Report

MnDOT RICWS Safety

Prepared for

Minnesota Department of Transportation

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CH2MHILL®

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1.0 Introduction

Because of a historically high number of fatal and serious injury crashes, intersection-related crashes are designated a state priority safety emphasis area in Minnesota's *Strategic Highway Safety Plan* (MnDOT, 2015). A variety of highway/traffic safety studies conducted in Minnesota indicate that the most severe type of intersection crash involves a two-vehicle, right-angle collision and many crashes occur at rural, Thru-STOP controlled intersections.

Safety research identifies a variety of potential rural intersection safety strategies to reduce right-angle collisions, including the installation of dynamic warning systems – warning signs that provide real time information for drivers about potential conflicts in the intersection based on detecting the presence of vehicles on major and minor approaches. In 2014, the Minnesota Department of Transportation (MnDOT) installed 29 dynamic warning systems (Rural Intersection Collision Warning Systems [RICWS]) at intersections around Minnesota (Figure 1-1) identified as candidates for RICWS devices based on a comprehensive systemic evaluation of risks at over 12,000 rural intersections.

One site selected for installation was the intersection of Trunk Highway (TH) 55 and Wright County State Aid Highway (CSAH) 3, west of Annandale (Figure 2-1).

Since activation of this RICWS in June 2014, there have been four crashes at the intersection that involved a right-angle collision and one of the crashes involved a fatality. In response to intersection safety concerns, and whether or not the RICWS may have contributed to the experience crashes, expressed by area residents, MnDOT initiated this study of the particular intersection in question (TH 55/CSAH 3) and a review of the other locations that were part of the initial RICWS deployment. The key objectives of this study include:

- Determine (to the extent possible with less than 1 year after data collection) if the apparent increase in the number of crashes at the TH 55/CSAH 3 intersection is different than what would be expected, determine if there is any indication that the RICWS is contributing to the increase, and determine what other short- and long-term mitigation strategies could be considered.
- Document crash patterns across the remaining RICWS sites, indicate likely trends, contrast the results with the experience at the TH 55/CSAH 3 intersection, and determine if the data support the identification of limitations for future installations based on physical roadway or traffic characteristics.

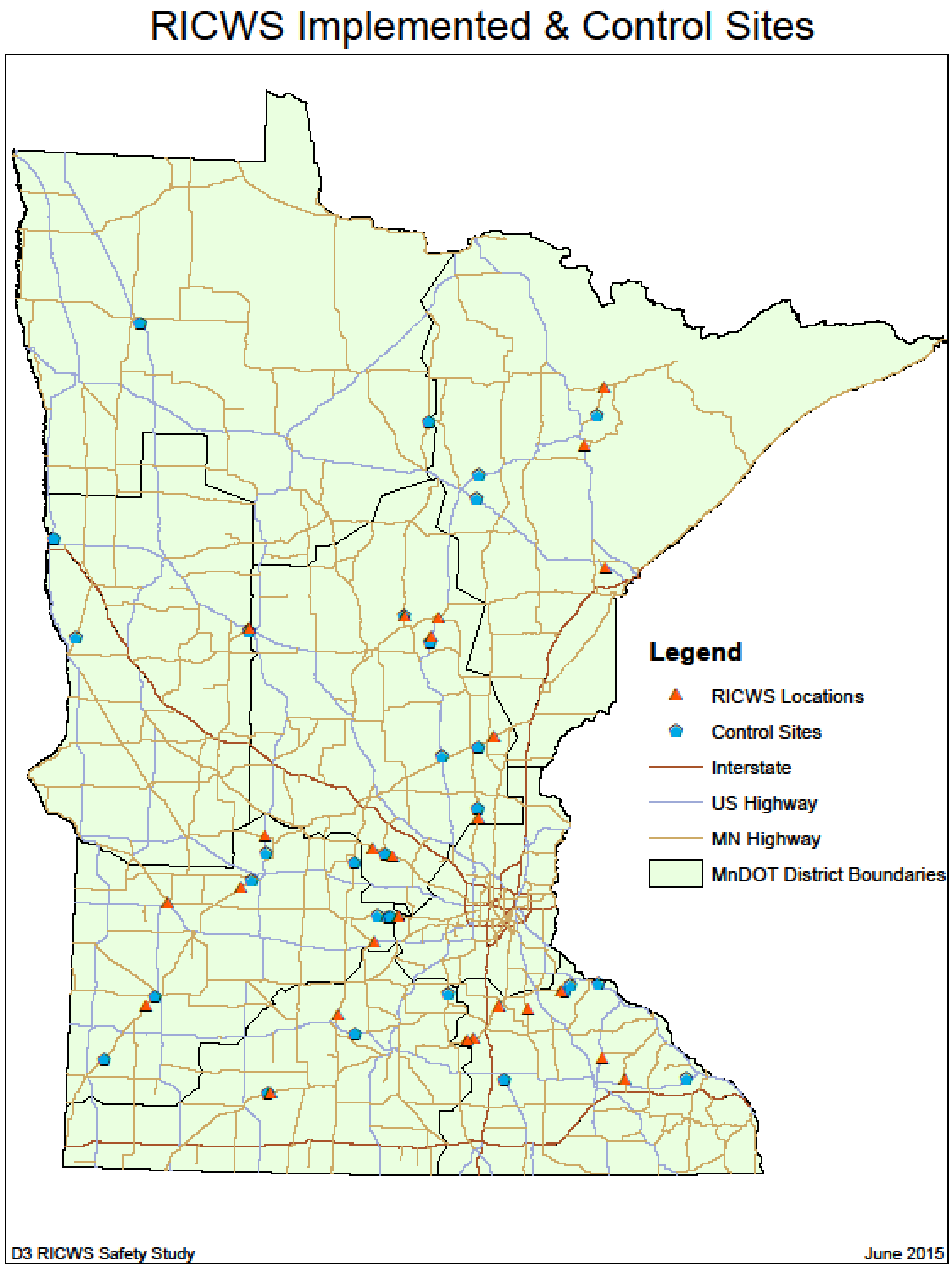


Figure 1-1: Minnesota's RICWS and Control Locations

2.0 Data Methodology

There were two major data components needed to perform the before/after analysis for the RICWS and control site locations: crash history and site characteristics. This section describes the methodology to construct the dataset used to evaluate the performance of the RICWS.

2.1 Crash Data Extraction

MnDOT provided an initial list of 29 rural intersections where RICWS was implemented. The analysis began with extracting crashes at these locations using the Minnesota Crash Mapping Tool (MnCMAT). In MnCMAT, a radius of 1,500 feet was set to capture the crashes near the intersections. The crashes were extracted as shapefiles because a secondary filtering process was executed in ArcGIS to replicate the MnDOT scan limits for identifying intersection crashes. Each site was individually assessed to determine if the crashes fell within the more specific range in ArcGIS. After completing the secondary crash filtering process, the separate intersection shapefiles were merged together and assigned a universal identifying number for each intersection.

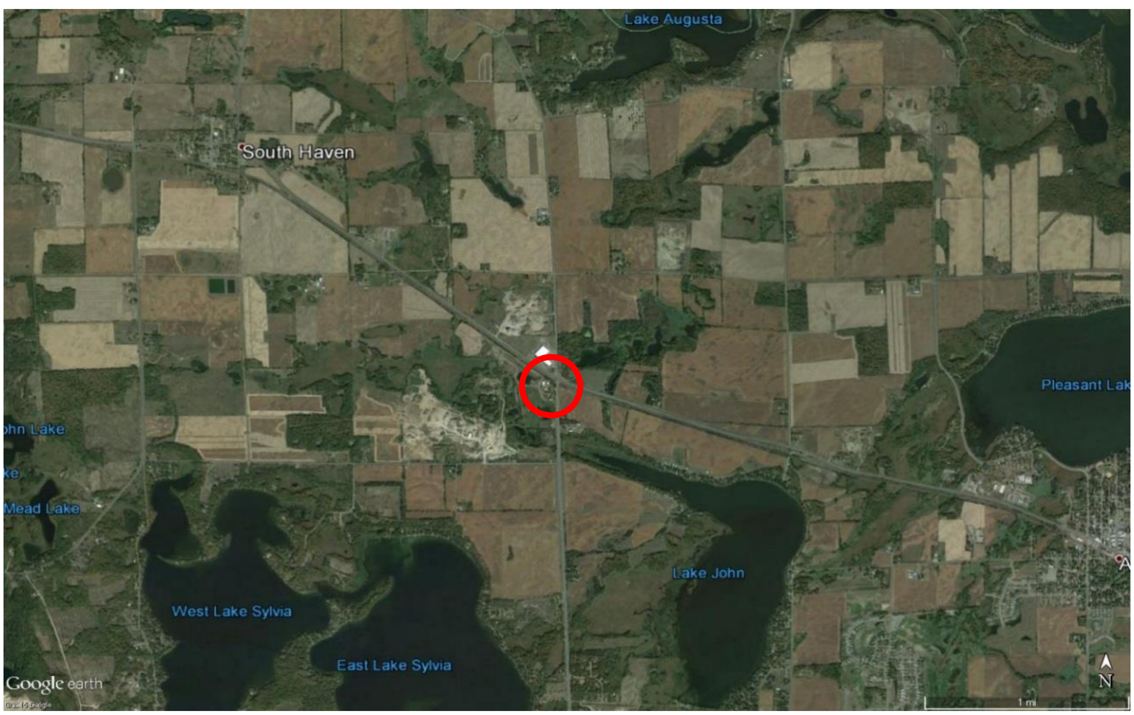


Figure 2-1: TH 55 and Wright CSAH 3

An initial list of 34 control sites were provided either by MnDOT staff, an Iowa State University driver behavior study of MnDOT's RICWS sites, or by logically selecting nearby intersections along the major corridor of existing RICWS locations. The district traffic engineers were surveyed; including nomination for control sites. The process for collecting crash data for the control sites was the exact same as the RICWS sites mentioned.

Upon completing the RICWS and control site crash history dataset, it was determined that two RICWS locations and four control sites would be removed. The two RICWS locations were removed because there were previous legacy conflict warning systems that differed from the specific system analyzed in this report. However, these legacy systems do not support the same before condition of the remaining 27 locations. Two control sites that were removed were county-county jurisdictions and generally experienced much lower volumes than the 27 studied intersections. One control site was removed because it was a low-speed, five-legged intersection. The final control site was removed because of a significantly unique design when compared to other control sites.

2.2 Intersection Characteristic Dataset

In addition to crash history, traffic and geometric intersection characteristics were identified for each RICWS and control site. The primary tool used for the construction of this dataset was Google Earth. Sixteen data fields were determined to be relevant characteristics to look at for each RICWS and control intersections. Table 2-1 lists the data collected including a brief description of the field.

TABLE 2-1
Data Fields and Descriptions

Data Field	Description
Major Approach Speed	Posted speed limit on the major road approach to the intersection
Intersection Skew	Measured angle of legs diverging from a 90 degree (°) (5° increments)
Intersection Near Development	Some type of major development within 200 feet of intersection
Lighting at Intersection	Presence of street lighting at intersection
Intersection On/Near Curve	Intersection on or near a curve with a radius less than 2,000 feet
Intersection Configuration 1	Four-legged or three-legged intersection
Intersection Configuration 2	Major road divided or undivided
Major Facility Type	Total number of major road mainline lanes
Presence of Major Left Turn Lanes	Total number of left-turn lanes on the major approach
Presence of Major Right Turn Lanes	Total number of right-turn lanes on the major approach
Presence of Minor Left Turn Lanes	Total number of left-turn lanes on the minor approach
Presence of Minor Right Turn Lanes	Total number of right-turn lanes on the minor approach
Major Entering average daily traffic (ADT[a])	Sum of major leg ADTs divided by the number of major legs
Minor Entering ADT[a]	Sum of minor leg ADTs divided by the number of minor legs
Total Entering ADT	Major Entering ADT + Minor Entering ADT
Cross Product	Major Entering ADT * Minor Entering ADT

[a] Source: **http://www.dot.state.mn.us/traffic/data/tma.html**

2.3 Time Periods

The RICWS before period was set to 3 years before the system was activated and the after period began on the activation date through March 31, 2015. The March 31, 2015 date was the most recent date that was considered for including crashes because that was the most recent date that had a complete month of crash records that were available through MnCMAT at the beginning of the project. There were a total of 19 unique dates during which the 27 RICWS intersections became active. In order to assign an "activation date" for the control sites, the median activation date of the RICWS sites was calculated and applied to the control sites. June 11, 2014 became the "activation date" for all of the control sites. Crashes collected from June 12, 2011 to June 12. 2014 represent the 3-year before period. Crashes collected from June 11, 2014 to March 31, 2015 represent the after period.

To appropriately compare crash rates and crash frequencies for RICWS and control sites, the before/after study periods had to be normalized by exposure. This was accomplished by multiplying the daily entering ADT [Source: MnDOT Traffic Mapping Application] by the number of days before and after the activation date for the 27 RICWS sites. The same calculation was performed for the control sites except there was only 1 activation date for the 30 sites. Crash rates and frequencies were calculated for total crashes as well as nine other crash types. The most relevant crash type for this particular study was right-angle crashes due to the predominant Thru-STOP traffic control device appearing at these intersections.

2.4 Literature Review

Five prior research reports dealing with the dynamic intersection warning systems were selected for review:

- *Determining the Effectiveness of an Advance LED Warning System for Rural Intersections* (Weidemann, 2011)
- *Planning Guidance for the Installation and Use of Technology Devices for Transportation Operations and Maintenance* [ENTERPRISE Pooled Fund Study] (Federal Highway Administration [FHWA], 2014)
- *Evaluation of the Safety Effectiveness of "Vehicle Entering When Flashing" Signs and Actuated Flashers at 74 Stop-Controlled Intersections in North Carolina* (NCDOT, 2012)
- *Macroscopic Review of Driver Gap Acceptance and Rejection Behavior at Rural Thru-Stop Intersections in the US – CICAS-SSA Final Report # 3* (FHWA, 2010)
- *FHWA Development of Crash Modification Factors* (DCMF) *Safety Evaluation of ICWS* (FHWA, 2015)

Document summaries of each report is included as Appendix A and the key findings include:

- The North Carolina DOT, using an Empirical Bayes analysis, found that their dynamic warning system reduced total intersection crashes by 32 percent and severe (Fatal + Serious Injury) crashes by 30 percent and these reduction were statistically significant.
- FHWA, also using an Empirical Bayes analysis, documented similar crash reductions, but also provided additional detail:
  - 4-Lane x 2-Lane Intersections: 17 percent total crash reduction/20 percent Severe crash reduction/15 percent right angle crash reduction
  - 2-Lane x 2-Lane Intersection: 27 percent total crash reduction/30 percent severe crash reduction/20 percent right angle crash reduction
- The *Planning Guidance for the Installation and Use of Technology Devices for Transportation Operations and Maintenance* (FHWA, 2014) included threshold volumes – 12,000 ADT on the major approaches and 3,000 ADT on the minor approaches - beyond which the use of the dynamic warning concept was not suggested.

2.5 Survey of Practice (District Traffic Engineers)

A survey about the rural intersection conflict warning systems was sent to the seven greater Minnesota district traffic engineers (DTEs). The survey asked the DTEs to comment on the RICWS performance, crash history/patterns, intersection characteristics/improvements made, and suggestions for potential controls sites within their district. The beneficial takeaways from the surveys include:

- Two districts commented that the flash time seemed short at a specific location and the districts have received occasional reports that vehicles (including motorcycles) are sometimes not detected by the system.
- A suggested improvement was to add WHEN FLASHING to the dynamic message sign rather than using a static plaque.
- Prior to implementing additional RICWS, the DTEs generally indicated a desire to see how the first locations perform and better understand the maintenance cost and time needed to keep the systems operational.
- Three additional control sites were suggested.

The questions and responses from the survey can be found in Appendix B.

3.0 TH 55/CSAH 3 Intersection Review

3.1 Site Characteristics

At the intersection of TH 55 and CSAH 3, both roads are conventional two-lane facilities and the TH 55 approaches also have right-turn lanes. Other site characteristics include:

- The posted speed limit along TH 55 is 55 miles per hour (mph).
- There is a horizontal curve along the mainline and the minor approaches are skewed.
- There is railroad grade crossing on the south approach.
- There is a commercial development (manufacturing) in the northwest quadrant.
- The traffic volume along TH 55 is approximately 6,000 vehicles per day and the volume on the minor approaches is 2,100 vehicles per day.
- The intersection has a history of crashes, the majority of which involve right-angle collisions.

This combination of roadway and traffic characteristics was cited in Wright County's Safety Plan and resulted in the intersection being assigned six (out of seven) risk factors. This accumulation of risk factors resulted in the intersection being ranked as the most at-risk intersection in Wright County and is reason the intersection was identified as a candidate for the installation of RICWS.

3.2 Site Crashes/Trends

- Before RICWS Installation
  - During a 3-year period prior to the RICWS installation, the intersection averaged 4 crashes per year.
  - No crashes involved a fatality or serious injury.
  - 38 percent involved a Right Angle collision and an equal fraction involved a Rear End or Sideswipe Passing.
  - Weather and road conditions were not issues and the most common driver behaviors cited were – No Contributing Factor (48 percent) and Failed to Yield (28 percent).
  - The Crash Rate was 0.98 crashes per million entering vehicles and this is greater than the Critical Crash Rate (0.66), which indicates that the difference is statistically significant and that is likely because of conditions at the intersection (as opposed to the random nature of crashes).
- After RICWS Installation
  - During the 9 months following the RICWS installation, the intersection averaged 5 crashes per year on an annualized basis.
  - One of the crashes involved a fatality.
  - 100 percent involved a Right Angle collision.
  - Weather and road conditions were not issues and the most common driver behaviors cited were – No Contributing Factor (50 percent) and Failed to Yield (50 percent).
  - The Crash Rate was 1.82 crashes per million entering vehicles, which remains above the Critical Crash Rate.

