A Study of the Traffic Safety at

Reduced Conflict Intersections

In Minnesota

(Photograph courtesy of Bolton and Menk, Inc. 2013. Cologne, MN)

Office of Traffic, Safety and Technology
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Executive Summary

In 2010, the Minnesota Department of Transportation installed the first Reduced Conflict Intersection (RCI)[1] in the City of Willmar. Since 2010, seven more were constructed, with more planned. The RCI concept is gaining popularity in several states, including Maryland, Mississippi, Missouri, North Carolina, and Wisconsin. This report includes findings from a safety performance evaluation of Minnesota Reduced Conflict Intersections. This evaluation found:

- A 100% reduction of fatal and serious injury right-angle crashes
- A 77% reduction of all severity right-angle crashes
- A 50% reduction of injury crashes

Additionally, compared to their untreated counterparts, Reduced Conflict Intersections showed significantly fewer severe[2] right-angle crashes and severe crashes, and the crashes observed at an RCI intersection were of lower crash severity than their untreated counterparts.

[1] Reduced Conflict Intersections are also referred to as J-Turns, Restricted Crossing U-Turns, RCUTs
[2] Severe crashes are crashes that result in one or more person killed and or seriously injured.

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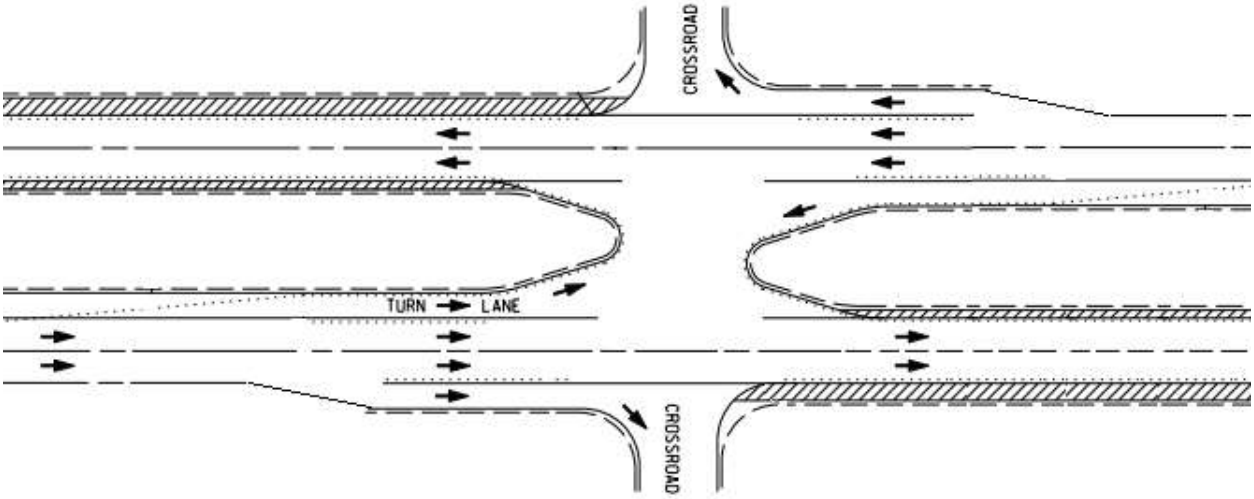
Introduction: Reduced Conflict Intersections

The Reduced Conflict Intersection (RCI) is an at-grade intersection on multi-lane high-speed[3] expressways. Standard at-grade intersections on multi-lane high-speed expressways typically allow drivers to turn left or right from the minor roadway onto the expressway or travel straight through the intersection by crossing all four-expressway lanes.

Historically, these intersections have more severe right angle crashes than most other intersections. Options such as traffic signals offer no benefit and are associated with an increased number of crashes. Other options, such as grade separation, are costly, which limits the application.

