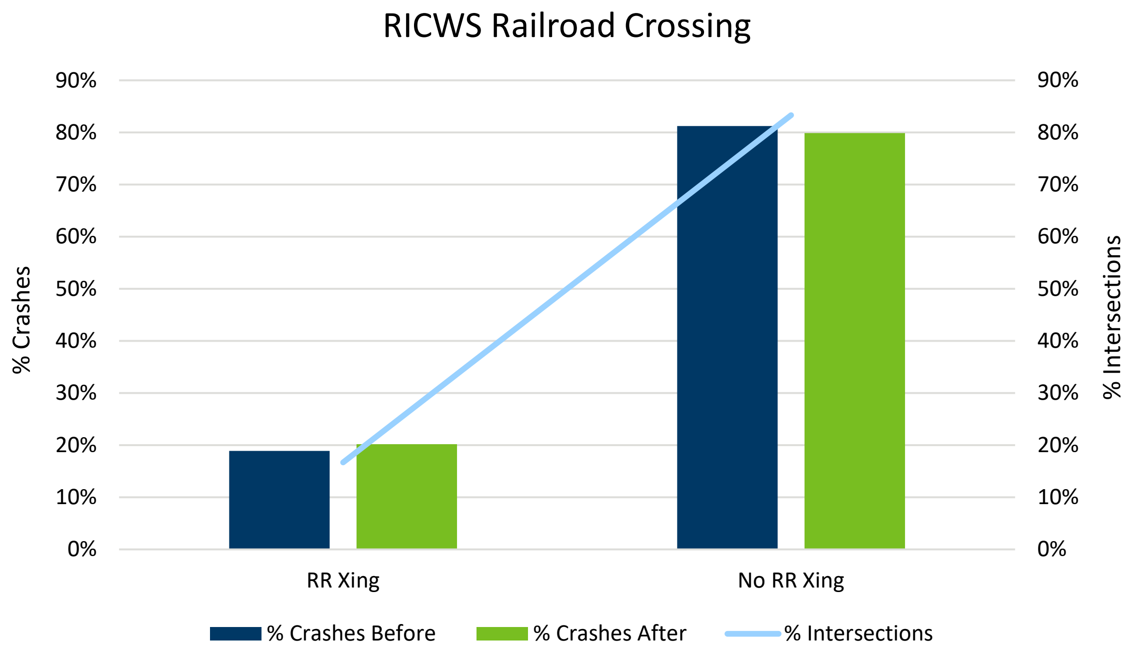

Figure D-7: Railroad Crossing [RICWS Locations]

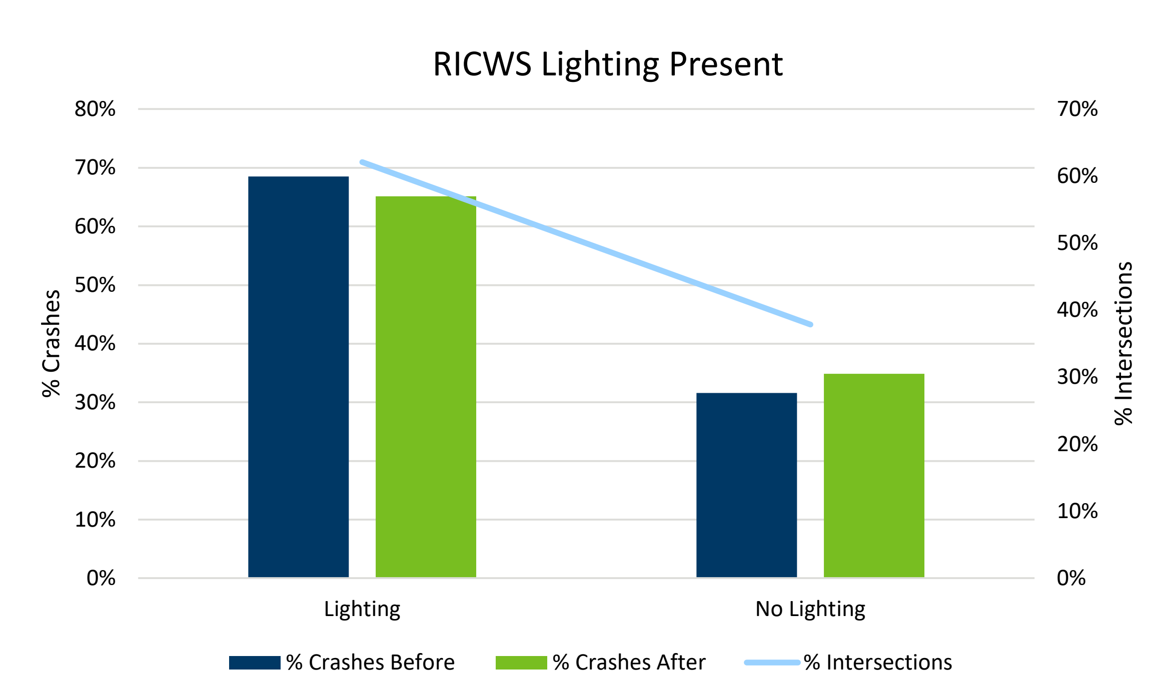

Figure D-8: Presence of Lighting [RICWS Locations]