- Trends
  - The increase in the annualized number of crashes at the intersection is not statistically significant.
  - There is nothing in the data that suggests that the RICWS is somehow associated with the increase or making the intersection more at-risk. The intersection was identified as being at-risk (the most at-risk for the Wright County highway system) before the installation and it appears that a variety of factors prevented the RICWS from mitigating the higher than expected frequency and rate of crashes.

3.3 Field Review

On May 27, 2015 a field review was conducted by CH2M HILL (CH2M) and MnDOT staff. The review was conducted between 10 am and Noon (to accommodate schedules) and there were no trains during that time period. Key observations include:

- The intersection sight distance (ISD) on the northbound and southbound approaches was observed to be at least 10 seconds in all directions.
- However, the combination of skew and mainline horizontal curvature could impair sight lines in vehicles (passengers and vehicle pillars) and utility poles, back slopes, and trees. Sight lines could be obstructed if drivers on the minor road stopped their vehicles at the wrong spot. Unobstructed sight lines are available/improved at points further into the intersection illustrated in Figure 3-1.

Sight Line from STOP Sign

Sight Line from Advanced Stopped Location

Figure 3-1: Intersection Sight Lines for Southbound CSAH 3 Looking East

- The volume of traffic moving through the intersection was high (including cars, pick-up trucks, recreational vehicles, and commercial vehicles) and resulted in a large number of conflicts.
- Driver behavior appears to contribute to conflicts at the intersection – a number of through vehicles on TH 55 used the right turn lanes to pass vehicles turning left, a maneuver which is illegal, enforceable, and potentially dangerous.

During the field review, both CH2M and MnDOT staff were aware that employees of the manufacturing facility adjacent to the intersection have shared their observations about safety and operations with District 3 staff. The employee's comments appear to center around four themes:

1. The intersection is not safe,
2. Driver behavior is a contributing factor
3. Obstructed sight lines are a contributing factor, and
4. They don't see the RICWS system providing useful information.

The project team observed that the location was identified as the most at-risk intersection in Wright County in 2010 and that driver behavior appears to be a contributing factor (bypassing in the right turn lanes). However, the intersection sight issue and the RICWS providing useful information are more complicated. During the field review, drivers were able to maneuver the vehicles to points where sight lines were not obstructed and at least 10 seconds of visibility was available. Regarding the RICWS installation, the project team clearly understood the message (which appeared to be consistent with the timing parameters programmed into the system) and found it useful but there appears to be anecdotal information indicating that untrained/unfamiliar drivers may not be comprehending the message and the primary safety benefits of dynamic warning systems may be associated with the mainline warning.

3.4 Suggestions for MnDOT Consideration

The observations at the intersection by the project team suggest that sight lines for drivers on the minor approaches would be greatly improved if they could be encouraged to move closer to the intersection (closer to the through lanes) before making a decision about initiating a turning or crossing maneuver. A low cost, short-term solution would involve moving the existing STOP Bars (now at the STOP signs) farther up into the intersection (8 to 10 feet from the TH 55 edge line). Another short-term option is to adjust the lane striping on TH 55. The suggested striping option is to make the current right-turn lane the thru-lane and converting the current thru-lane to a left-turn lane.

It also appears that the most likely long-term solution would be to reconstruct the intersection to provide left turn lanes along TH 55. Adding left turn lanes, installing a traffic signal, and lowering the speed limit along TH 55 were recommended improvements from the employees at the manufacturing facility. The project team suggest that if MnDOT pursues the installation of a traffic signal, efforts should be made to manage expectations about the safety effectiveness (traffic signals at rural, high-speed locations are not a proven countermeasure) and consider the possibility of extending the project in an attempt to reduce conflicts at nearby intersections (extending median channelization to create right-in/right-out only situations) to capture likely crash reduction scenarios. The project team is aware that attempting to change driver's choice of a travel speed by merely changing the posted speed limit is likely to fail. Instead, a better approach is to change a driver's perception of the roadway environment by adding features that suggest an urban environment (curb and gutter, boulevards, sidewalks, and corridor street lighting).

4.0 Statewide System Review

4.1 RICWS Sites

The intersections selected for the RICWS installations were identified as candidates for safety investment based on a systemic evaluation of risk factors – roadway and traffic characteristics – and not solely on the presence of crashes. As a result, a traditional before versus after analysis of individual sites is not the recommended analytical approach because the results would likely not be credible due to the very low number of crashes at each intersection (fewer than two crashes per intersection per year). Instead, the approach to the evaluation involved looking at the entire group of locations where the improvement was deployed collectively, thereby increasing the size of the crash dataset (127 crashes across all of the RICWS sites in the before period) and increasing the credibility of the results.

This approach ended up assembling and analyzing a set of 27 locations where the RICWS was installed (Table 4-1 provides the list of locations).

- For the before period, 3 years of crash data was used and the after period was limited to March 31, 2015; which was typically 9 months. To account for the different length of the reporting periods, crash numbers were annualized for comparison purposes. Because of concerns about the short after period and statistical reliability, the results will be referred to as trends identified by the data. The key trends based on totals for the 27 RICWS sites include (Table 4-2):
    - A 22 percent decrease in overall annualized crash frequency
    - A 24 percent decrease in overall crash rate
    - A 30 percent decrease in fatal crashes and 62 percent decrease in severe (fatal +serious injury) crashes
    - A total of 19 of the 27 sites (69 percent) had reductions in (annualized) crash frequency and in crash rates

Another key trend suggests that traffic volume appears to make a difference. Both sites with a daily traffic volume cross-product (sample equation below) greater than 12 million entering vehicles (MEV) experienced increases in both annualized crash frequency and crash rate (Figure 4-1).

$$Cross\ Product = Major\ Entering\ ADT * Minor\ Entering\ ADT = 5{,}950 * 2{,}100 = 12{,}495{,}000$$

In addition, the 25 sites with a cross-product less than 12 MEV experienced a 73 percent reduction in crash frequency and crash rate. Looking at the nine sites with a cross-product under 6 MEV as a group, they experienced reductions of approximately 80 percent. Another volume trend suggests that minor road entering volume appears to be a larger factor than either major road entering volume or cross-product – 8 of 10 sites with minor entering volumes less than 1000 vpd experienced a decrease and 7 of 10 sites had 100 percent decrease.

TABLE 4-1
Implemented RICWS Intersections

County	District	Major Road	Minor Road	Major Entering ADT	Minor Entering ADT	Cross Product
Aitkin	3	MNTH 210	CSAH 12	5950	1765	10,501,750
Aitkin	3	USTH 169	CSAH 28	3750	700	2,625,000
Carver	8	MNTH 7	CSAH 33	7500	1900	14,250,000
Chippewa	8	MNTH 7/USTH 59	CSAH 15 (W Jct)	2175	1745	3,795,375
Cottonwood	7	MNTH 60	CSAH 1	5300	1100	5,830,000
Crow Wing	3	MNTH 6	CSAH 30	3600	740	2,664,000
Goodhue	6	MNTH 56	CSAH 9	1975	1600	3,160,000
Goodhue	6	MNTH 19	CSAH 7	2050	340	697,000
Isanti	3	MNTH 47	CSAH 8	5575	1177	6,561,775
Kanabec	3	MNTH 23	CSAH 11 (E Jct)	4950	400	1,980,000
Kandiyohi	8	MNTH 23	CSAH 1	5400	805	4,347,000
Kandiyohi	8	MNTH 71	MNTH 9	3625	1550	5,618,750
Lyon	8	MNTH 23	CSAH 30 (N Jct)	4450	470	2,091,500
McLeod	8	USTH 212	MNTH 22 (N Jct)	4975	2025	10,074,375
Nicollet	7	MNTH 15	CSAH 5	4100	1175	4,817,500
Olmsted	6	USTH 63	CSAH 21/CR 121	6900	1340	9,246,000
Olmsted	6	MNTH 42	CSAH 9	3100	1825	5,657,500
Otter Tail	4	USTH 10	CSAH 75	6900	830	5,727,000
Rice	6	MNTH 60	CSAH 13	5950	392	2,332,400
Rice	6	MNTH 3	CSAH 20	7650	1385	10,595,250
Rice	6	MNTH 60	CSAH 16	4700	915	4,300,500
Rice	6	MNTH 60	CSAH 44/CR 72	5200	1258	6,539,000
St. Louis	1	USTH 2	CSAH 98	3150	1675	5,276,250
St. Louis	1	MNTH 1/169	CSAH 77	3650	1850	6,752,500
St. Louis	1	USTH 53	Hat Trick Ave	10800	860	9,282,600
Wright	3	MNTH 55	CSAH 3/CR 136	5950	2100	12,495,000
Wright	3	MNTH 55	CSAH 37	7900	1325	10,467,500

TABLE 4-2
RICWS Data Table Reductions

Key: # Before Activation/# After Activation [Percent Reduction]*	All Locations	Cross Product		
		< 6 mil	< 12 mil	> 12 mil
# of Locations	**27**	**16**	**25**	**2**
Annual Crash Frequency	45.5/35.7 [22 percent]	22.0/12.2 [45 percent]	35.6/23.0 [35 percent]	6.7/7.5 [-13 percent]
Crash Rate	0.68/0.52 [24 percent]	0.74/0.40 [46 percent]	0.64/0.40 [37 percent]	1.05/1.16 [-11 percent]
Right Angle Crash Frequency	21.1/22.3 [-6 percent]	12.0/6.1 [49 percent]	17.3/11.5 [34 percent]	2.33/6.59 [-182 percent]
Fatal Crash Type [K] Annual Crash Frequency	2.15/1.49 [31 percent]	1.33/0.00 [100 percent]	2.00/0.00 [100 percent]	0.00/0.94 [N/A]
Incapacitating Injury Crash Type [A] Annual Crash Frequency	1.79/0.00 [100 percent]	1.00/0.00 [100 percent]	1.67/0.00 [100 percent]	0.00 / 0.00 [N/A]

* "Negative" sign equates to an increase in crash rates/frequencies

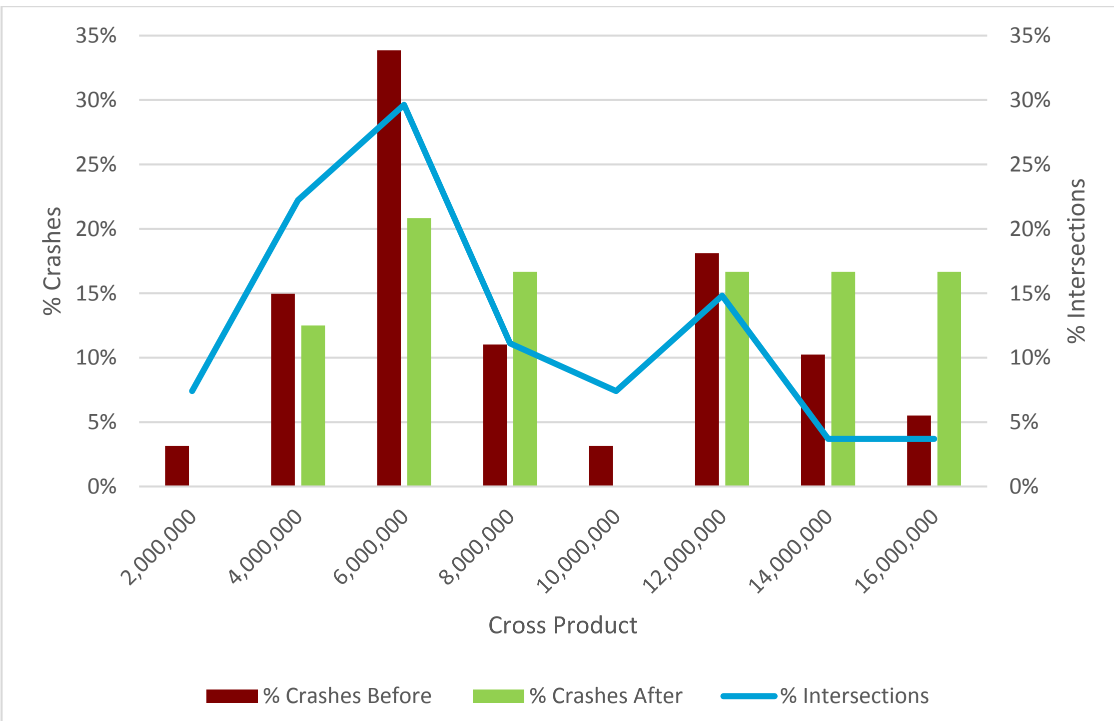


Figure 4-1: Before/After Cross Product Comparison [RICWS Intersections]

From a roadway characteristics perspective, intersections On/Near Curves (Figure 4-2) and the presence of Major Left (Figure 4-3) and Minor Right Turn Lanes (Figure 4-4) appears to make a difference – the overall annualized crash frequency increased at these sites. It appears that other roadway characteristics – skew, number of lanes, and proximity to a rail road grade crossing – did not influence the performance of the RICWS. Charts for these characteristics can be found in Appendix C.

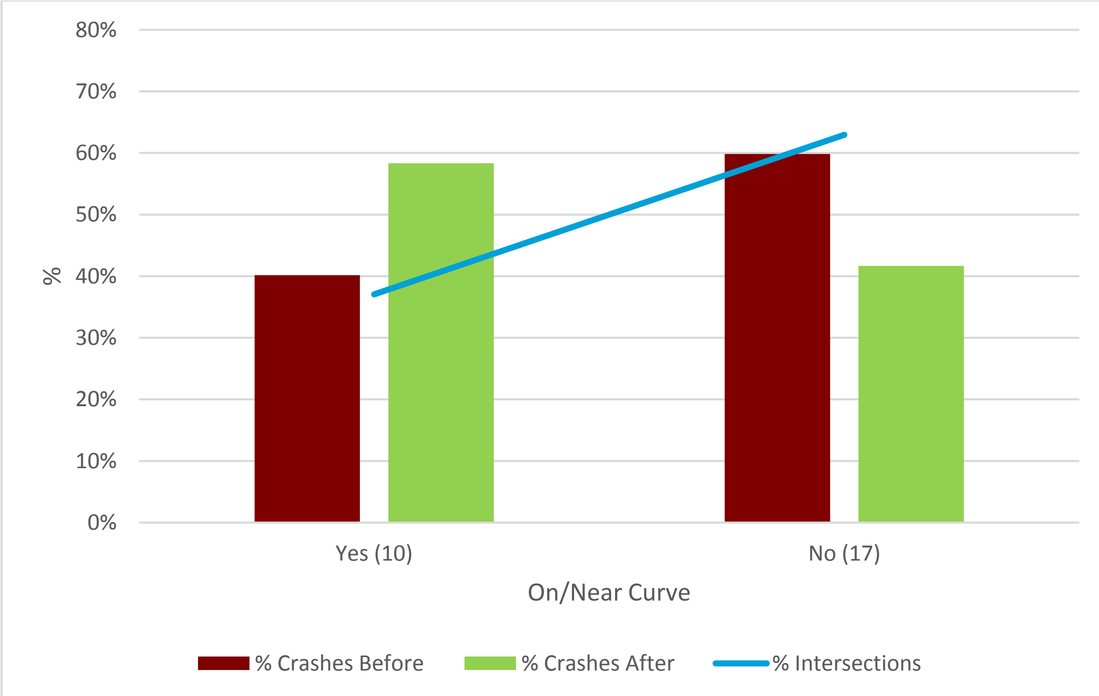


Figure 4-2: Before/After On/Near Curve Comparison
[RICWS Intersections]

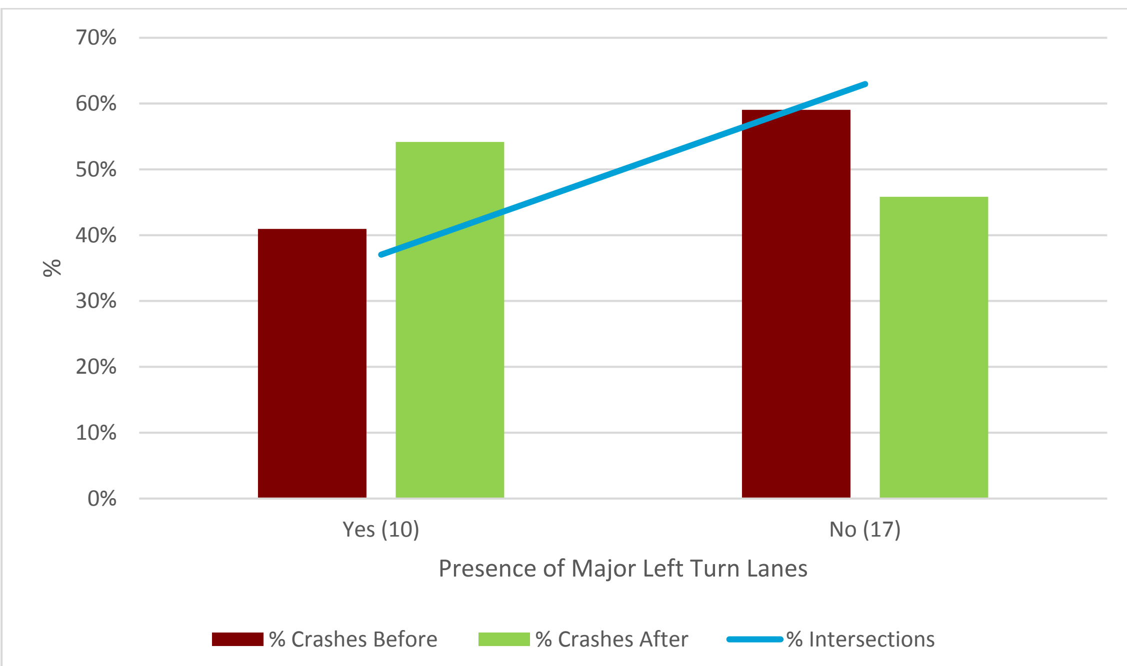


Figure 4-3: Before/After Presence of Major Approach Left Turn Lanes Comparison
[RICWS Intersections]