Figure 1: *An illustration of a standard at-grade expressway intersection. All movements from the major road (going left and right) and the minor road (going up and down) are allowed.*



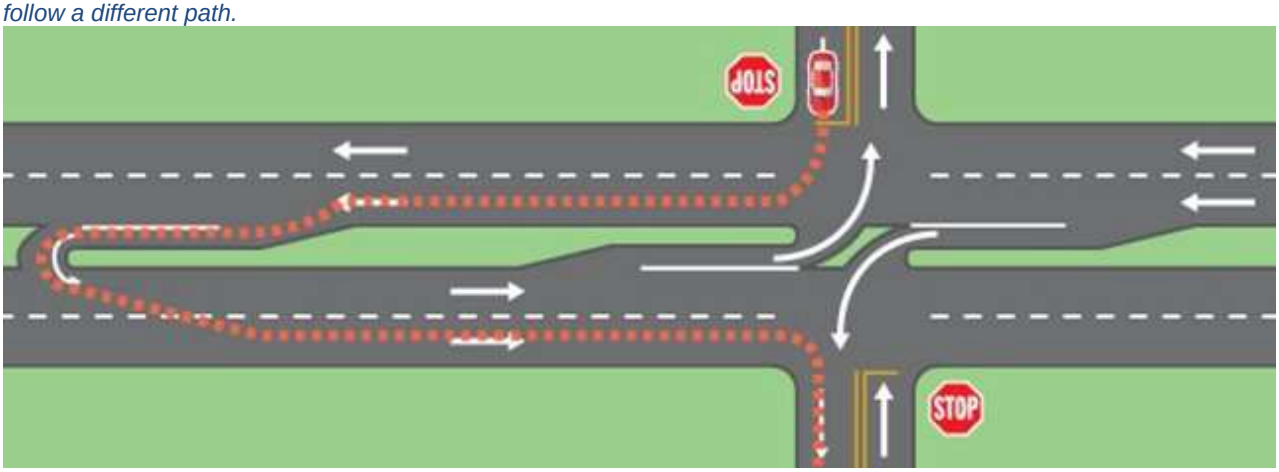
Source: Modified from the Minnesota Road Design Manual, September 2016.

The Reduced Conflict Intersection is a newer treatment where minor road drivers who want to continue through the intersection and along the minor road or who want to turn left, will now take a different path. These drivers will turn right onto the major road, drive to a designated U-turn, turn around, and then turn right onto the minor road. There are no changes for the expressway drivers. See Figure 2.

Drivers on the minor-road no longer expose themselves to the most common and severest crash type -- the right-angle crash (also called the T-bone, broadside, or perpendicular). Minor road drivers now complete a series of maneuvers that reduce the probability of a severe crash and reduce the risk of death or serious injury.

[3] High-speed indicates a posted speed limit of 55 miles per hour or more.

Figure 2: *An illustration of a Reduced Conflict Intersection. All movements from the major road (going left and right) are unaltered. The minor-road (going up and down) drivers wanting to go through or left, are still allowed, but now follow a different path.*



Source: "Mike on Traffic." http://www.mikeontraffic.com/restricted-crossing-u-turn-rcut-intersections/ September, 2016.

At-grade intersections on expressways continue to be problematic for transportation officials, and given the future financial constraints for transportation funding in Minnesota, the RCI will play an important role in solving these issues. The RCI is significantly less costly and take less time to construct than traditional interchanges.

More information available at: http://www.dot.state.mn.us/roadwork/rci/

Common Concerns

These are common concerns from the motoring public:

With more traffic, and the increased exposure to through-traffic, will rear-end crashes increase?

> Answer: While this appears to be a possible risk, the crash data has not seemed to support that it will happen. The increased number of crashes was tested for statistical significance against a comparison group, and found to not be significant.
>
> An important factor that is considered is the severity of the crash types. Rear-end crashes tend to be low-severity with few injuries, and the most common crash type in Minnesota. Right-angle crashes are more likely to be deadly and result in serious injuries, and are the most common fatal and serious-injury crash in Minnesota. For a further analysis of the after crashes, see Appendix B: "Reviewing and Analyzing After Crashes".

Now that I need to travel with traffic and merge over, will sideswipe crashes become more problematic?