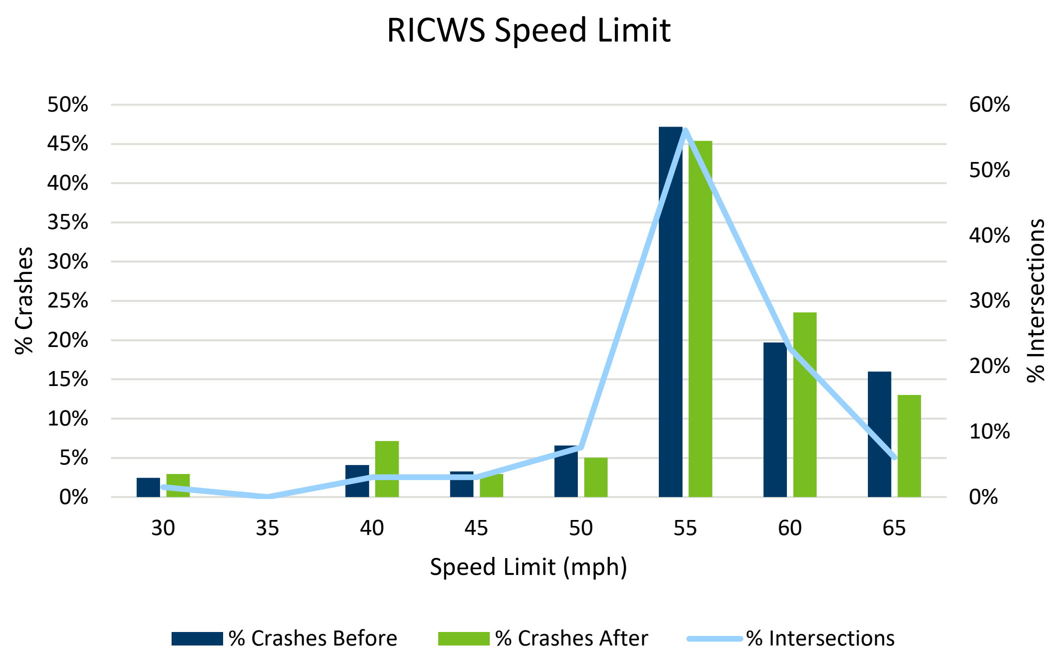

Figure D-9: Speed Limit [RICWS Locations]

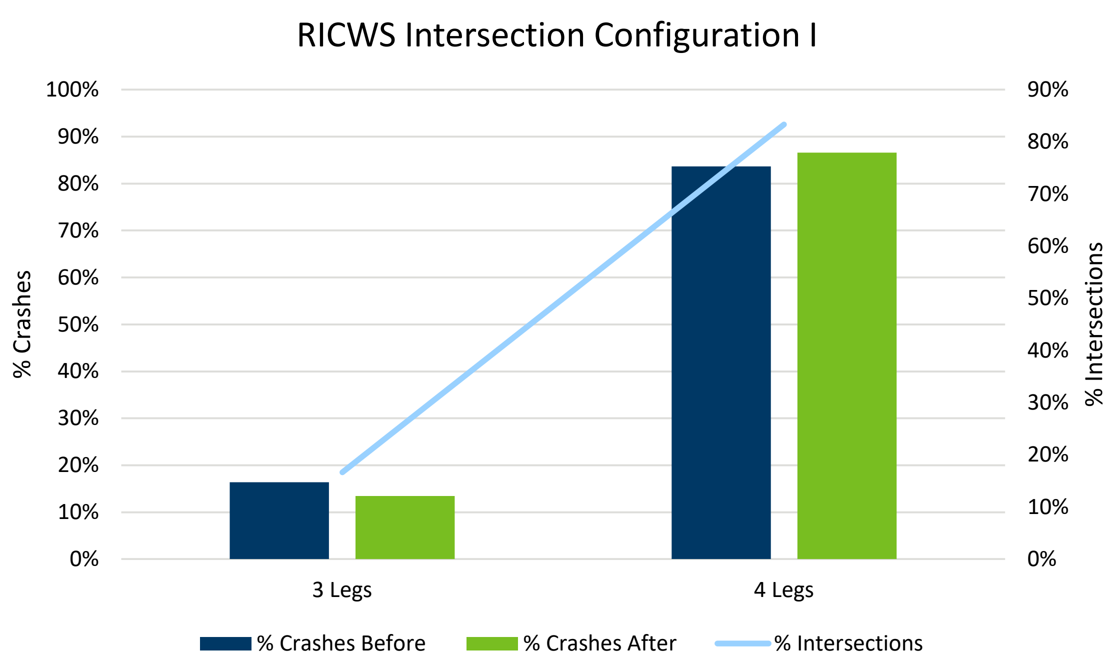

Figure D-10: Intersection Configuration I (3- or 4-Legged) [RICWS Locations]