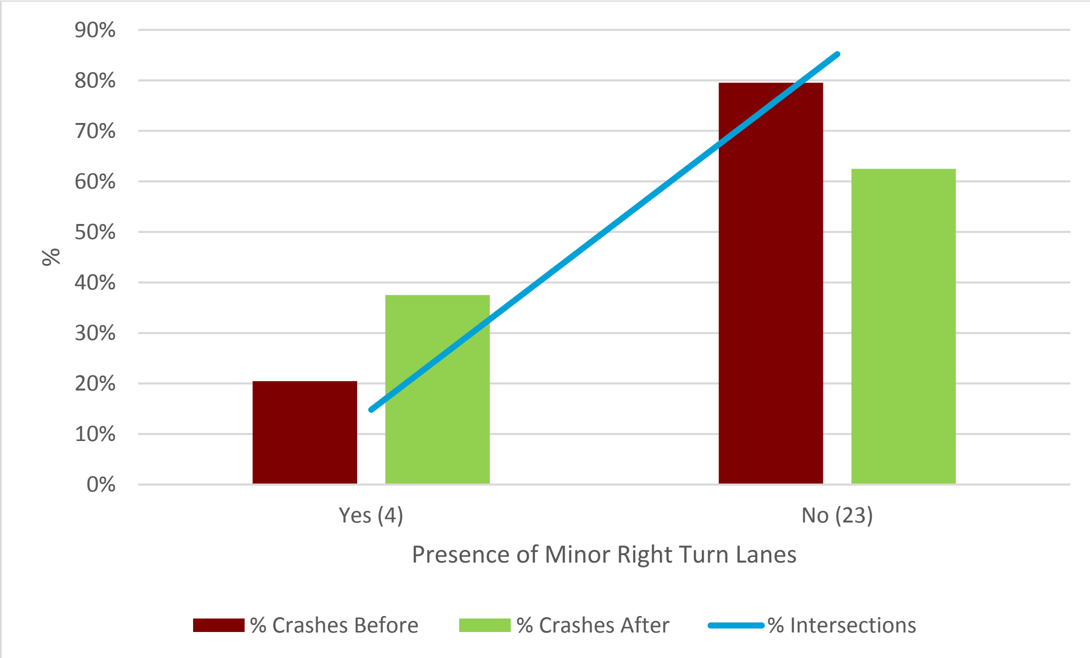


Figure 4-4: Before/After Presence of Minor Approach Right Turn Lanes Comparison [RICWS Intersections]

4.2 Control Sites

To enhance the credibility of the identified trends associated with the RICWS data set, a companion set of control sites was assembled. The idea behind the use of control sites is that if similar trends are observed in the control sites as in the RICWS sites, the differences are probably not because of the effect of the RICWS. A total of 30 intersections were identified for the control set, shown in Table 4-3, including those identified in a separate research study of driver behavior being conducted by Iowa State University, other intersections identified through a systemic risk assessment process as candidates for RICWS but that were not included as part of the initial deployment and other nearby intersections in the same highway corridor as the RICWS installations.

The key trends based on the totals for the 30 control sites include (Table 4-4):

- A 4 percent increase in overall annualized crash frequency (versus 22 percent decrease for RICWS sites)
- A 4 percent increase in overall crash rate (versus 24 percent for RICWS sites)
- A 100 percent decrease in fatal and severe crashes (versus 30 percent and 62 percent for RICWS sites)[1]
- A total of 20 of 30 sites (67 percent) had reductions in annualized crash frequency and crash rate (versus 66 percent and 69 percent for RICWS sites)

[1] The 100 percent decrease may be a result of regression to the mean in combination with expected low crash frequencies and a short after period.

TABLE 4-3
Control Site Intersections

County	District	Major Road	Minor Road	Major Entering ADT	Minor Entering ADT	Cross Product
Aitkin	3	USTH 169	CSAH 11	3,075	347	1,067,025
Clay	4	USTH 75	CSAH 18	3,900	1,030	4,017,000
Cottonwood	7	MNTH 60	570th Ave (CSAH 27)	5,400	1,027	5,545,800
Crow Wing	3	MNTH 6	CSAH 11	2,975	878	2,610,563
Goodhue	6	MNTH 19	CSAH 51	2,050	212	434,600
Goodhue	6	MNTH 19	CSAH 6	3,125	600	1,875,000
Goodhue	6	USTH 61	CSAH 21	6,850	360	2,466,000
Isanti	3	MNTH 47	CSAH 5	3,750	1,875	7,031,250
Itasca	2	MNTH 6	MNTH 286	795	560	445,200
Itasca	1	USTH 169	CSAH 15	6,600	445	2,933,700
Itasca	1	USTH 2	CSAH 71	4,800	322	1,545,600
Kanabec	3	MNTH 23	CSAH 12	5,100	910	4,641,000
Kandiyohi	8	MNTH 23	CSAH 5	4,675	1,800	8,415,000
Kandiyohi	8	USTH 71	CSAH 10	5,275	1,200	6,330,000
Le Sueur	7	MNTH 21/13	CSAH 28	4,450	1,475	6,563,750
Lyon	8	MNTH 19	CSAH 7	2,650	1,325	3,511,250
McLeod	8	MNTH 7	CSAH 1	6,750	3,550	23,962,500
McLeod	8	MNTH 7	CSAH 88	6,400	387	2,476,800
McLeod	8	MNTH 7	CSAH 9	7,100	1,265	8,981,500
Meeker	8	MNTH 15	CSAH 27	3,825	745	2,849,625
Mille Lacs	3	USTH 169	CSAH 9	9,400	727	6,833,800
Nicollet	7	USTH 14	CSAH 21	6,800	190	1,292,000
Otter Tail	4	MNTH 29	CSAH 75	3,075	910	2,798,250
Pennington	2	USTH 59	CSAH 8	4,900	743	3,638,250
Pipestone	8	MNTH23	CSAH 16	2,675	250	668,750
St. Louis	1	MNTH 169	CSAH 21	4,600	900	4,140,000
Steele	6	USTH 218	CSAH 6	4,900	393	1,923,250
Wilkin	8	MNTH 9	CSAH 18	700	58	40,250
Winona	6	USTH 14	CSAH 20	3,850	140	539,000
Wright	3	MNTH 55	CSAH 6	7,950	1,775	14,111,250

TABLE 4-4
Control Site Data Table Reductions

Key: # Before Activation/# After Activation [Percent Reduction]*	All Locations	Cross Product		
		< 6 mil	< 12 mil	> 12 mil
# of Locations	**30**	**22**	**28**	**2**
Annual Crash Frequency	30.0/31.1 [-4 percent]	15.3/19.9 [-30 percent]	25.7/24.9 [3 percent]	4.3/6.2 [-44 percent]
Crash Rate	0.50/0.52 [-4 percent]	0.41/0.54 [-30 percent]	0.49/0.47 [3 percent]	0.46/0.85 [-44 percent]
Right Angle Crash Frequency	13.00/4.98 [62 percent]	4.67/2.49 [47 percent]	9.67/2.49 [74 percent]	3.33/2.49 [25 percent]
Fatal Crash Type [K] Annual Crash Frequency	0.67/0.00 [100 percent]	0.33/0.00 [100 percent]	0.67/0.00 [100 percent]	0.00/0.00 [N/A]
Incapacitating Injury Crash Type [A] Annual Crash Frequency	1.33/0.00 [100 percent]	0.67/0.00 [100 percent]	1.33/0.00 [100 percent]	0.00 / 0.00 [N/A]

* "Negative" sign equates to an increase in crash rates/frequencies

The same traffic volume and roadway characteristics were reviewed for the control sites as for the RICWS sites. No volume trends are apparent among the control sites – either Cross Product (Figure 4-5), major or minor road volumes. For roadway characteristics, On/Near Curve (Figure 4-6) did have an effect as did the presence of Major Left Turn Lanes (Figure 4-7) (but not Minor Right Turn Lanes [Figure 4-8]).

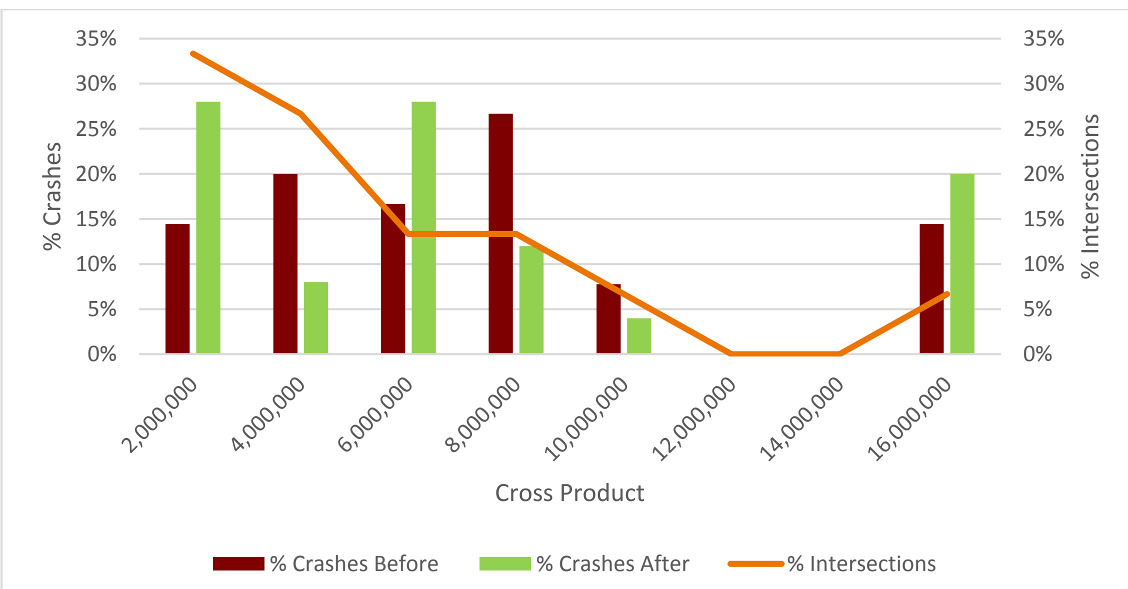


Figure 4-5: Before/After Cross Product Comparison [Control Intersections]

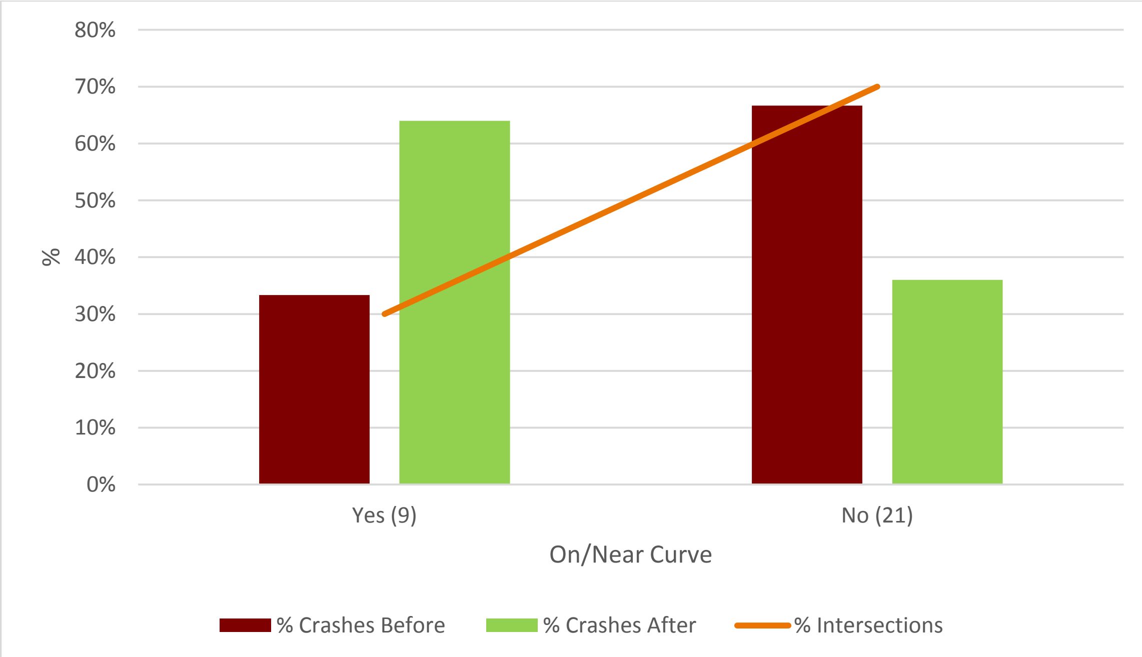


Figure 4-6: Before/After On/Near Curve Comparison
[Control Intersections]

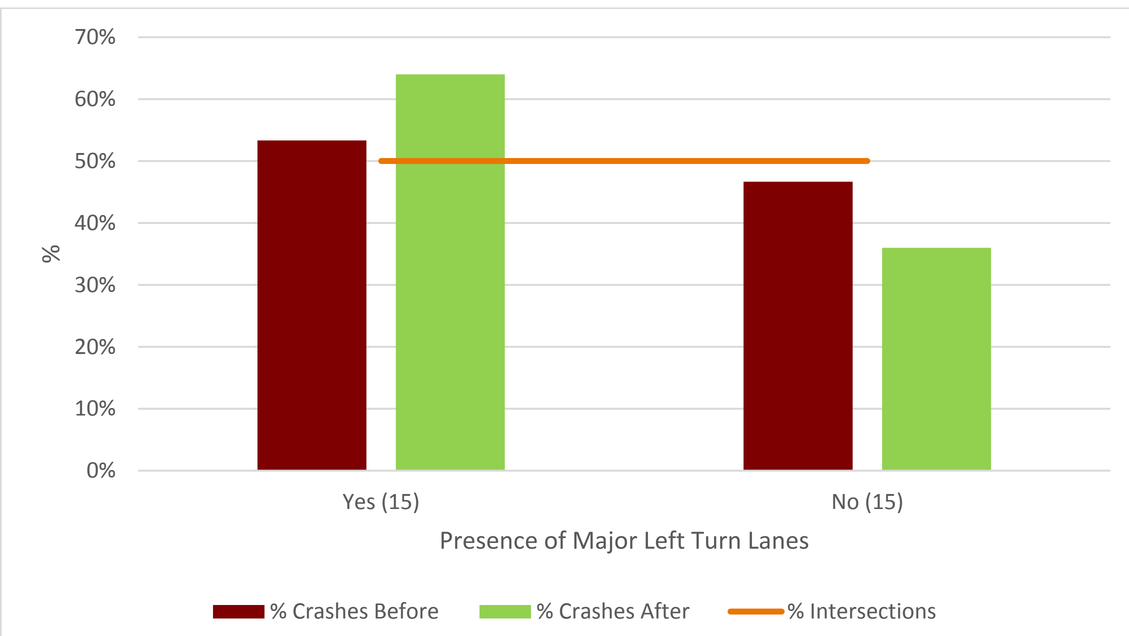


Figure 4-7: Before/After Presence of Major Left Turn Lanes Comparison
[Control Intersections]

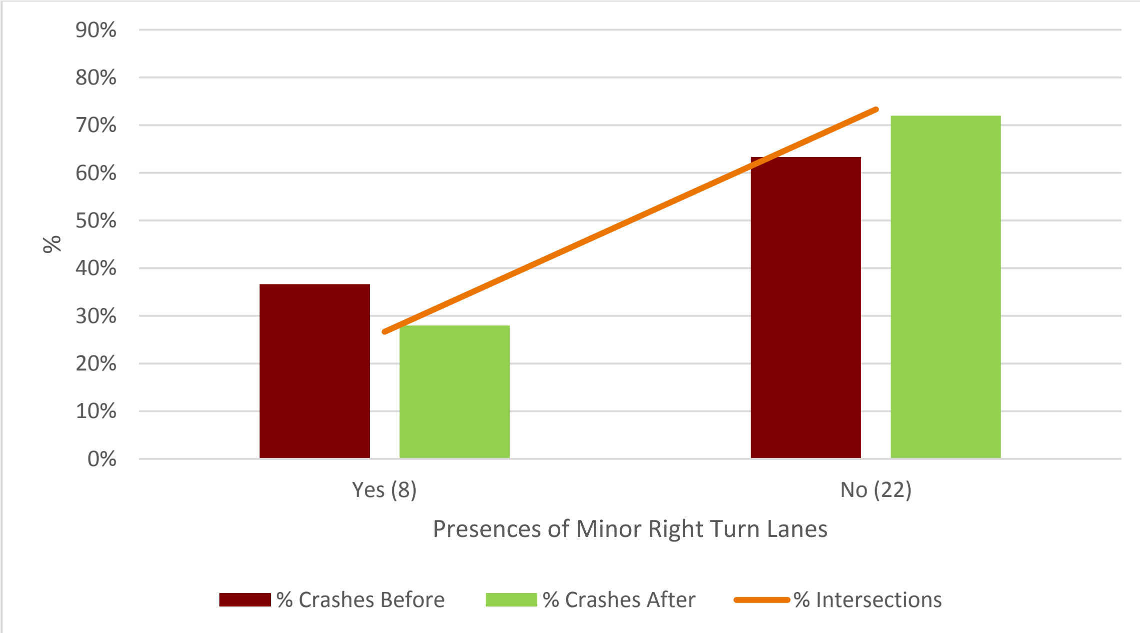


Figure 4-8: Before/After Presence of Minor Right Turn Lanes Comparison [Control Intersections]

5.0 Conclusions

5.1 TH 55/CSAH 3 Intersection

The intersection was identified as an at-risk intersection in 2010 as part of Wright County's Safety Plan based on a systemic risk assessment and as a candidate for the installation of a system of dynamic warning signs. The intersection was ultimately selected for installation of a RICWS and the device was activated in June 2014. A review of the available crash data indicate that after installation, the annualized number of crashes and the crash rate increased. However, neither increase is statistically significant (could be due to chance) and there is no information from the officer reports to suggest that the installation of the RICWS contributed to the increase.