> Answer: While this also appears to be a possible risk, the crash data seems to be inconclusive that it will happen directly as a result of the RCI. The number of crashes before was 4 crashes, and 8 crashes after. The increase has shown to be statistically insignificant.
>
> Sideswipe Crashes tend to be low-severity and infrequent crashes. For a further analysis of the after crashes, see the see Appendix B: "Reviewing and Analyzing After Crashes".

How will heavy/large vehicles use these? Can they use these?

> Answer: RCIs are designed to accommodate all legal vehicles, including semi tractor-trailers, firetrucks, school buses, etc.
>
> MnDOT has conducted studies trying to address and understand these issues and to help alleviate these concerns.
>
> The first report examines the traffic safety and crashes after installation for heavy commercial vehicles and agricultural equipment. The study, conducted by Iowa State, examined numerous locations across the country. Though a small sample size, it found no increase in the number of crashes involving heavy commercial vehicles or agricultural equipment. The report, titled *"EVALUATION OF THE IMPACT OF REDUCED CONFLICT INTERSECTIONS ON TRUCK AND LARGE*

AGRICULTURAL VEHICLE CRASHES ", can be found online at: http://www.dot.state.mn.us/roadwork/rci/docs/rci-study.pdf

The other major study regarding this issue has been recently released (also by Iowa State) and is titled, "*EVALUATION OF TRUCK AND AGRICULTURAL VEHICLE BEHAVIOR AT REDUCED CONFLICT INTERSECTIONS".* The report examined three sites with RCIs and three control sites without RCIs. The evaluation examined exposure time of heavy commercial and agricultural vehicles using the intersections, the number of conflicts between these vehicles and passenger cars, travel times, wait times, and also near-misses between vehicles. The report found no evidence that validated concerns expressed about large vehicle operations at RCIs.

The report can be read online at: http://www.dot.state.mn.us/roadwork/rci/docs/truckandagbehaviorfinalreport.pdf

How to Read This Report

Crash Records Data

These analyses used Minnesota crash data to assess crash frequency and severity before the construction of a Reduced Conflict Intersection to after construction. These analyses included eight installation sights against the crash records of 34 comparable control sights without an RCI. These analyses excluded data from the RCI construction year.

A *site-year* is a way to quantify the amount of exposure to traffic by site. For example, a site with three years of data would have three site-years and another with four years would have four site-years. Combined, the two sites have seven site-years. This study includes 19 pre-construction site-years and 19 post construction site-years. The analyses excluded crash data from the RCI construction year.

Injury Severity of Crash

Crash severity means the greatest level of injury sustained by all persons involved in a crash. One fatal crash may include one or more person killed and any number of persons who sustained other levels of injury, but it is a *K Injury Crash.*

K-Injury Crash: One or more person involved in the crash died due to injuries sustained in the crash

A-Injury Crash: One or more person involved in the crash sustained a serious life-altering injury due to the crash

B-InjuryCrash: One or more person involved in the crash sustained moderate injury, e.g. broken bones in the crash

C-Injury Crash: One or more person involved in the crash sustained a minor injury in the crash

PDO-Injury Crash: No person involved in the crash sustained an injury and only vehicular or property damage occurred

Crash Type

Crash type means the manner 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: When two vehicles traveling 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.

Run-off-the-road crash: When a single vehicle departs the roadway surface and collides with a roadside object or rolls over. This includes both departing right and left from the roadway surface. This type of crash is among the highest risk of death and serious injury.

Head-On: 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.

Sideswipe crash: Two vehicles collide off-center and scrape the sides of both vehicles. Sideswipe includes vehicles heading in the same direction or vehicles traveling in opposing directions. This type of crash is typically at lower risk of death and serious injury.

Left-Turn-Into-Traffic: A left turning vehicle, from either the major or the minor road collides with a vehicle crossing its intended path. This type of crash typically results in a right-angle crash or a sideswipe crash.

Multi-vehicle crash: Involves two or more motor vehicles.

Methodology

Study Locations

This study includes all eight Reduced Conflict Intersection sites in Minnesota. These analyses include a comparison of pre-construction and post construction crash records.