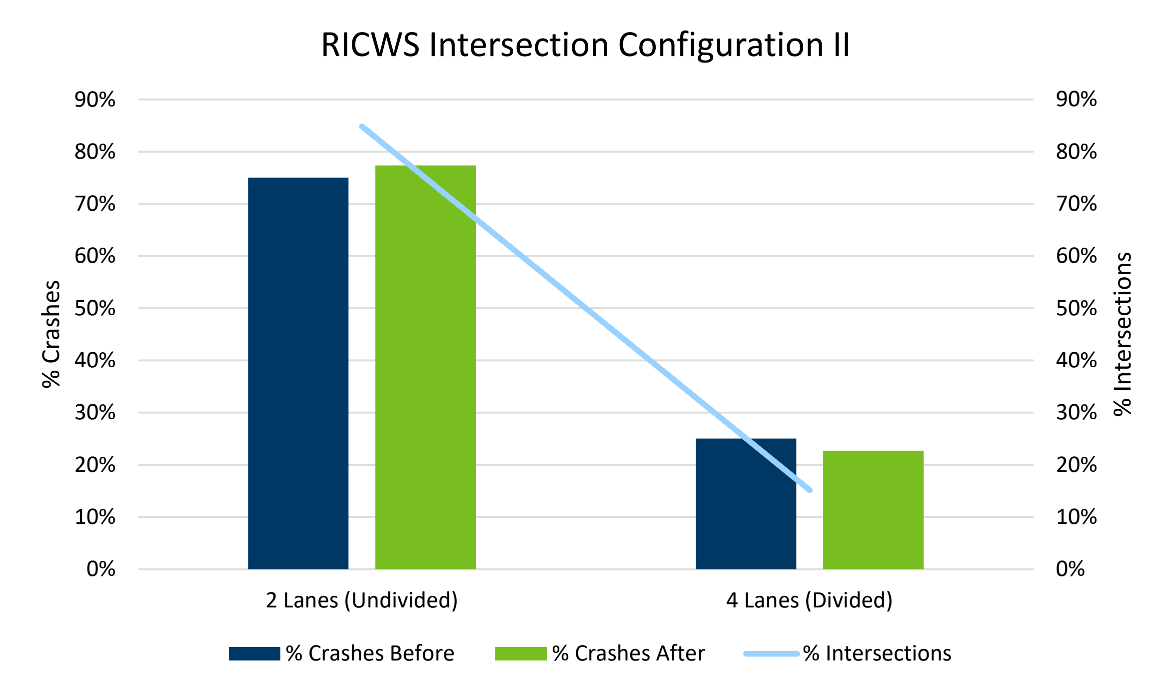

Figure D-11: Intersection Configuration II (Divided or Undivided) [RICWS Locations]

Control Locations – Observed Trends in the Before and After Periods

Figure D-12: Cross Product

Most of the intersections had a cross product of 2-8 million entering vehicles. In the after period, there appears to be no consistent trend. This is consistent with the results for the RICWS locations.

Figure D-13: Major Road AADT

The majority of intersections have a major road AADT of 2,000 – 8,000 daily entering vehicles. In the After period, there appears to be no pattern when comparing AADT and increasing/decreasing crash percentages. This lack of trend was also seen with at RICWS sites.

Figure D-14: Minor Road AADT

In the After period, intersections that have minor roads with 500 – 2,000 daily entering vehicles saw an increase in crashes. It is hard to discern if this is an actual trend in the data. This "trend" is different from that seen with RICWS sites, which saw a decrease at a majority of intersections with an AADT of 0 – 2,500 daily entering vehicles.

Figure D-15: Located On/Near A Curve

There are similar numbers of intersections that is located on/near a curve and those that are not located on/near a curve. In the after period, intersections located on/near a curve saw an increase in crashes, while intersections not located on/near a curve saw a decrease in crashes. This trend is similar to the one observed for RICWS sites.

Figure D-16: Skew

Intersections that have a skew of zero were over represented compared to intersections with any amount of skew. In the After period, it is hard to determine a trend based on speed limit. RICWS locations also were over represented with intersections that had no skew. However, RICWS sites saw an increase in crashes for these intersections, while control sites saw a decrease in crashes. The overall lack of a trend for skew was seen at both the RICWS and control sites.

Figure D-17: Development In A Quadrant

In the after period, sites that are located in a commercial development saw an increase in crashes, while sites not in a development saw a decrease in crash frequency. This is the exact opposite of what was seen at RICWS sites.

Figure D-18: Railroad Crossing

In the after period, there was no change in the crashes that occurred both at intersections located near a railroad crossing and those that were not located near a railroad crossing. This agrees with the trend observed at RICWS locations.

Figure D-19: Presence of Lighting

Intersections that have street lighting present make up a large portion of the intersections used in the study. In the after period, intersections with lighting saw an increase in crashes, while intersections without lighting saw a decrease in crashes. This trend is different than that seen at RICWS locations, which saw no effect at sites with and without lighting present.

Figure D-20: Speed Limit

Approximately 83% of intersections have a speed limit of 55 – 65 MPH. Almost all the groups of intersections for the speed limits shown saw increases in crashes in the after period. However, intersections that have a speed limit of 55 MPH, which make up the largest portion of intersections in the study, saw a decrease in crashes. This differs from the RICWS sites as RICWS sites saw more decreases in crashes. However, RICWS sites also saw a decrease in crashes at sites that had a speed limit of 55 MPH.

Figure D-21: Intersection Configuration I (3-Legged or 4-Legged)

Four-legged intersections make up a majority of the intersections used in this study. For both T-intersections and four-legged intersections, there was very little change in the number of crashes observed in the after period. This agrees with the trend observed at RICWS sites.

Figure D-22: Intersection Configuration II (Divided or Undivided)

Two-lane intersections on an undivided highway are over represented in the figure. In the after period, undivided intersections saw a small increase in crashes, while divided intersections saw a slight decrease in crashes. This agrees with the trend observed at RICWS sites.