A field review of the intersections was conducted by the project team (accompanied by MnDOT staff) and roadway and traffic conditions that stood out to the observers – high volume of traffic, mainline horizontal curve, and effect on site lines and bad behavior of drivers – several observed bypassing left turning vehicles in the Right Turn Lanes.

The project team suggests that MnDOT pursue a very low cost short term improvement – moving the STOP Bars on the minor approaches closer to mainline in order to take advantage of improved sight lines. Development of a longer term improvement that would add left turn lanes at the intersection for traffic on TH 55 would also mitigate some of the factors that are contributing to crashes. If MnDOT were to signalize the intersection, the project team suggests that the District to perform an access management review in order to reduce conflicts. Finally, seeking law enforcement's assistance to provide a greater presence at the intersection could be effective in dealing with the observed driver behavior, which was mentioned by area residents as adversely effecting safety at the intersection.

5.2 RICWS Sites

The before versus after analysis of the 27 RICWS sites found a 22 percent reduction in annual crash frequency and a 24 percent reduction in crash rate across the locations.

The data suggest a traffic volume effect – the two highest volume sites (> 12m cross-product) experienced increases in crash frequency, crash rate, and the number of right-angle crashes. The lower volume sites (< 12M cross-product) averaged greater reductions than the entire set in crashes, rates, and number of angle crashes - approximately 35 percent. In addition, greater reductions (approximately 45 percent) were documented for the lowest volume sites (< 6M cross-product).

It should be noted that overall crash reduction across the RICWS sites and the possibility of a volume effect are consistent with conclusions of the prior research reports cited in the literature review.

An overview of data fields that traffic or geometric characteristics may influence the performance of the RICWS is shown in Table 5-1. A brief commentary is provided for each characteristic, but additional time is needed to determine which, if any, may influence the RICWS's ability to reduce right-angle crashes.

TABLE 5-1
Data Fields and Associated Relevance for RICWS Locations

Data Field	Apparent Level of Influence	Commentary
Speed	○	There were two locations where the posted speed limit was less than 50 mph between the RICWS and control locations.
Skew	○	The presence of skew did not seem to have adverse/beneficial influence at RICWS locations.
Development	○	Since the intersections were in rural areas, sites that were near developments did not perform any worse than other locations where there was not a development when compared to the control sites.
Lighting	○	Presence of lighting did not adversely/beneficially effect the intersection performance for RICWS or control sites
On/Near Curve	◑	At both RICWS and Control Sites, the intersection being located on/near a horizontal curve was more prevalent in the after crash history. At this time, no explanation is available, including if the presence affects the performance of the RICWS.
Configuration	○	Whether the intersection had three or four legs, or if the major highway was divided or undivided, no correlation to crashes could be attributed.
Facility Type	○	Four-lane or two-lane roads did not have a distinction between performances.
Turn Lanes	◑	The presence of turn lanes on the major/minor roads seemed to be directly related to the volume. The higher the volume, the more likely turn lanes would be present.
Volume	●	Traffic volume appears to be the characteristic with the greatest influence on the performance of the RICWS system. Until a detailed performance evaluation can be completed, MnDOT should carefully evaluate locations that have daily volumes that exceed: 1000 vpd as minor entering volume, 6000 vpd as a major entering volume, and/or a cross product greater than 12 million.

Legend: ● = High Importance; ◑ = Medium Importance; ○ = Low Importance

Appendix

Appendix A – District Survey Responses

The contents of Appendix A are the questions and responses from a survey taken by the district traffic engineers regarding components of the RICWS safety study performed.

Q1) Refer to the accompanied Excel spreadsheet listing existing RICWS sites. Are there any corrections or additions to this list for your District?

District	Response
1	The major street AADT is incorrect for the RICWS at TH 1/169 and CSAH 77. The other volumes should be verified as well.
2	District 2 has one of the original trial RICWS currently installed that is slated for being upgraded in the summer of 2015.
3	NO!
4	[-]
6	No
7	Not sure how the “Intersection Configuration” correlates to the field conditions.
8	Attached is a list of RICWS systems that are planned to be installed by the end of 2015 (calendar year)

Q2) Refer to the same spreadsheet’s list of control sites. Please confirm or provide corrections for each of these sites, including whether there is currently a RICWS system installed and whether there have been any significant changes to the intersection as of the beginning of 2010.

District	Response
1	Could I get a map of these locations? I was not able to quickly find them.
2	[-]
3	OK as listed.
4	[-]
6	The spreadsheet is correct. The following three intersections had lighting added in 2011: 63/21/121, 42/9, and 56/9. To my knowledge, there have not been any other significant changes to the intersections as of 2010.
7	TH 22 & Le Sueur CR 21 had rural intersection lighting added within the past three years. Control locations shown are for rural two-lane highways. RICWS installed in Cottonwood County is on a rural high-speed expressway.
8	- Changes since 2010: To our knowledge here are the following changes since 2010 - TH71/TH9 – Solar powered, LED perimeter stop sign in February of 2013, still installed with RICWS system. - TH23/CR7 (Lyon County) – County realigned road in 2012? (assumed) - CICAS system was removed 2 months prior to installation of the RICWS system.

Q3) In addition to the control sites listed in the spreadsheet, please provide 2-3 locations that may be added to the list; sites that have not had any significant changes since the beginning of 2010 and with similar design and traffic patterns to RICWS-installed locations.

District	Response
1	[-]
2	Due to maintenance and operational duties, the District is not looking to add additional systems at this time.
3	[-]
4	[-]
6	US 61/CSAH 21/Flower Valley Road in Goodhue County, south of Red Wing RP 86.426; MN 19/CSAH 6 in Goodhue County, south of Red Wing RP 204.801
7	Sorry, no locations come to mind.
8	Although we are currently not seeking additional RICWS locations, 2 other possible sites would be the following: TH30/CR18 (Pipestone County)

Q4) Generally, are the RICWS devices functioning as expected? If not, please describe for each specific location.

District	Response
1	To my knowledge they are functioning correctly. I have not spent much time at each location.
2	Yes
3	I have not reviewed most sites to date but I believe them to be functioning as expected. The RICWS at TH 55/CSAH 3/CR 136 did receive significant review and the gap seems rather short for the speed.
4	[-]
6	Yes. We had issues at the MN 42/CR 9 site (six failures in two months) but the contractor finally find the faulty piece of hardware and replaced it. No issues since then.
7	Have had at least one complaint that the Cottonwood County system did not detect traffic when observed.
8	They appear to be functioning as intended. Seems that flashing range could be a little longer and earlier on minor legs at times. Have had some sign installation issues that have need repeated fixing.

Q5) Have there been any safety and/or operational concerns or problems identified with the current installations? If yes, please describe for each specific location.

District	Response
1	I have been told that the flasher does not activate soon enough at the intersection of TH 2/CSAH 98. I reviewed the intersection for about an hour after I heard this complaint. During this time I felt the flashers turned soon enough to provide an adequate amount of warning time.
2	Replacement of blank out panels after being shot out – Approximately $5000 apiece.
3	The city of St. Cloud engineer and the Wright County engineer along with a number of people from Malco (business in NW corner of TH 55/CSAH 3 RICWS) have expressed concerns that the device may be more of a distraction and maybe data overload at this particular location.
4	[-]
6	Yes. A general comment I receive is that the “when flashing” needs to be included on the “Traffic Approaching” sign. For some reason, people do not read the “when flashing” plaque. I have heard this from co-workers and my husband, as well as citizens who call in. Cory received a strongly worded email from Jeff Broberg, after I spoke to him, with these concerns about the 42/9 site. I have also heard from someone who drives the 42/9 site, that the system does not pick up motorcyclists.
7	See No. 4.
8	Not to our knowledge

Q6) Have you observed any road or traffic characteristics that have contributed to the RICWS device not operating as intended? If yes, please describe for each specific location.

District	Response
1	I have heard that traffic on the frontage road (not traffic entering TH 53) at Hat Trick Ave sometimes activates the mainline flashers.
2	No
3	The RICWS at TH55/CSAH 3 may not be aligned to the proper stop bar location resulting in a dim sign with poor command
4	[-]
6	Yes. Technically no. When there was a crash at the 42/9 site (on 3-18-2015), the signs went black. However, there was a vehicle parked on the loop, so the sign is supposed to shut down. Our maintenance staff was confused and worried that the system wasn’t working properly at the time of the crash. There is no evidence of that. A system check after the vehicles cleared showed the signs working properly.
7	See No. 4.
8	Not to our knowledge

Q7) Are you aware of any RICWS locations that experienced a crash since the device was activated? If yes, please share the location, crash type, and any known contributing circumstances (e.g., driver ran the STOP sign). *Please Note: We will be using MnCMAT to evaluate the crash history of each site, but we appreciate you sharing any knowledge you have of crashes after RICWS was installed.*

District	Response
1	Yes. TH 2 and CSAH 98 has had at least one crash since the installation of the system. The driver on the minor street apparently pulled out in front of someone after completing their stop. I do not have any specific information.
2	No
3	The only crashes I checked was at TH 55/CSAH 3. I believe there were 4 or 5 right angle crashes since installation. One being a fatality where the stop sign was ran other seem to be gap related.
4	[-]
6	At the 42/9 site, there was a crash on 3-18-2015. Right angle crash, non-life threatening injuries. I do not know the circumstances.
7	TH 60 / Cottonwood CR 1: 7/9/2014; failure to yield
8	I have heard of one crash at TH71 and TH9, but it was only by word of mouth and was expressed as a low severity crash.

Q8) Have any local agencies provided feedback on the operation of the RICWS device? If yes, please share for each specific location.

District	Response
1	No local agencies have provided feedback to me.
2	No
3	City of St. Cloud and Wright County Engineer have expressed concerns on the systems on TH 55.
4	[-]
6	Yes. Since there were issues at the 42/9 site, both Mike Sheehan, Olmsted County Engineer, and Jim Schumann, Eyota Township Supervisor, contacted me for information on how the system is supposed to work, and what the problems were. Jim drove through the intersection every day, and would call me when it wasn't working properly. Greg Isakson, Goodhue County Engineer, must like the signs, as he submitted a request for HSIP dollars to fund another intersection in his county, at MN 58/CR 9 near the city of Goodhue.
7	Cottonwood County Sheriff's office relayed a Commissioner's observation that the RICWS failed to detect an eastbound semi (May 2015).
8	Kandiyohi County has mentioned that they'd prefer the "when flashing" sign to be a part of the LED blankout sign.

Q9) Have any law enforcement agencies provided feedback on the operation of the RICWS device? If yes, please share for each specific location.

District	Response
1	State Patrol provided the following feedback at TH 2/CSAH 98: MSP just talked to me about a crash that occurred at this intersection recently. They asked "why is the LED sign that says TRAFFIC APPROACHING always lit up?" There is a WHEN FLASHING sign below but the driver involved in the crash did not recognize the distinction. Would it be possible to turn the sign black when no one is approaching?
2	Concern with increase in rolling stops
3	No!
4	[-]
6	State Patrol asked me to explain how they operate. They also asked what type of education we provided. I noted we did press releases and were on the TV news, but that the signs are meant to be intuitive.
7	See No. 8.
8	Only a few positive feedbacks that they like the systems

Q10) With respect to safety and/or operational benefits, would you be willing to implement more RICWS devices? If yes, at what type of locations? In no, please explain why not.

District	Response
1	I would like to hold off on providing more MnDOT RICWS systems in D1 on the state highway system until we get a better "Minnesota picture" of their benefits. Is there a significant benefit and how does the benefit compare to the cost? The initial systems are fairly expensive. It should be note that D1 is allowing St. Louis County to add several mainline RICWS systems on the state highway system as part of their safety plan. I have some concerns that we are encouraging the minor road to not come to a complete stop when there is no conflicting traffic. This is probably more of an issue on minor roads with a lot of repeat traffic. I have long term maintenance concerns about the systems. Many of our ITS systems require a significant amount of maintenance as the systems age. We have been adding ITS type systems without adding staffing for them. Also we may not get prompt notice when the system is not functioning correctly unless we routinely review the systems. I would avoid installing a system on a roadway that has a higher volumes. The impact of the system will be diminished if the flasher is always on.
2	Not at this time due to lack of staff to adequately maintain and operate systems.
3	Not sure until more crash data is known. There is also a concern on the future operational and maintenance needs.
4	[-]
6	Not at this time. After this year, we will have eleven installations (twelve if Goodhue site is approved) in the district. I would like to see the research results before we commit to adding more systems.
7	No. High cost, absence of proof of the concept. Also, we have a lack of maintenance resources to tend to this higher-maintenance type of system.
8	We would be willing to install more RICWS systems, but we'd like to see how the 12 that are proposed will function and also the maintenance demand that they will generate before pursuing more.

Appendix B – Literature Reviews

The contents of Appendix B are the literature reviews for five documents reporting the effectiveness of intersection conflict warning systems in Minnesota and North Carolina.

1. Determining the Effectiveness of an Advanced LED Warning System for Rural Intersections

Overview:

The Minnesota Department of Transportation (MnDOT) developed a low-cost countermeasure to address rural thru-stop intersection crashes. The Advanced LED Warning System (ALWS) was deployed at the intersection of West Tischer Road (major road) and Eagle Lake Road (minor road) in Duluth Minnesota to assess driver behavior and interaction with the system. This location was selected for this research project because there is poor intersection sight distance due to a vertical curve on the westbound approach.

System Design:

The ALWS had one mainline LED sign which displayed a static sign and plaque “CROSS TRAFFIC” and “WHEN FLASHING,” respectively. The LED lights along the perimeter of the sign would begin flashing when a vehicle approached the intersection on either of the minor legs. This sign was placed 525’ from the intersection and the posted speed limit is 55 mph. The stop-controlled legs had the sign say “VEHICLE APPROACHING” and the same “WHEN FLASHING” plaque below. These signs were placed at the intersection on the opposing traffic side of the road. Passive infrared detectors, when actuated, would transmit a signal and set off the minor leg LED signs for a duration of 10 seconds. These minor leg signs provide a warning to vehicles at the stop signs on that a vehicle has been detected approaching the intersection from the east or west on the major road. Two cameras were placed along the major corridor, one approximately 600 feet east of the intersection to capture westbound traffic and the second was placed within 150 feet of the intersection to capture the movements at the intersection.

Data Collection:

There were two phases of data collection. The first phase time period was 48 days and the cameras recorded the turning movements at the intersection before the ALWS was installed and the second phase had a duration of 204 days which recorded the traffic after the ALWS was installed. The primary data collected was the speed of vehicles entering the intersection from the eastern approach. The ‘before’ period average, median and standard deviation of speeds were 46.3, 46.3 and 9.8 mph respectively. The ‘after’ period average, median and standard deviation speeds were 47.1, 47.1 and 12.0 mph respectively. It is important to note that with this study only lasting one year, a before/after crash analysis was not conducted. Reasons for this include the short duration of the project and the intersection had relatively low volume.

Results:

The average vehicle speeds decrease overall when the system was actuated during a potential conflict. Table B.1 shows the average speeds of approaching vehicles based on whether or not a conflict existed. In all cases where there was a conflict, mean vehicle speeds decreased after the warning system was installed. A z-test found that the mean speeds for before and after the installation of the warning system that a 95% confidence interval, significant differences between the vehicle speeds were observed. Overall, this this report concluded that the ALWS was found to be effective at changing driver behavior at a rural thru-stop intersection with limited sight distance. However, there was an increase in roll-thrus when there wasn’t a conflict. The researchers commented that this concern should be addressed for any potential future implementable location for the ALWS.

Table B.1: Comparison of No-Conflict and Conflict Average Speeds After Installation of ALWS

Condition	No Conflict (mph)	Conflict (mph)
Daytime	47.73	43.35
Nighttime	44.94	41.17
a.m. peak	47.09	40.88
p.m. peak	46.92	45.9
Off peak	47.15	42.44
Weekday	47.33	42.06
Weekend	46.66	40.79
November	48.12	45.61
December	43.92	38.59
January	44.95	36.25
February	48.41	46.76
March	47.35	43.68
April	49.79	41.57
May	46.29	44.37

2. Website: Planning Guidance for the Installation and Use of Technology Devices for Transportation Operations and Maintenance [ENTERPRISE Pooled Fund Study]

Overview:

The website provided the following definition for an Intersection Conflict Warning System (ICWS):

> *For purposes of the ITS device guidance process, ICWS is defined as a traffic control device placed on major, minor or both roads of an intersection to provide drivers with a real-time dynamic warning of vehicles approaching the or waiting to enter the intersection. ICWS are typically installed to address crash factors associated with limited sight distance and poor gap selection at stop-controlled intersections.*

Implementation Guidance:

The website provides five initial points for consideration for when to consider an ICWS. The five points are:

1) The configuration of the device should be selected by the engineer.
2) An ICWS is one available countermeasures and the guidelines are not intended to mandate the use of ICWS.
3) Guidelines for implementation consider reactive (ICWS #1: Intersections with High Crash Frequencies or Rates) and proactive (ICWS #2: Intersection Characteristics) situations. Both guidelines may be used for a comprehensive approach or individually.
4) Suggested maximum ADT thresholds were recommended to be:
   - Major Road ADT typically does not exceed 12,000.
   - Minor Road ADT typically does not exceed 3,000.
5) Prior to implementation, engineers are encouraged to apply their judgment to identify and assess potential "implications that may result from installation of ICWS at candidate intersections".

In addition to the five initial points, two specific guidelines for implementation are provided for engineers considering an ICWS. The first guideline is for situations where an intersection has a high crash frequency or rate while the second criteria is for intersections that have characteristics indicating a potential for future severe right angle crash.