Table 1: Reduced Conflict Intersection Locations

CITY	COUNTY	INTERSECTION
Willmar	Kandiyohi	Old TH 71/ CSAH 24-Golf Course Road
Cotton	St. Louis	US 53 / CSAH 52
Cologne	Carver	US 212 / MN 284
Ham Lake	Anoka	MN 65/ 169th Ave
Vermillion	Dakota	US 52/ CSAH 66
Lake Elmo	Washington	MN 36/ Demontreville Trail
St Peter	Nicollet	US 169/ Julien Street
St Peter	Nicollet	US 169/ Dodd Street

Analyses

The Minnesota Department of Transportation is a partner in the Minnesota Zero Deaths Program; therefore, the focus of safety is to reduce roadway fatalities and serious injuries. These analyses focus primarily on how Reduced Conflict Intersections affects fatal and serious injury crashes.

These analyses compare crash data from two time points – pre-construction and post construction. These analyses did not include crash data from the construction year. In order to control for regression to the mean, crash data for treatment sites we compared to the similar, randomly selected intersections.

Treatment sites: indicates intersections with a Reduced Conflict Intersection.

Comparison segments: indicates similar intersections with no Reduced Conflict Intersection.

In order to test our hypotheses, the research team used 2x2 cross tabulation with a Chi-square test. A crosstab analysis is a relatively simple analysis suitable for comparison of four groups, as is the case here; the Chi-square yields the linear-by-linear association test. For these analyses our alpha is set at a p values of 0.05 or lower are statistically significant. This means that changes from pre and post condition of the treatment group compared to the non-treatment group is consistent and profound enough to rule out random fluctuations in crashes (regression to the mean).

Pre-construction Crashes

Crashes included in these analyses took place at or within 250 feet of the intersection. This includes crashes that occurred on the mainline and the minor road.

Table 2: Summary of Pre-construction Crashes within 250 feet of Future Reduced Conflict Intersection Sites

Total Crashes	Site - Years	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity	Total Vehicles Entering
81	19	4	3	22	17	35	134.4 million

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Table 2 highlights crashes that were coded as being "intersection-related."

Table 3: Summary of Pre-construction 'Intersection Relate' Crashes

Total Crashes	Site - Years	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
53	19	4	2	15	10	22

Note. These are all intersection-related crashes recorded at or near the intersection. Crashes are aggregated by crash severity.

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Reduced Conflict Intersections primarily affect right-angle crashes; however, this investigation considered other crash types.

Table 4: Summary of Pre-Construction Crashes by Crash Type

Total Crashes	Site - Years	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	U-Turn Related	Multi-Vehicle
81	19	32	12	13	12	5	7	0	59

Note. These are all crashes recorded at or near the intersection. Crashes are aggregated by crash diagram.

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Table 5: Summary of Pre-Construction 'Intersection Related' Crashes

Total Crashes	Site - Years	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	U-Turn Related	Multi-Vehicle
53	19	31	7	3	4	5	3	0	48

Note. These are all crashes recorded at or near the intersection. Crashes are aggregated by crash diagram.

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Among pre-construction intersection-related crashes, 58% were right-angle crashes. Among the seven fatal and serious injury crashes, 71% were right-angle crashes. (One of these crashes was defined as “Other” since it involved a snowplow performing snow removal operations. However, the vehicles hit at a right-angle to one another). When taking this into account, 71% of the severe crashes were right-angle related.

Post Construction Crashes

The Minnesota Department of Transportation constructed seven Reduced Conflict Intersections over a four year period. Consequently, some RCIs sites have only one year of post construction crash data, and others offer up to five years of crash data. Post construction crash data included all crashes that extended to the new U-turn locations. This ensured that any crashes within the new configuration remained in these analyses.

Table 6: Summary of Post Construction Crashes within 250 feet of Future Reduced Conflict Intersection Sites

Total Crashes After	Site-Years After	K-Severity After	A-Injury Severity After	B-Injury Severity After	C-Injury Severity After	PDO-Injury Severity After	Vehicles Entering
71	**19**	**0**	**1***	**8**	**16**	**46**	**135.1 Million**

Note 1. Crashes are aggregated by crash severity.