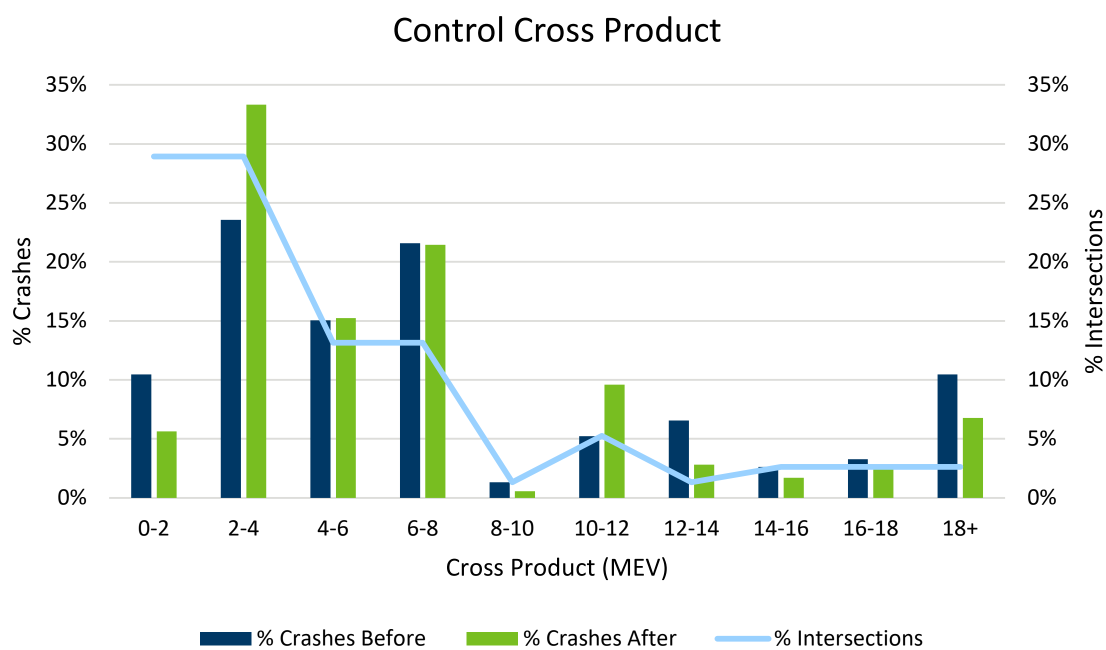

Figure D-12: Cross Product [Control Locations]

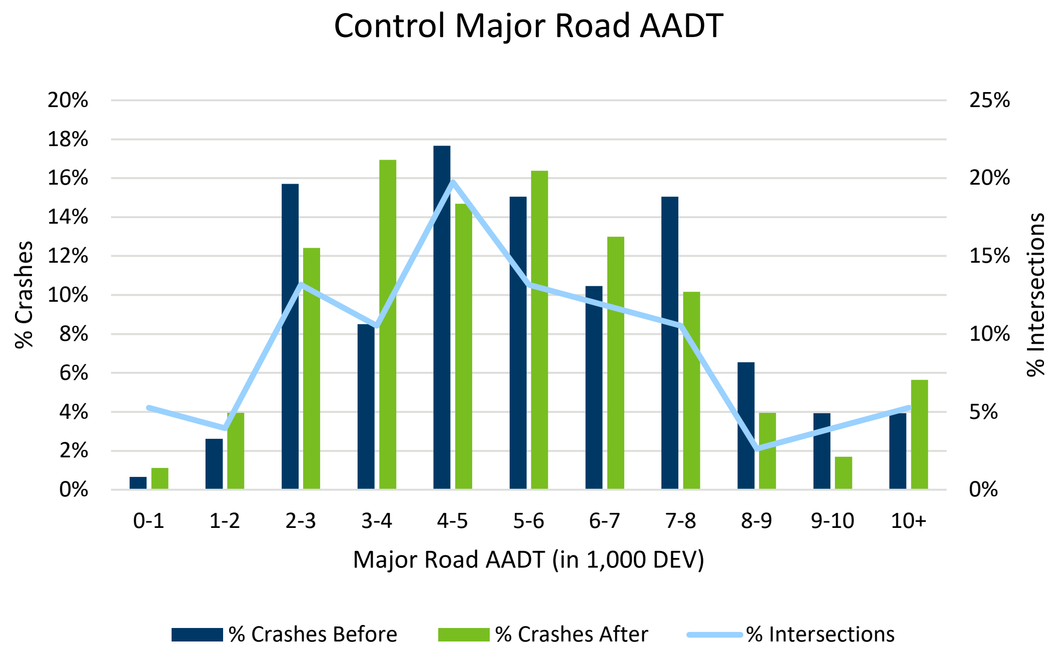

Figure D-13: Major Road AADT [Control Locations]