ICWS Guideline 1 - Intersections with High Crash Rates

Purpose: To influence driver behavior at stop-controlled intersections (typically 45 mph or greater posted speed on the major road) where right-angle crashes are the predominant crash type.

Device should be considered if:

1. Crashes or Crash Rate at the intersection are higher than expected over a 5-year period for a region, with agency-specific thresholds as determined by using one of the following:
   a. The 5-year crash rate is higher than an agency-defined threshold for the average crash rate in a region.

   OR

   b. The total number of crashes over a 5-year period exceeds an agency-defined threshold that is higher than expected in a region.

   AND

2. One or both of the following conditions is observed at the intersection:
    a. Limited sight distance
    AND/OR
    b. Poor gap acceptance for the minor road driver is observed at the site (e.g. actual crashes and/or near misses)

ICWS Guideline 2 - Intersection Characteristics

Purpose: To influence driver behavior at stop-controlled intersections (typically 45 mph or greater posted speed on the major road) where conditions are such that the intersection could be susceptible to right-angle crashes.

Device should be considered if:

1. One or both of the following conditions is observed at the intersection:
    a. Limited sight distance
    AND/OR
    c. b) Poor gap acceptance for the minor road driver is observed at the site (e.g. actual crashes and/or near misses)

    AND

2. 2. One or more of the following conditions are present at the intersection. These conditions have been found to be associated with a higher frequency of right-angle crashes at stop-controlled intersections. (2) The combination of conditions present at the intersection should be assessed using engineering judgment.
    - The intersection skew angle is greater than 15 degrees.
    - A horizontal curve and/or vertical curve is present at the intersection.
    - A railroad crossing is present on one of the minor leg approaches to the intersection.
    - Commercial development is present in one or more of the intersection quadrants.
    - The minor leg approach does not have a STOP sign within 5 miles prior to the intersection.
    - Crashes or Crash Rate at the intersection are trending higher than expected over a 5-year period for a region.

3. Evaluations of the Safety Effectiveness of "Vehicle Entering When Flashing" Signs and Actuated Flashers at 74 Stop-Controlled Intersection in North Carolina

Overview:

This before/after study analyzed 74 locations in North Carolina where a Vehicle Entering When Flashing (VEWF) system was implemented. The reason for this study was to assess the safety performance of these systems and to determine if they are effective in reducing crashes. This report also provides Crash Modification Factors (CMFs) that were developed for two-lane at two-lane intersection configurations.

There were four distinct Categories that were analyzed:

1. Overhead signs and flashers on the major road and vehicle detection on the minor road
2. Overhead signs and flashers on the minor road and vehicle detection on the major road
3. Advance post-mounted signs and flashers on the major road and vehicle detection on the minor road
4. Locations with a combination of the first three categories

There was also a specific intersection sites criteria where the VEWF systems were deployed. These sites were selected by searching the NCDOT Spot Safety Program Database in which many of the VEWF systems were completed through this program in order to identify a smaller range of improvements projects to address the frequency of correctable crashes and the severity of crashes. The criteria for selecting location where potential treatment could occur is

1. At grade, thru-stop control intersections
2. At least three years of 'before' crash data
3. At least one year of 'after' crash data
4. Presence of the VEWF system during the after period

There were 74 intersections that met the criteria and Category 1 consisted of 24 intersection, Category 2 consisted of 19, Category 3 consisted of 23 intersections and 8 intersections for Category 4. Locations were distributed between rural and urban environments, with speed limits ranging from 35 to 55 mph and AADT ranging from 3,000 to 30,000 entering vpd. Facility geometry also consisted of two-lane at two-lane, multilane (3-5 lanes) undivided at two-lane and four-lane divided at two-lane sites. Similar criteria was used to identify approximately five reference sites per treatment site as well.

Results:

Table B.2 provides results for all sites and all types of geometry. Table B.3 provides the results only for two-lane at two-lane intersection geometry due to this being the most representative sample of the VEWF implementations. Table B.4 provides average cost estimates and volume thresholds that were used in the study.

Table B.2: Crash Modification Factors for All Sites

Category	CMF (+/- Standard Deviation)			
	Total Crashes	Frontal Impact Crashes	Injury Crashes	Severe Injury Crashes
All sites	0.932 (0.043)	0.968 (0.050)	0.936 (0.055)	0.836 (0.159)
Category 1	1.091 (0.094)	1.096 (0.105)	0.950 (0.104)	0.689 (0.242)
Category 2	0.965 (0.081)	1.043 (0.097)	0.976 (0.105)	0.859 (0.282)
Category 3	0.807 (0.067)	0.827 (0.076)	0.890 (0.090)	0.932 (0.279)
Category 4	0.749 (0.120)	0.797 (0.144)	0.870 (0.187)	0.242 (0.212)

Table B.3: Crash Modification Factors for Two-Lane at Two-Lane Sites

Category	CMF (+/- Standard Deviation)			
	Total Crashes	Frontal Impact Crashes	Injury Crashes	Severe Injury Crashes
Category 1	1.06 (0.10)	1.07 (0.11)	0.92 (0.11)	0.61 (0.24)
Category 2	0.95 (0.08)	1.00 (0.10)	0.93 (0.11)	0.76 (0.27)
Category 3	0.68 (0.08)	0.68 (0.09)	0.73 (0.10)	0.70 (0.30)
Category 4	0.75 (0.12)	0.80 (0.14)	0.87 (0.19)	0.24 (0.21)

Table B.4: Cost Estimate and Volume Thresholds

Category	Total Crashes [CMF (Std Dev.)]	Average Cost [$]	Intersection AADT
Category 1	1.06 (0.10)	$22,800	1,500 – 12,200
Category 2	0.95 (0.08)	$21,900	3,200 – 12,100
Category 3	0.68 (0.08)	$21,200	2,800 – 9,700
Category 4	0.75 (0.12)	$28,000	2,400 – 9,300

Category 3 was selected overall as being the most beneficial specifically with the intersection consisting of two-lane at two-lane configuration with a posted speed limit of 45 mph.

4. Macroscopic Review of Driver Gap Acceptance and Rejection Behavior at Rural Thru-Stop Intersections in the US – Data Collection Results for Eight States

Overview:

The researchers performed an analysis of driver behavior that was collected at rural thru-STOP intersections located in each of the nine states (CA, GA, IA, MI, MN, NC, NH, NV, and WI) that participated in a previous pooled-fund study. The stated goal of the analysis was to "identify whether drivers in different regions of the county exhibit different gap acceptance/rejection behavior, and if different driver behaviors are identified, determine whether they are different enough to inhibit the deployment of a common" intersection collision avoidance system throughout the country. The researchers also sought to identify the alert and warning timing sufficient to assist drivers in "recognizing and taking appropriate action when presented with a gap which could be considered unsafe."

An important observation about the technology being tested in the research is that the system is designed to help drivers reject unsafe gaps. The collision warning system was never intended to help drivers select a safe gap.

Research Findings

Based on the analysis, the researchers reported that the system can be deployed nationally. In other words, driver behavior was consistent when it came to gap selection at the rural, thru-STOP intersections where data was collected.

The researcher identified three important findings.

- Drivers are extremely consistent in gap rejection behavior, including any regional or state influences.
- Drivers were not observed to change their gap rejection behavior based on the amount of time that drivers had spent waiting for an acceptable gap. The researchers stated that if the alert and warning timing are conservative (i.e., warnings provided earlier to give drivers more time to comprehend the sign and react accordingly), the driver's frustration is unlikely to increase to the point where the alerts and warnings are no longer obeyed.
- Vehicle type appeared to have no impact on drivers' gap rejection behavior. It is commonly accepted that drivers of larger vehicles will wait for larger gaps, but that was not found to be accurate in the observed drivers. Instead, drivers of heavy vehicles accepted similar gaps, but this behavior did produce greater speed reduction on the major approach lanes. This finding is important because it indicates that using the same warning time for all vehicles is reasonable.

The researchers also reported that findings were insensitive to time of day, maneuver, average size of available gap, and point of departure.

For the information collected at the Minnesota intersection (rural, expressway intersection) regarding the size of rejected gaps, it was found that 80% of gaps that drivers rejected were 6.67 seconds.

5. ENTERPRISE ICWS Webinar Series: FHWA Development of Crash Modification Factors Safety Evaluation of ICWS

Overview:

The document is a presentation used for an ENTERPRISE webinar. The focus of the webinar was on the development of crash modification factors (CMFs) for ICWS that were developed through FHWA's Development of Crash Modification Factors (DCMF) Program.

The development of CMFs include sites from Minnesota, Missouri and North Carolina. This include a mix of locations (two-lane intersecting two-lane and two-lane intersecting four-lane) as well as devices (overhead versus post-mounted, mainline versus minor warning, and message displayed). However, not all of the Minnesota devices included in the study were the current RICWS.

The study's objectives were stated as to determine the impact by type of treatment (overhead versus post-mounted, mainline versus minor approach, combination) and site characteristics (traffic volume, speed limit, geometry). An Empirical Bayes before-after methodology was used to develop the CMFs.

Resulting CMFs

The combined CMFs from the three participating states were reported as:

- Two-Lane at Two-Lane:
  - Total Crashes = 0.73 (Std Err = 0.04)
  - Fatal and Injury = 0.70 (Std Err = 0.05)
  - Right Angle = 0.80 (Std Err = 0.05)
  - Rear End = 0.43 (Std Err = 0.07)
  - Nighttime = 0.90 (Std Err = 0.10)

- Two-Lane at Four-Lane:
  - Total Crashes = 0.83 (Std Err = 0.06)
  - Fatal and Injury = 0.80 (Std Err = 0.07)
  - Right Angle = 0.85 (Std Err = 0.08)
  - Rear End = 0.97 (Std Err = 0.22)
  - Nighttime = 0.61 (Std Err = 0.11)

Additional CMFs were provided presence of lighting, presence of "WHEN FLASHING", and overhead versus post mounted, but based on the presentation it appears the results are limited to sites from North Carolina.

Economic Analysis:

An economic analysis resulted in a B/C value of 35:1 for two-lane at two-lane [sensitivity testing provided a range of from 20:1 up to 50:1]. For the two-lane at four-lane sites, the B/C ratio was 13:1 [sensitivity analysis revealed a range from 8:1 to 19:1]

Appendix C – Additional Charts & Data Elements

The contents Appendix C are the remaining charts that were produced for the RICWS and Control Sites. These characteristics summarized in these charts did not appear to be significant factors which ultimately lead to suggestions on where/how the Rural Intersection Conflict Warning Systems should be deployed.

RICWS Locations – Observed Trends Before vs. After

Figure C.1 – Major Entering ADT

Crashes in the "Before" condition were basically proportional to the distribution of the daily traffic volumes on the major entering legs. In the "After" condition crashes decreased at the RICWS sites where the major entering volume was less than 6,000 vehicles per day and increased at the sites with volumes greater than 6,000 vehicles per day.

Figure C.2 – Minor Entering ADT

Crashes in the "Before" condition were generally uniformly distributed across the range of minor entering daily traffic but with the majority of crashes occurring at the sites with volumes greater than or equal to 1,000 vehicles per day. In the "After" condition crashes decreased at the RICWS sites with less than 1,200 vehicles per day and increased at the sites with volumes greater than 1,200 vehicles per day.

Figure C.3 – Skew

Crashes in the "Before" condition were proportional to the distribution of skew angles observed at the intersections with the majority of the crashes occurring at the intersections with deviations of 10 degrees of less from 90 degrees. In the "After" condition the trend is difficult to discern, the RICWS sites with No skew or 10 degrees skew had virtually no change in crashes, RICWS sites with 5 degrees skew had the greatest reduction (approximately 45%) and the majority of the crash reduction (64%) occurred at RICWS sites with skew angles between 15 and 25 degrees.

Figure C.4 – Development Present

Crashes in the "Before" condition were over represented at intersections where development is present (this is consistent with the fact that the presence of development was considered to be a risk factor in the assessment of rural intersections). In the "After" condition there was no change in the distribution of crashes which suggests that installation of the RICWS had no effect at these locations.

Figure C.5 – Lighting Present

Crashes in the "Before" condition are slightly over represented at intersections where street lighting is present. In the "After" condition there was virtually no change in the distribution of crashes which suggests that installation of the RICWS had no effect at these locations.

Figure C.6 – Speed Limit

Crashes in the "Before" condition were proportional to the distribution of the intersections by speed limit, almost 80% of the crashes occurred at intersections with either a 55 or 60 MPH speed limit. In the "After" condition crashes decreased at RICWS sites with 50 and 55 MPH speed limits, increased at sites with a 60 MPH limit and were unchanged at sites with 45 and 65 MPH speed limits.

Figure C.7 – Intersection Configuration [1] (Cross or Tee)

Crashes in the "Before" condition were proportional to the distribution of the intersections based on the number of entering legs. In the "After" condition there was no change in the crashes which suggests that installation of the RICWS had no effect at these locations.

Figure C.8 – Intersection Configuration [2] (Undivided or Divided)

Crashes in the "Before" condition were proportional to the distribution of the intersections based on whether or not they were divided. In the "After" condition, there was no change in crashes which suggests that installation of the RICWS had no effect at these locations.

Figure C.9 – Near Railroad Crossing

Crashes in the "Before" condition were over represented at intersections near railroad crossings (this is consistent with the fact that the presence of a nearby railroad crossing was considered to be a risk factor in the assessment of rural intersections). In the "After" condition crashes increased at the RICWS sites with nearby railroad crossings and decreased at the RICWSD sites without any railroad crossing. This appears to suggest that locations with nearby railroad crossings are not good candidates for the RICWS installation.

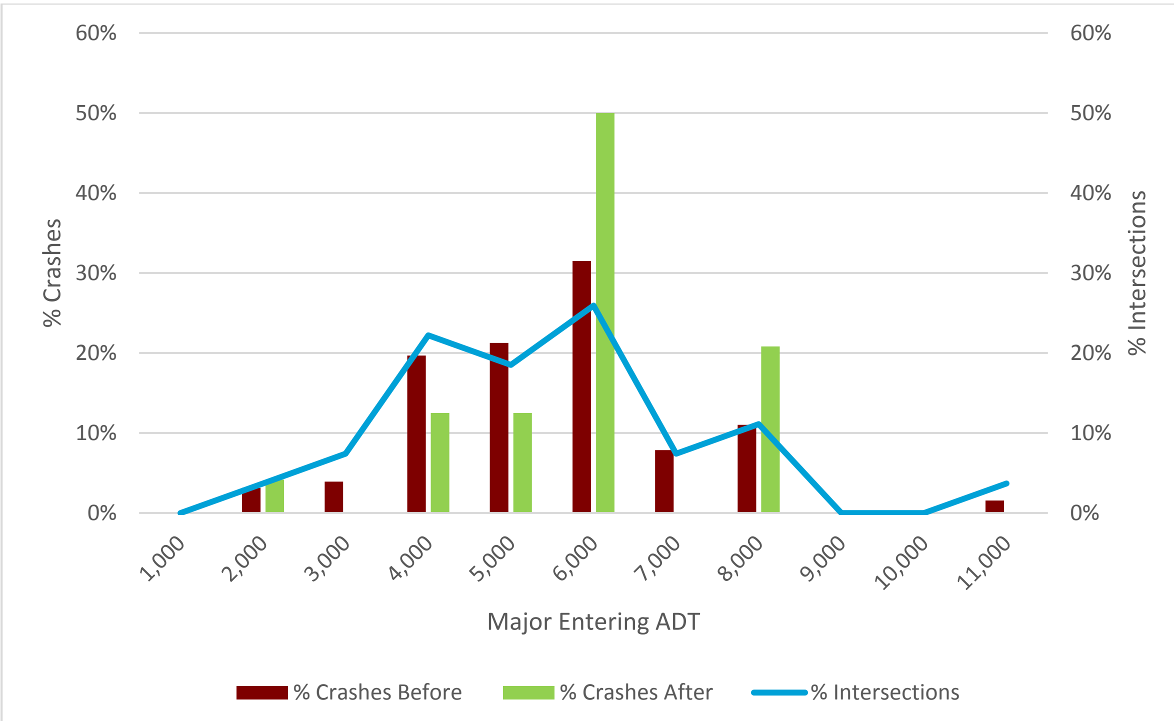


Figure C.1 [RICWS Locations]

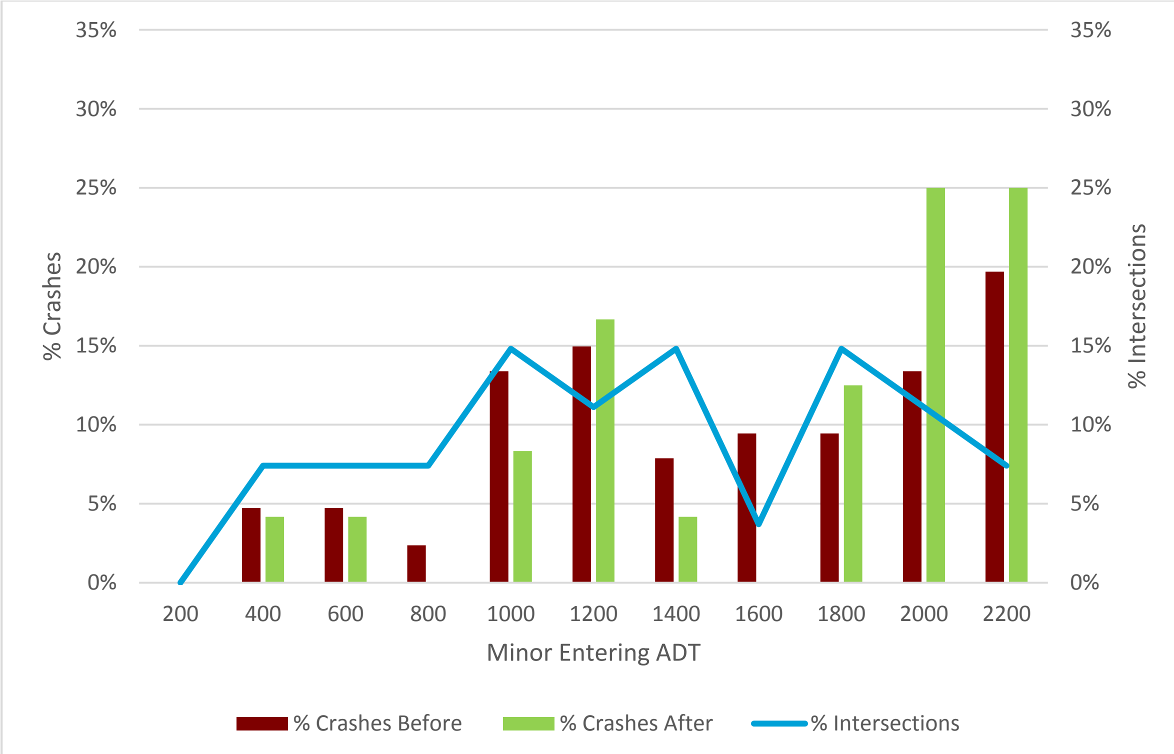


Figure C.2 [RICWS Locations]