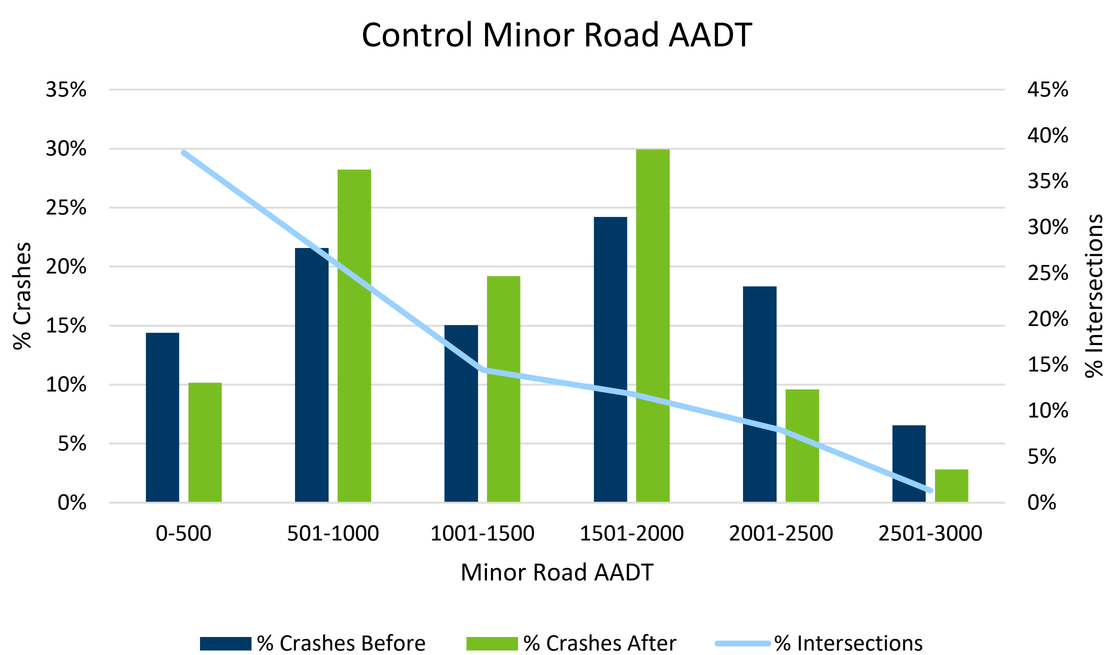

Figure D-14: Minor Road AADT [Control Locations]

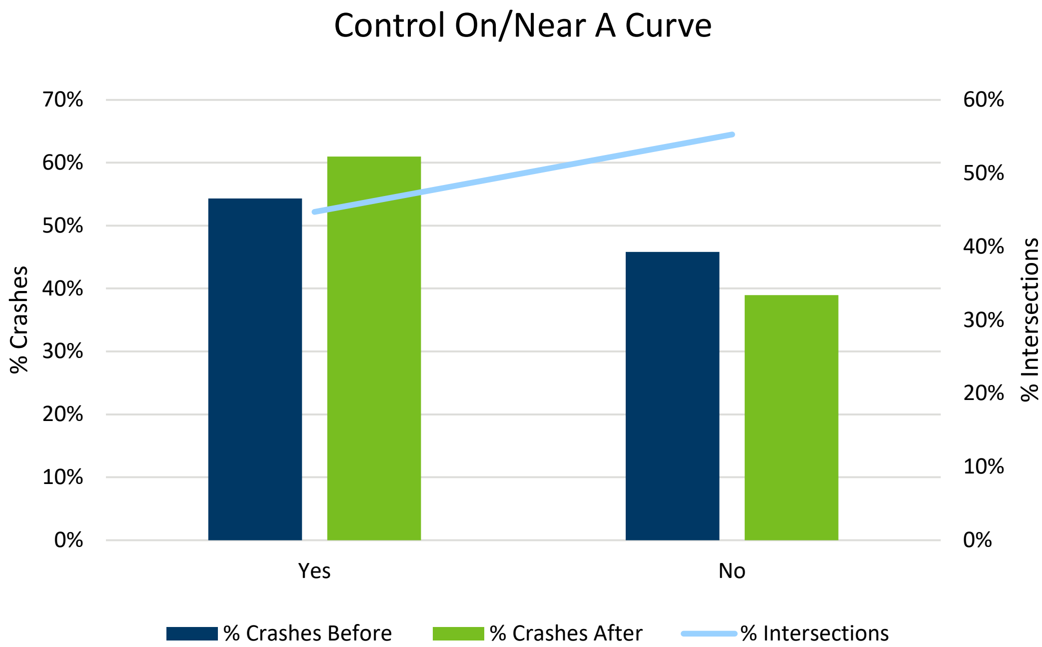

Figure D-15: Located On/Near a Curve [Control Locations]