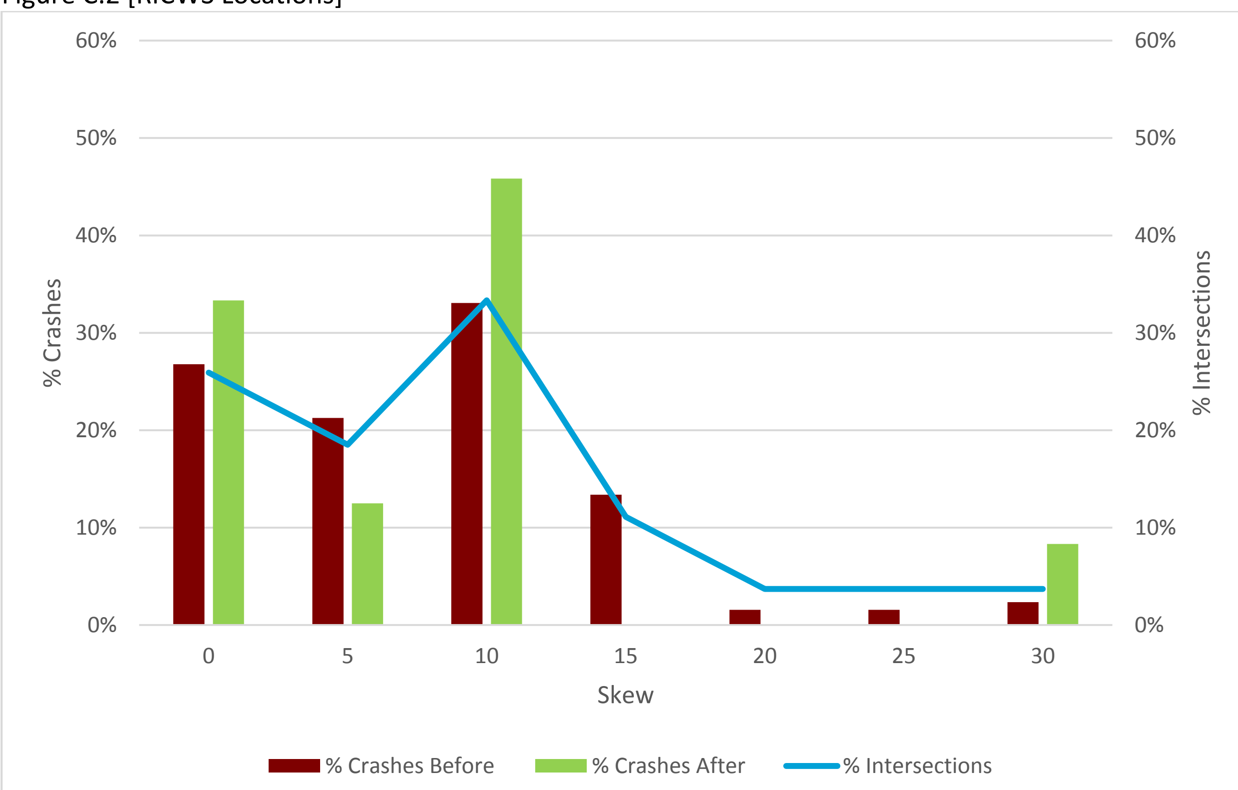


Figure C.3 [RICWS Locations]

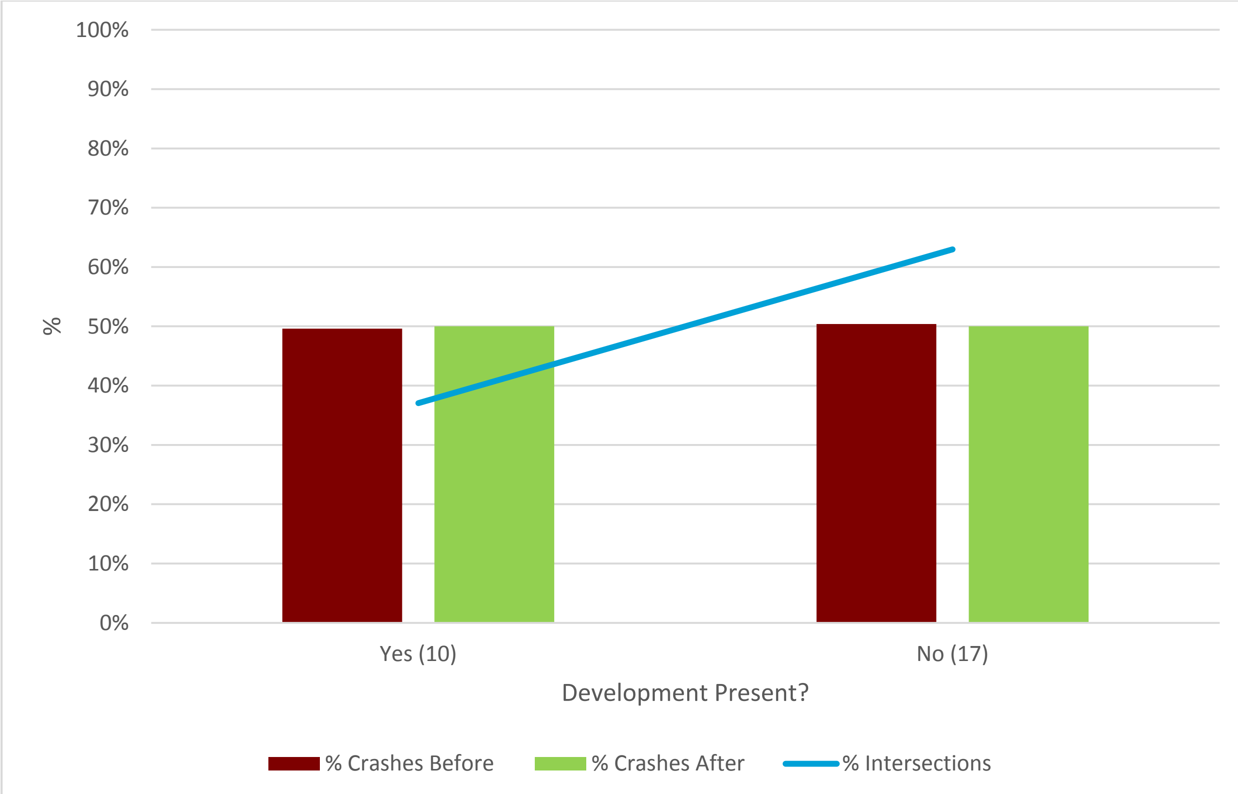


Figure C.4 [RICWS Locations]

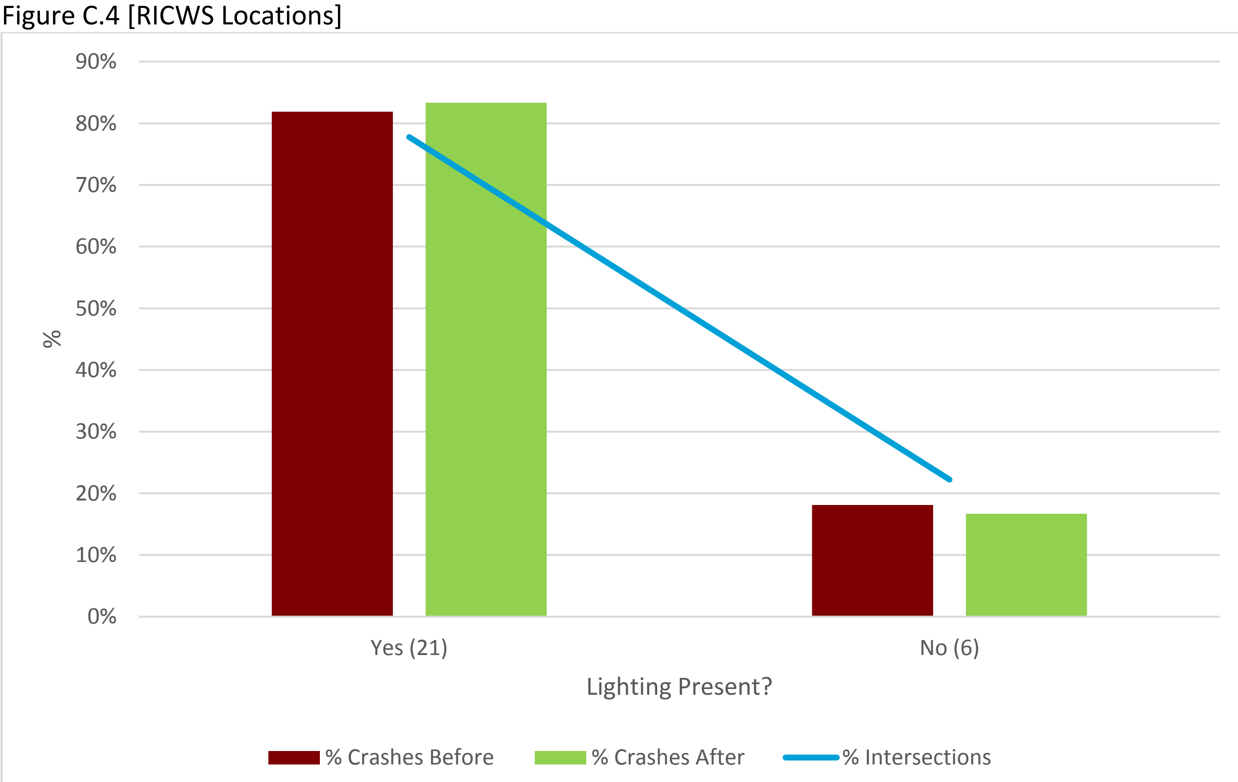


Figure C.5 [RICWS Locations]

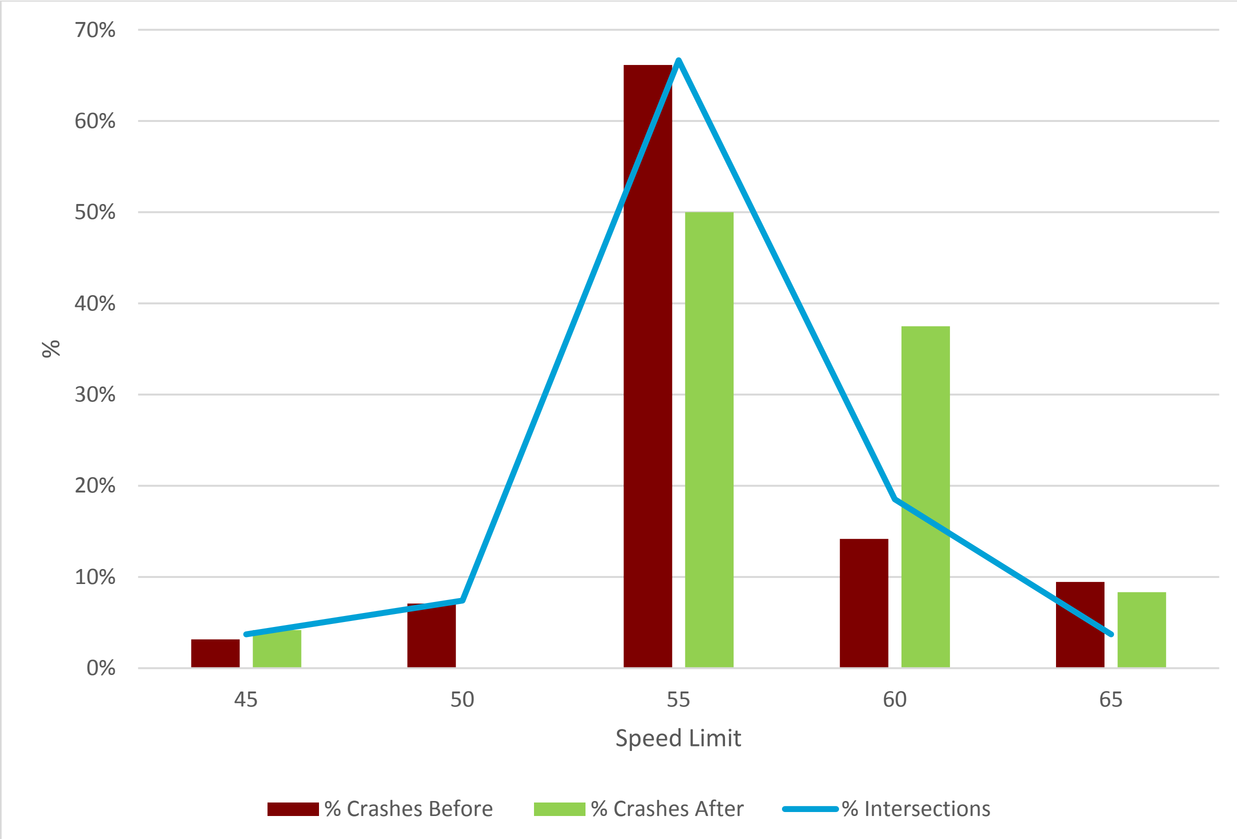


Figure C.6 [RICWS Locations]

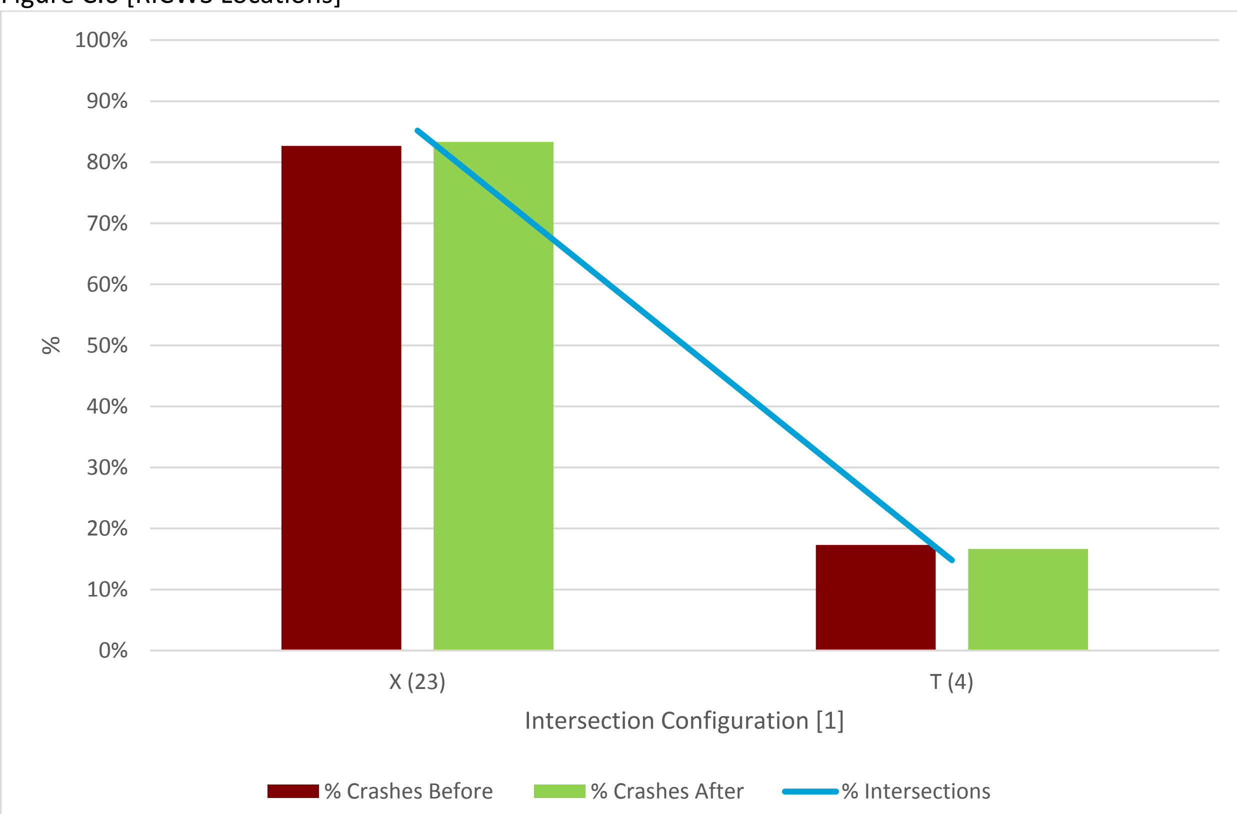


Figure C.7 [RICWS Locations]

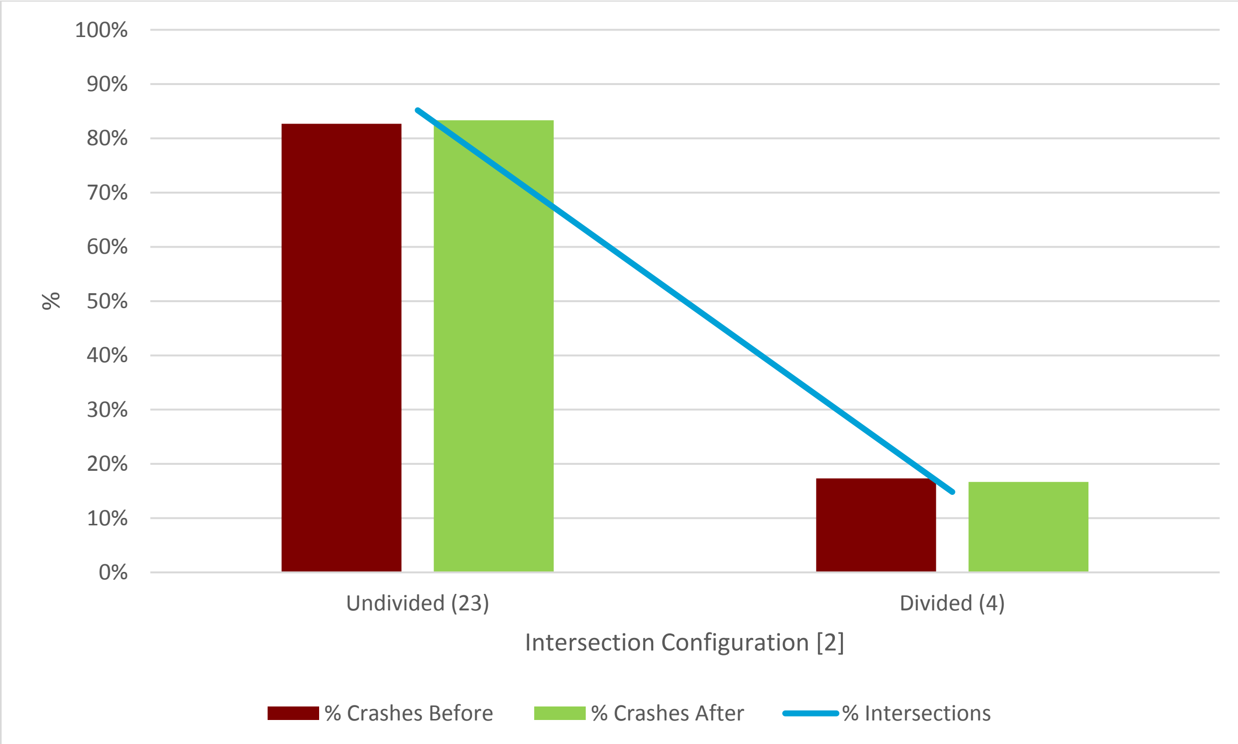


Figure C.8 [RICWS Locations]

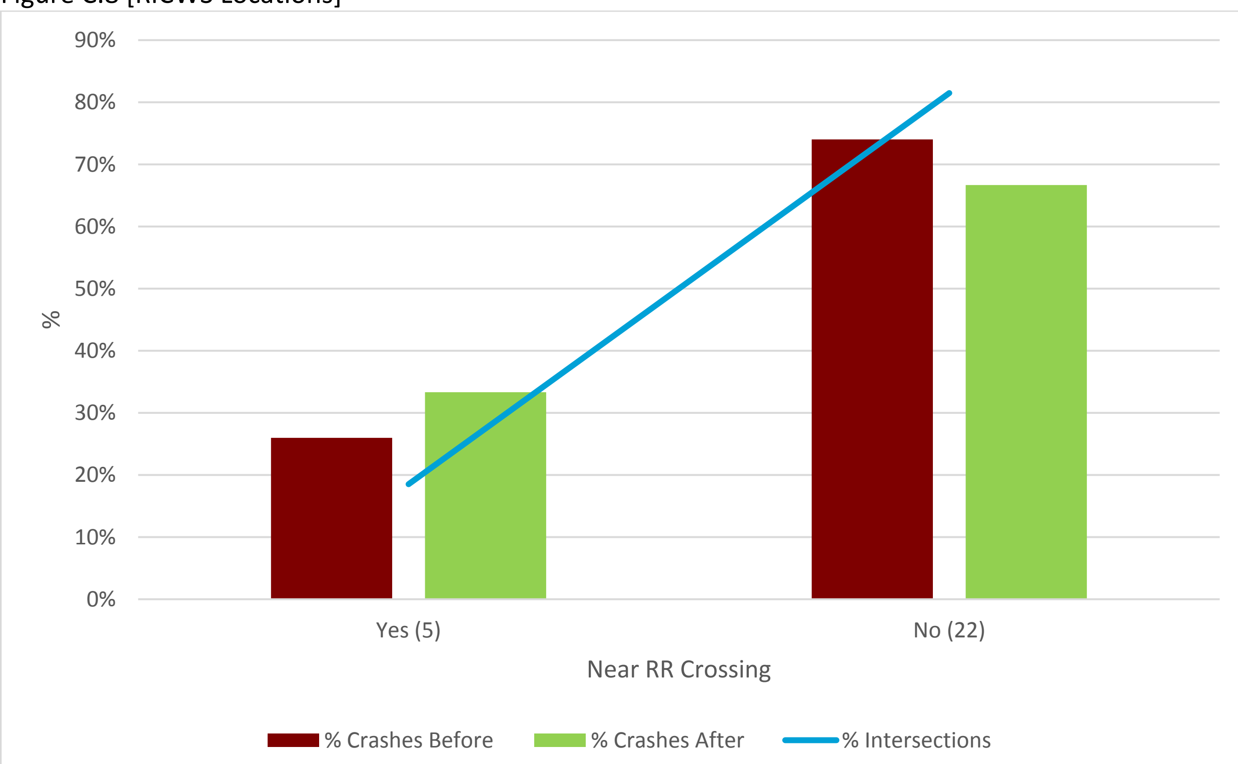


Figure C.9 [RICWS Locations]

Control Site Locations

Figure C.10 – Major Entering ADT

Crashes in the “Before” condition were basically proportional to the distribution of the daily traffic volumes on the major entering legs. In the “After” condition crashes decreased at locations with volumes under 5,000 vehicles per day and over 8,000 vehicles per day and increased at volumes between these values. This trend is different than what was observed at the RICWS sites where crashes decreased at lower volume intersections and increased at higher volume intersections.

Figure C.11 – Minor Entering ADT

Crashes in the “Before” condition were under represented at low volumes (600 vehicles per day and less) and over represented at higher volumes (800 vehicles per day and greater). In the “After” condition crashes decreased in some volume categories and increased in others, with no apparent pattern. This trend is different than what was observed at the RICWS sites where crashes decreased at lower volume intersections and increased at higher volume intersections.

Figure C.12 – Skew

Crashes in the “Before” condition were basically proportional to the distribution of the skew angles at the selected intersections. In the “After” condition there was not a consistent pattern - crashes decreased at intersections with little or no skew (5 degrees or less) and at intersections with moderate skew (15 and 20 degrees). However, crashes increased at intersections with a skew angle of 10 degrees and more than 25 degrees. This pattern has only one similarity to the RICWS sites, the majority of the crash reduction occurred at sites with skew angles between 15 and 25 degrees.

Figure C.13 – Development Present

Crashes in the “Before” condition were proportional to the presence of development across the control sites. In the “After” condition crashes decreased at sites with development and increased at sites without development. This trend is different than what was observed at the RICWS sites, where there was no change in crashes at intersections either with or without development present.

Figure C.14 – Lighting Present

Crashes in the “Before” condition were proportional to presence of lighting across the control sites. In the “After” condition crashes increased at sites with lighting and decreased at sites without. This trend is different than what was observed at the RICWS sites, where there was no change in crashes at either sites with or without lighting.

Figure C.15 Speed Limit

Crashes in the “Before” condition were proportional to the distribution of the intersections by speed limit. In the “After” condition crashes increased at sites with 55 and 60 mile per hour speed limits and decreased at sites with a 65 Mile per hour limit. This trend is different than what was observed at the RICWS sites where crashes decreased at sites with a 55 mile per hour limit and were flat at sites with a 65 mile per hour limit.

Figure C.16 – Intersection Configuration [1] (Cross or Tee)

Crashes in the “Before” condition were over represented at sites with four approaching legs and under represented at sites with three. In the “After” condition crashes decreased at sites with four legs and increased at sites with three legs. This trend is different than what was observed at the RICWS sites where there was no change in crashes at either sites with four or three approaching legs.

Figure C. 17 – Intersection Configuration [2] (Undivided or Divided)

Crashes in the "Before" condition were proportional to the distribution of the intersections based on whether or not they were divided. In the "After" condition crashes increased at undivided intersections and decreased at divided intersections. This trend is different than what was observed at the RICWS sites where there was no change in crashes at either undivided or divided sites.

Figure C.18 – Near Railroad Crossing

Crashes in the "Before" condition were proportional to the distribution of intersections based on the presence of a nearby railroad crossing. In the "After" condition crashes did not change at either category of intersection. This trend is different than what was observed at the RICWS sites where crashes increased at sites with a nearby railroad crossing and decreased at sites without.

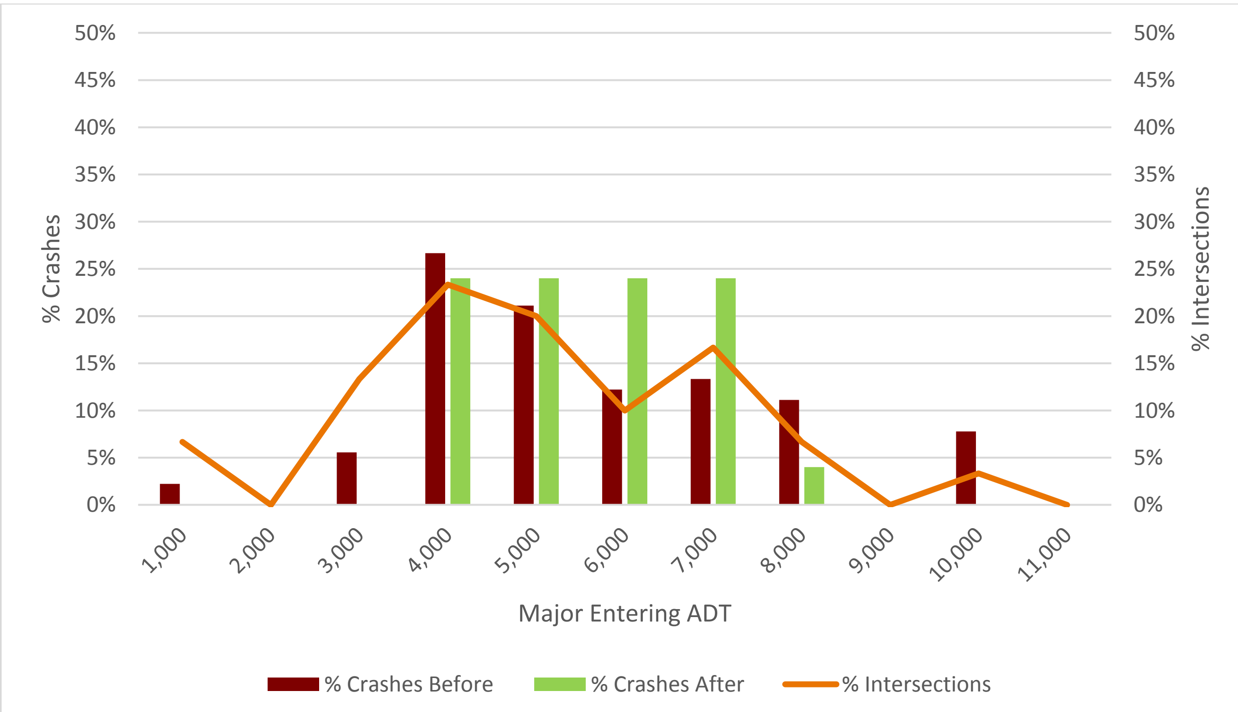


Figure C.10 [Control Sites]

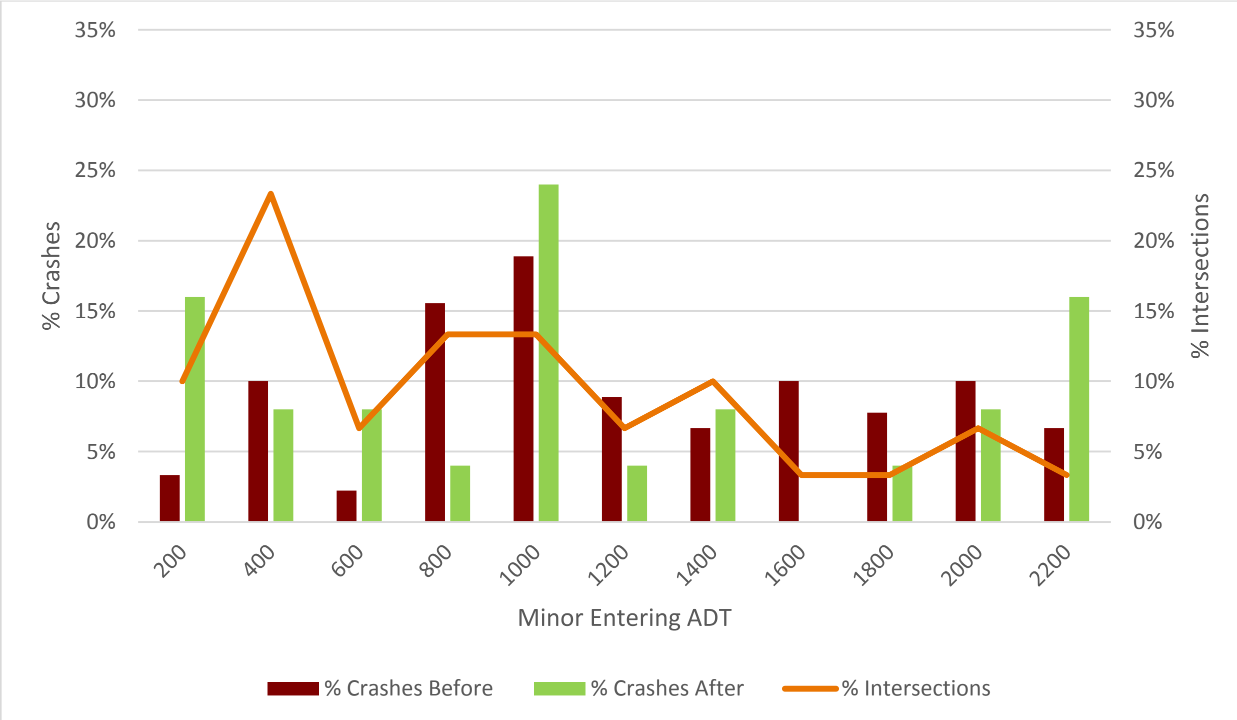
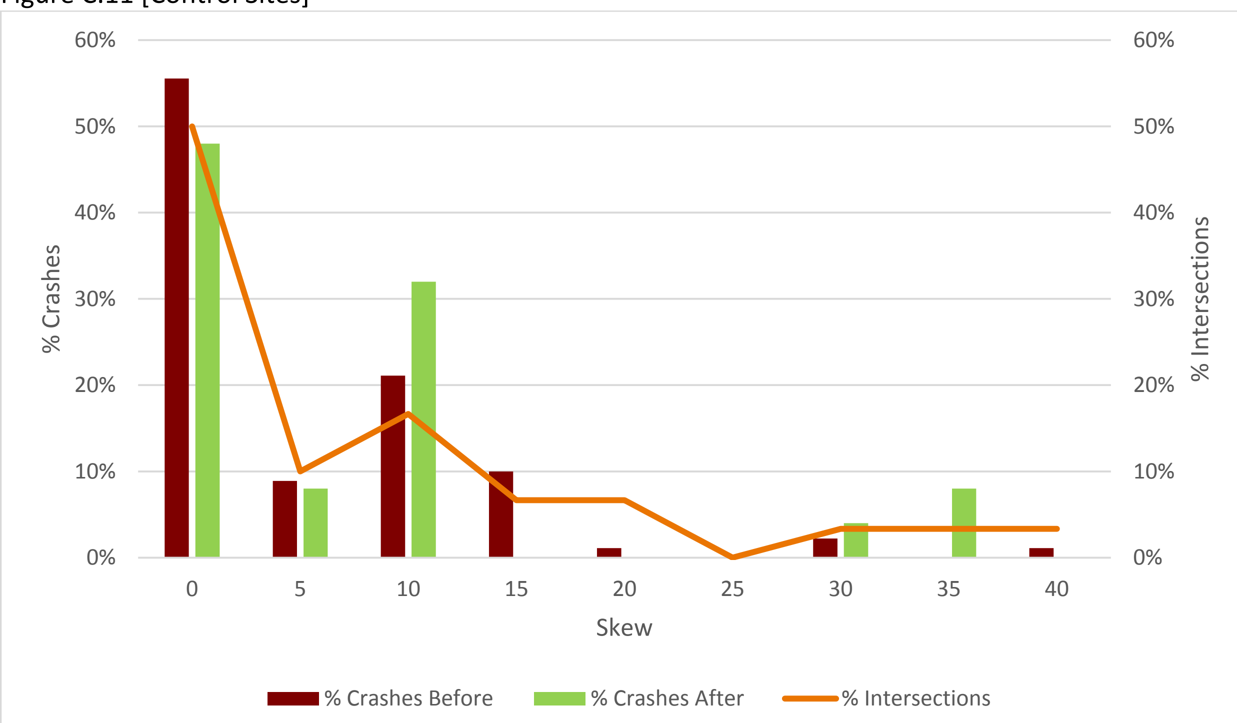


Figure C.11 [Control Sites]