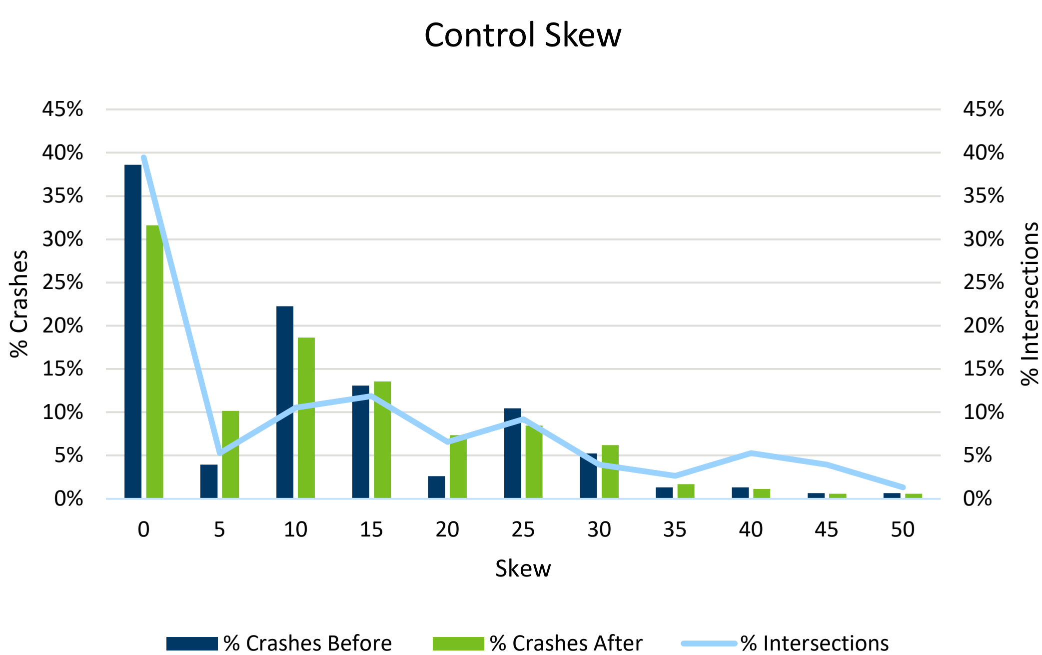

Figure D-16: Skew [Control Locations]

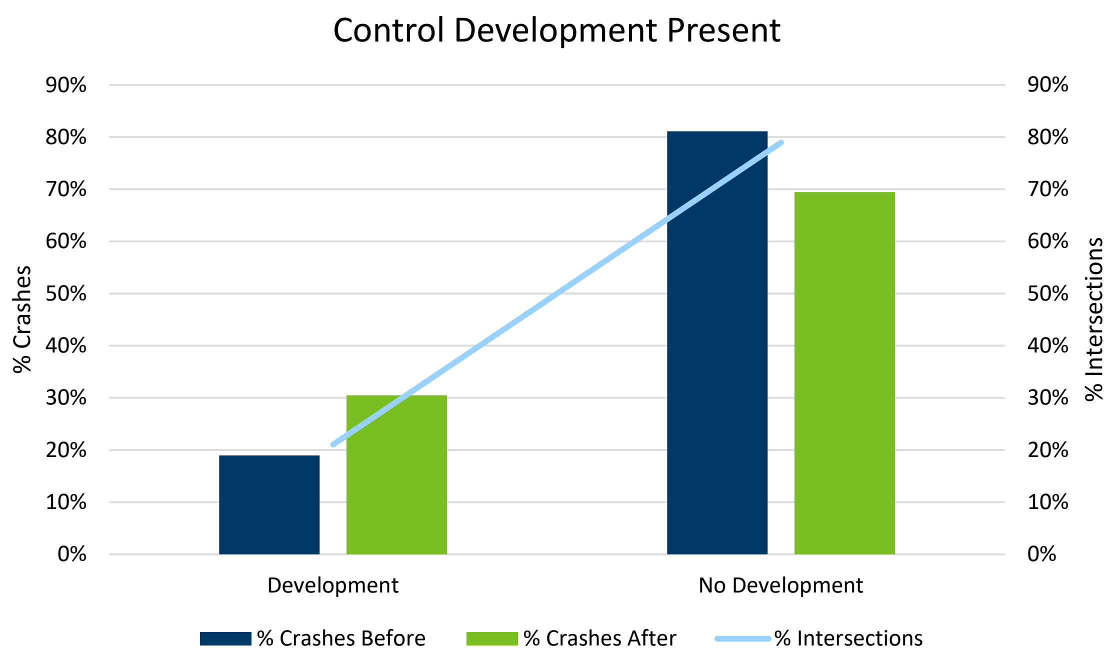

Figure D-17: Development in a Quadrant [Control Locations]