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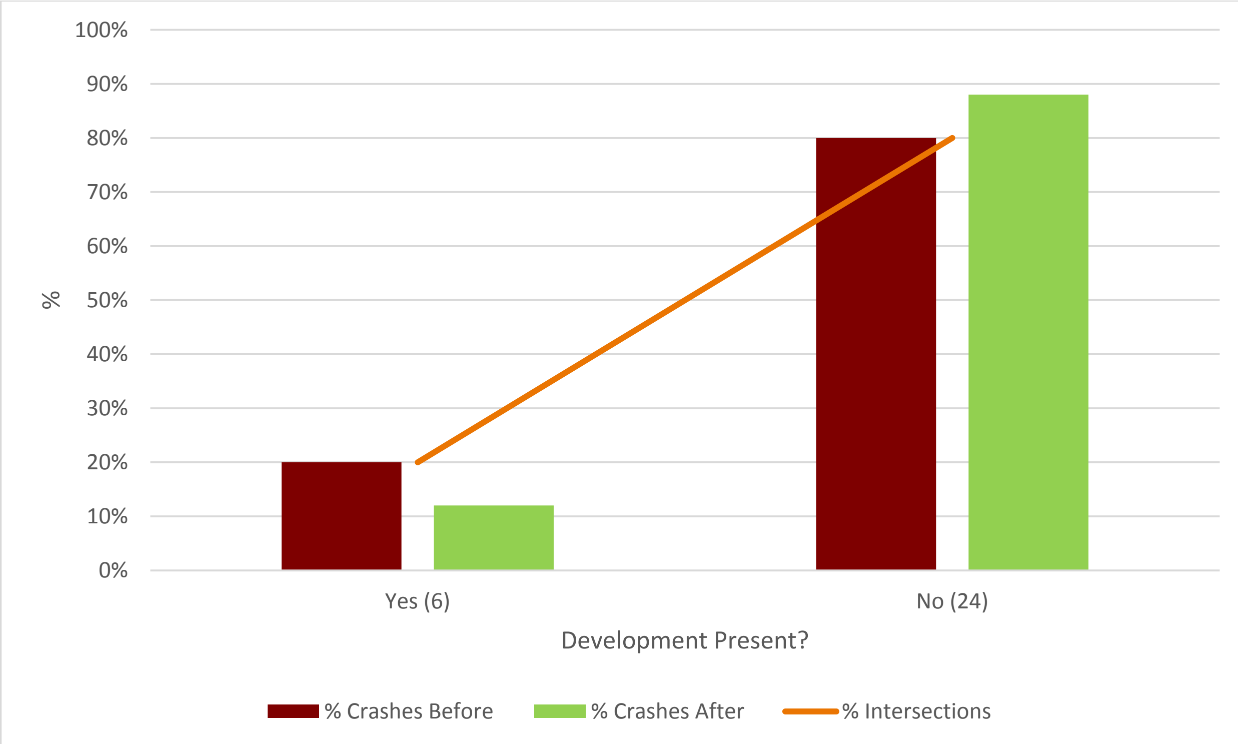
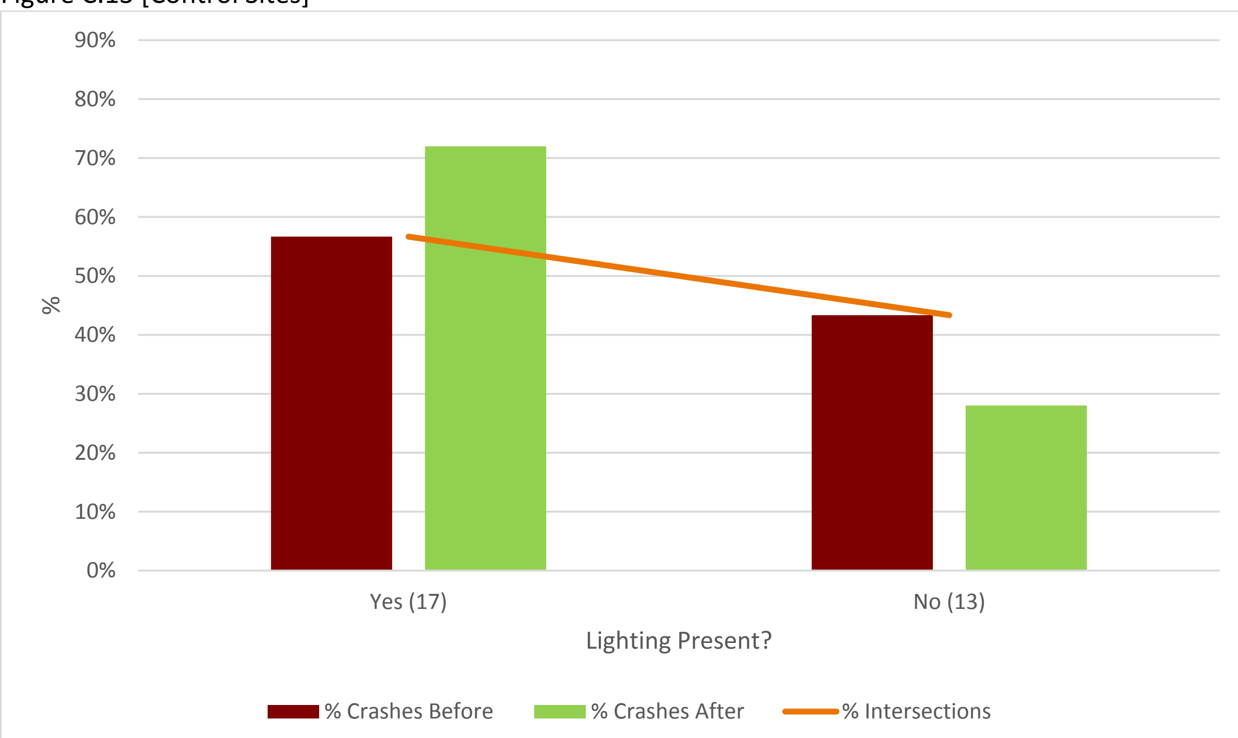


Figure C.13 [Control Sites]



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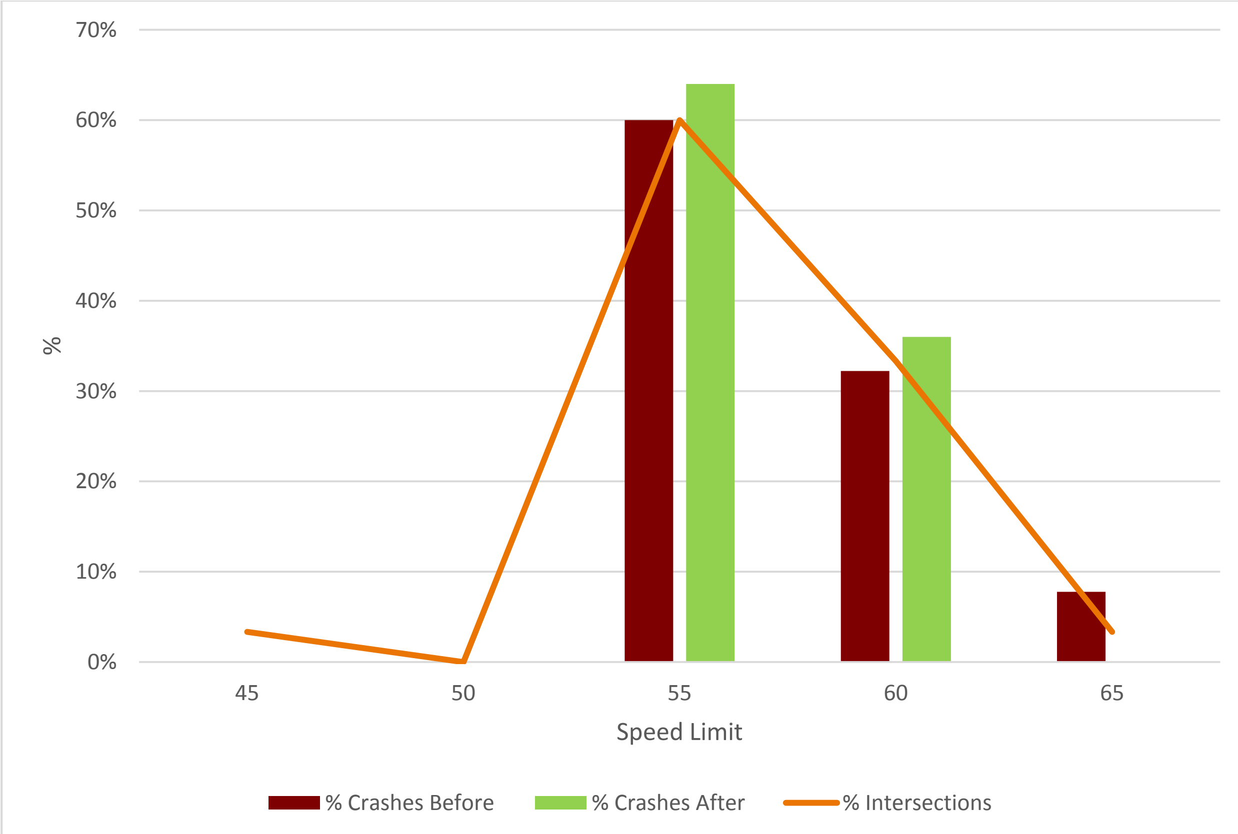

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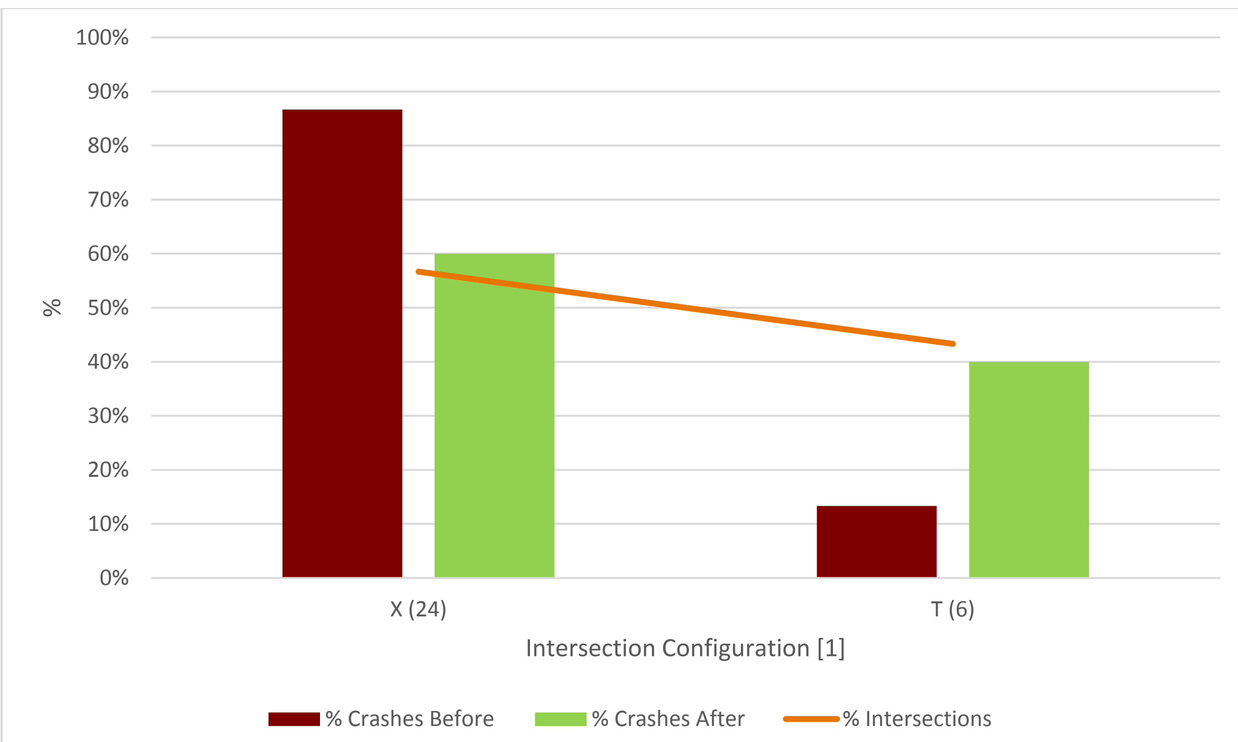

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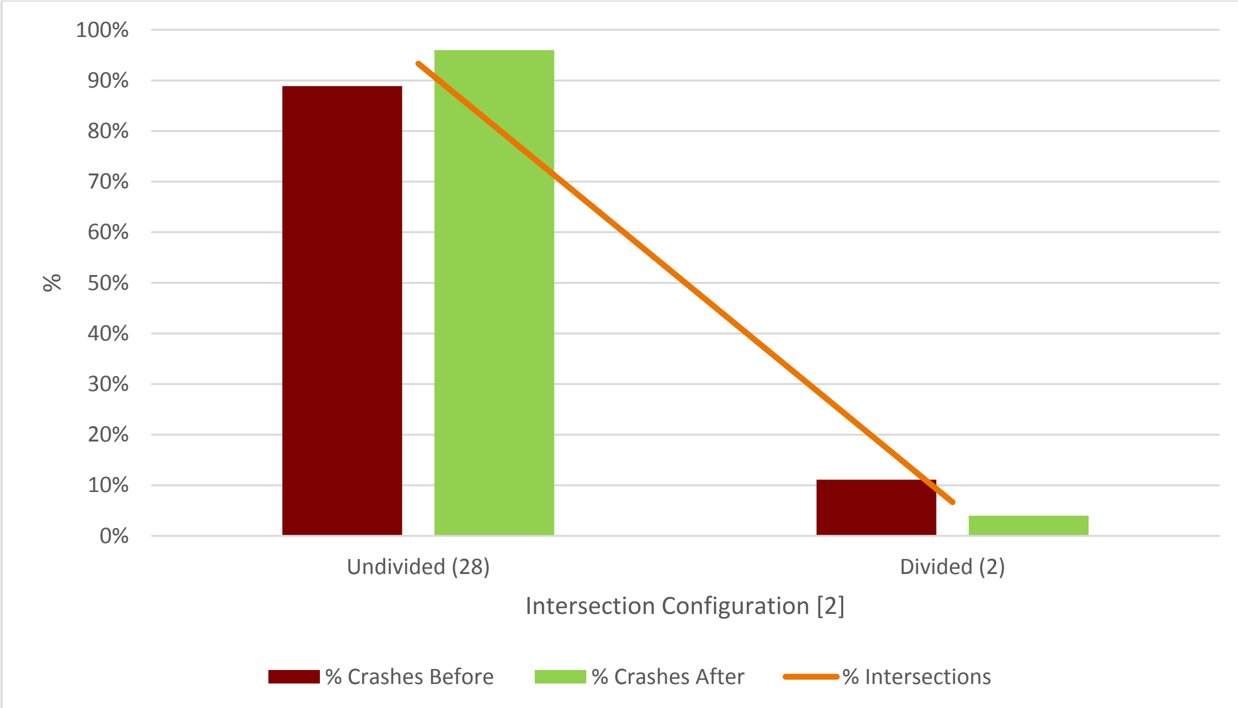

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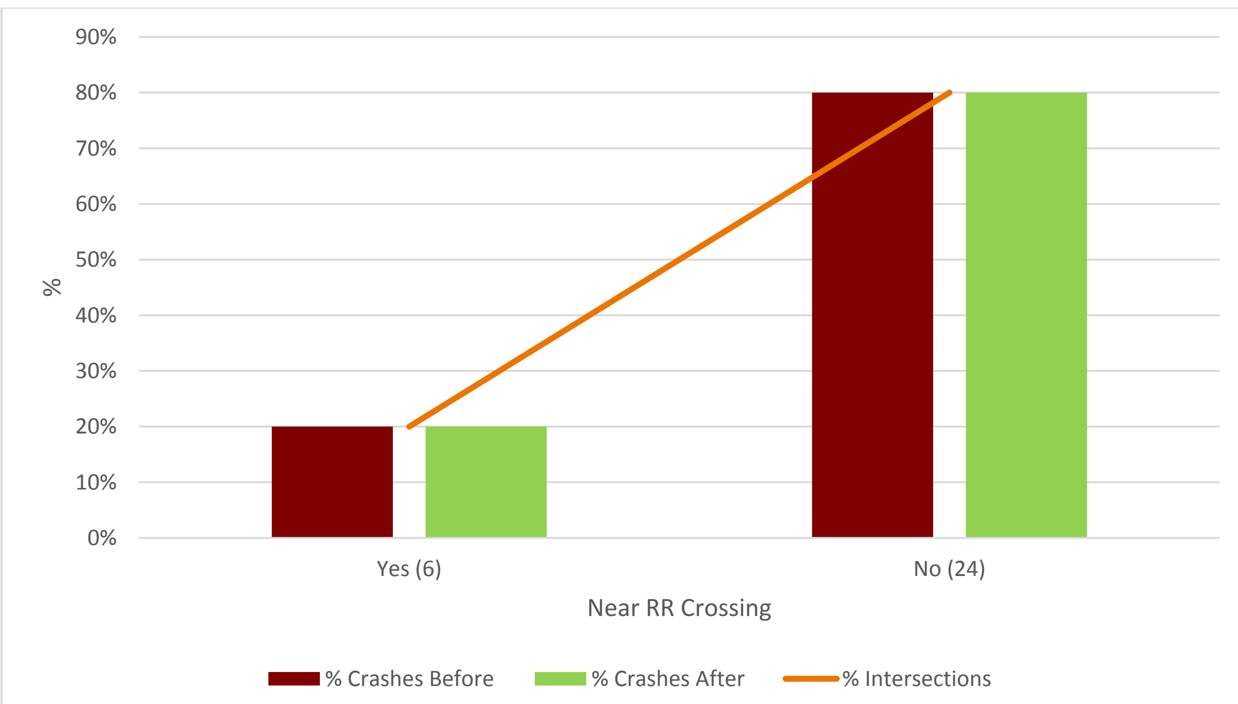

Figure C.18 [Control Sites]