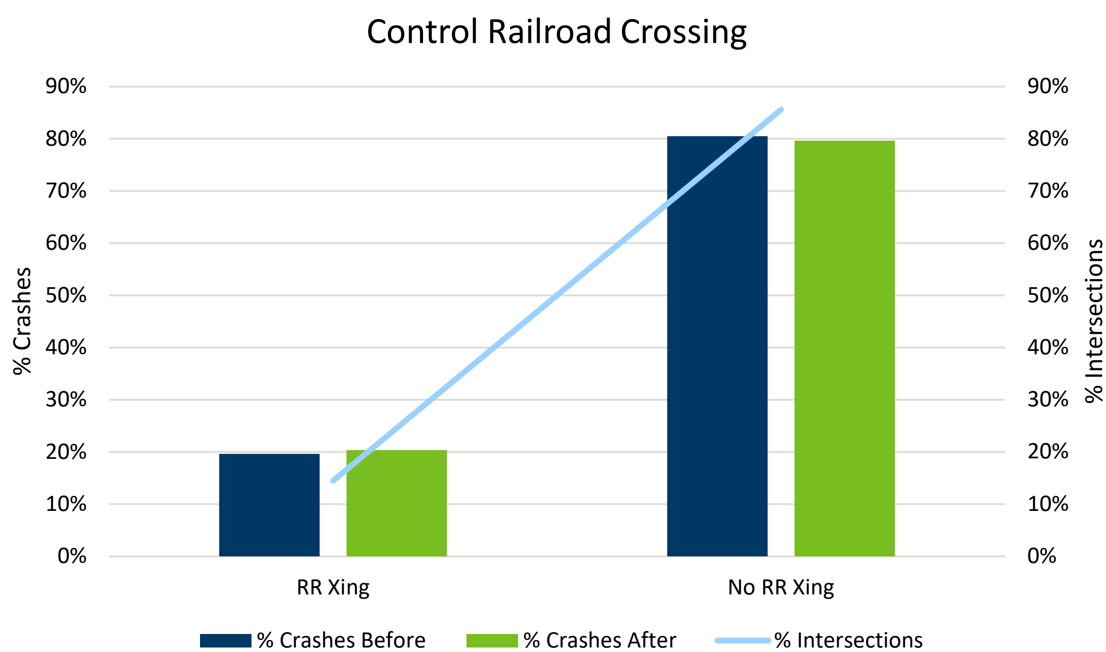

Figure D-18: Railroad Crossing [Control Locations]

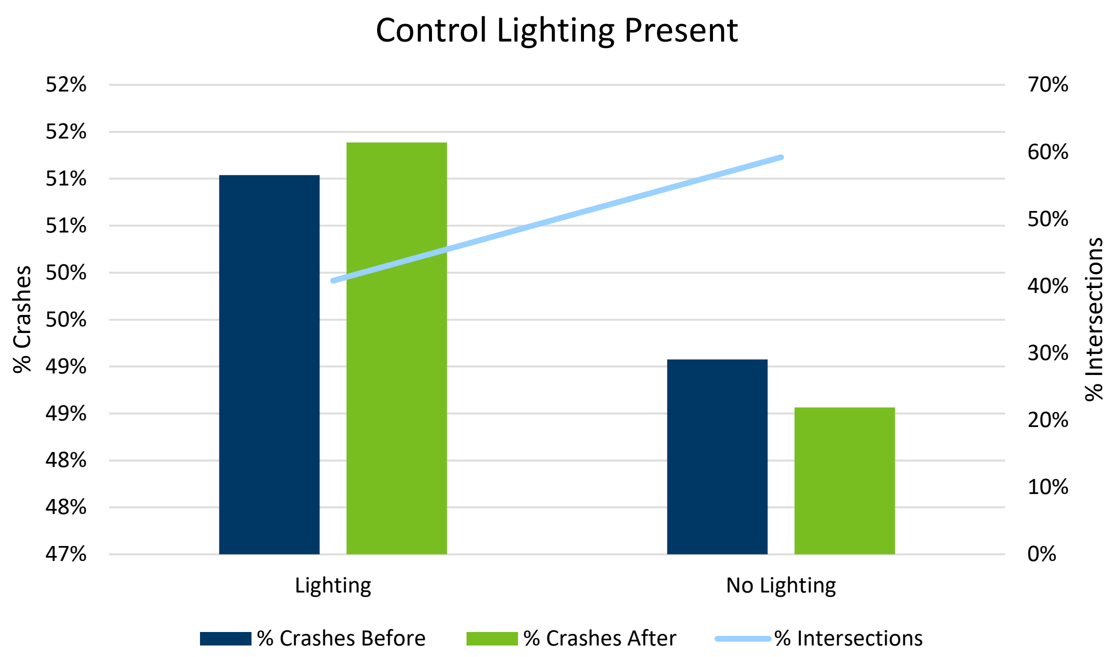

Figure D-19: Presence of Lighting [Control Locations]

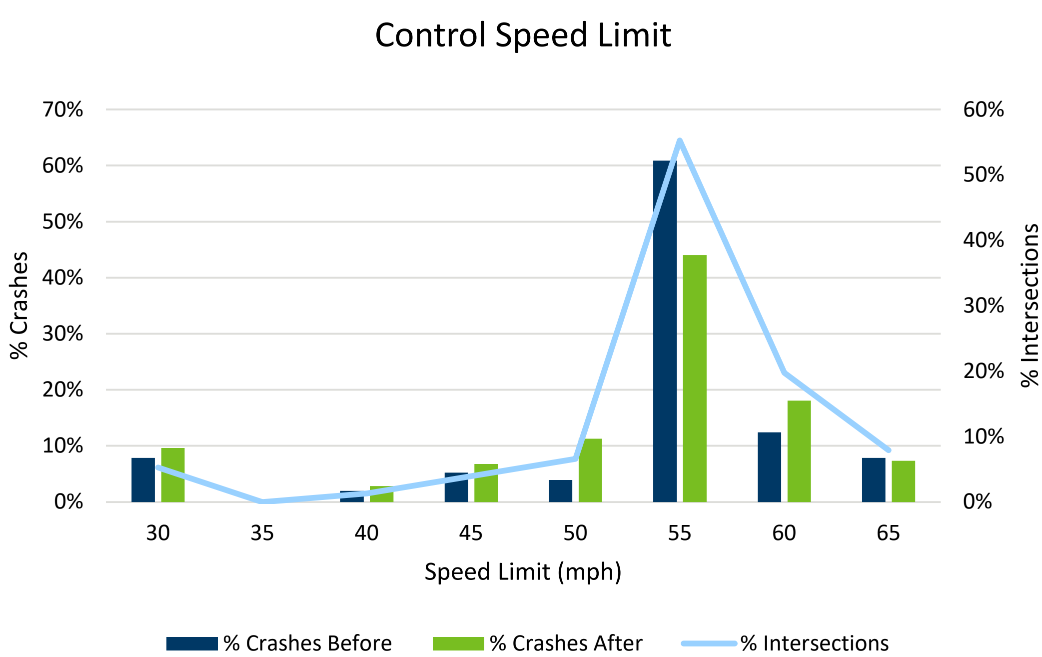

Figure D-20: Speed Limit [Control Locations]

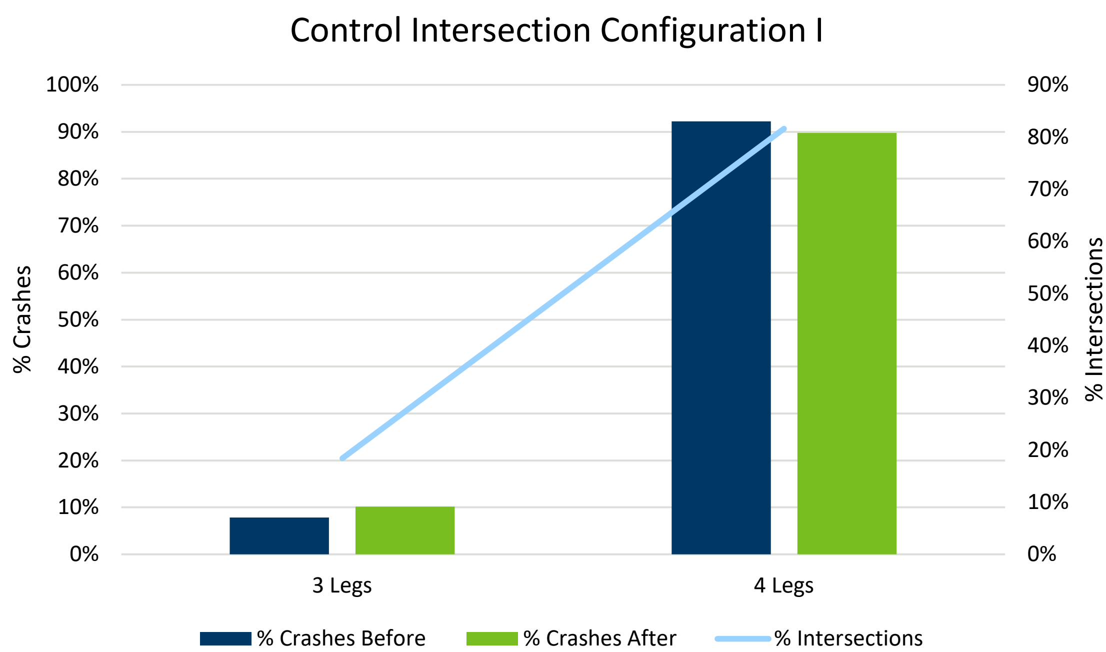

Figure D-21: Intersection Configuration I (3- or 4-Legged) [Control Locations]

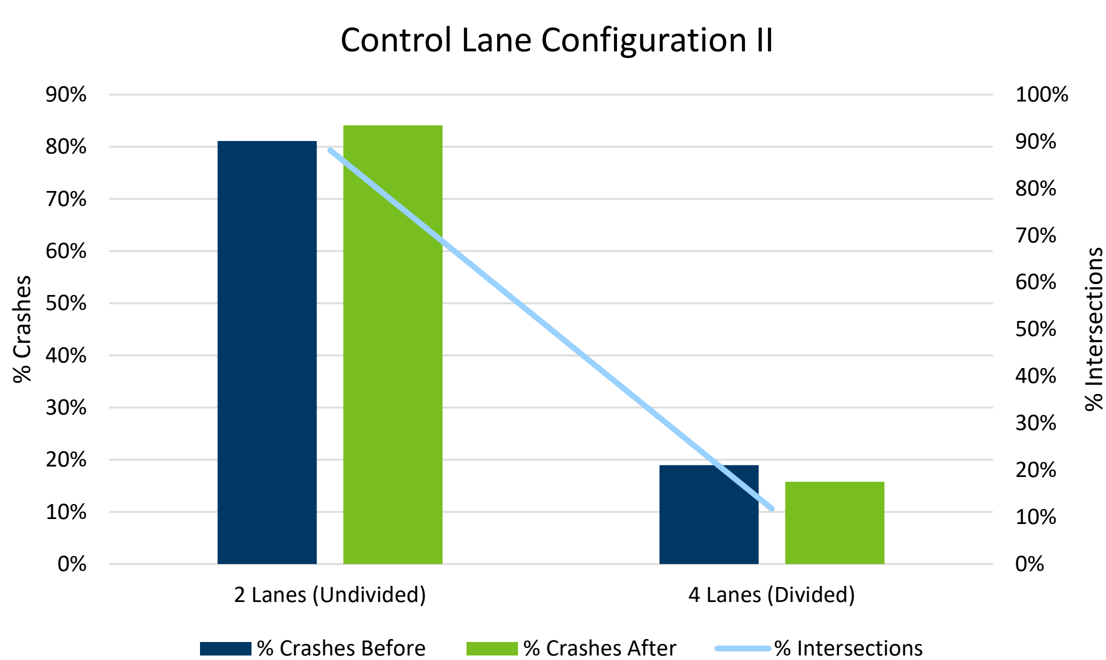

Figure D-22: Intersection Configuration II (Divided or Undivided) [Control Locations]