Note 2. An A-Injury crash was associated with the Vermillion intersection. After interviewing the responding state trooper, the sideswipe crash appeared to be between the U-turn locations, and had not occurred due to any interaction or vehicles using the intersection.

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016. Traffic volume: The Minnesota Department of Transportation, Traffic Forecasting and Analysis “Traffic Mapping Application”

Table 6 shows crashes coded as “intersection-related” and fell within the designated U-turn locations after the completion of the RCI.

Table 7: Summary of Post Construction ‘Intersection Relate’ Crashes

Total Crashes After	Site-Years After	K-Severity After	A-Injury Severity After	B-Injury Severity After	C-Injury Severity After	PDO-Injury Severity After
45	**19**	**0**	**0**	**5**	**10**	**30**

Note. These are all intersection-related crashes recorded at or near the intersection within the U-turn locations. Crashes are aggregated by crash severity.

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Table 8 shows all crashes at the intersection or within the designated U-turn locations by crash diagram.

Table 8: Summary of Post Construction Crashes by Crash Type

Total Crashes	Site - Years	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	U-Turn Related	Multi-Vehicle
71	19	7	15	19	13	5	8	4*	42

Note. These are all crashes recorded at or near the intersection within the designated U-turn locations. Crashes aggregated by crash diagram.

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

*The U-turn crashes are typically coded as sideswipe, and have been highlighted separately for this analysis.

Table 9 shows all 'intersection-related' crashes that were at the intersection, or within the designated U-turn locations by crash diagram.

Table 9: Summary of Post Construction 'Intersection Related' Crashes

Total Crashes	Site - Years	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	U-Turn Related	Multi-Vehicle
45	19	7	11	11	6	3	3	4	33

Note. These are all intersection-related crashes recorded at or near the intersection within the U-turn locations. Crashes are aggregated by crash diagram.

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

This increase represented a 1.2% increase over the before-condition. Traffic volume was taken from MnDOT's Traffic Forecasting and Analysis "Traffic Mapping Application" and used the most current data available. When traffic counts were not specifically available for a given year, interpolation and extrapolation were used. The Traffic Mapping Application can be found online at:

http://www.dot.state.mn.us/traffic/data/tma.html

Comparing Before and After Analyses

The Reduced Conflict Intersections aim to reduce the number of fatal and serious injury right-angle crashes. Based on the limited after crash data, the RCI is reducing the target crashes (fatal, injury, and right-angle crashes). Table 10 and Table 11 show the aggregated crash data both by the severity of injury, and the diagram of the crashes (the type/configuration of the vehicles at impact), respectively for all crashes.

Table 10: Pre and Post Construction Crashes by Injury Severity

Description	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	**81**	**4**	**3**	**22**	**17**	**35**
After	**71**	**0**	**1**	**8**	**16**	**46**
Reduction/ Increase (%)	**-12.3%**	**-100%**	**-66.7%**	**-63.6%**	**-5.9%**	**+31.4%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Table 11: Pre and Post Construction Crashes by Crash Type

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	U-Turn Related	Multi-Vehicle
Before	**32**	**12**	**13**	**12**	**5**	**7**	**0**	**59**
After	**7**	**15**	**19**	**13**	**5**	**8**	**4***	**42**
Reduction/ Increase (%)	**-78.1%**	**+25.0%**	**+46.2%**	**+8.3%**	**0.0%**	**14.3%**	**+100%**	**-28.8%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

*The U-turn crashes are coded originally as two sideswipes, one rear-end, and one other and have been highlighted separately for this analysis.

Table 12 and Table 13 show the aggregated crash data both by the severity of injury, and the diagram of the crashes (the type/configuration of the vehicles at impact); respectively for all crashes that have been designated as intersection-related.

Table 12: Pre and Post Construction Intersection-related Crashes by Injury Severity

Description	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	**53**	**4**	**2**	**15**	**10**	**22**
After	**45**	**0**	**0**	**5**	**10**	**30**
Reduction/ Increase (%)	**-15.1%**	**-100%**	**-100%**	**-66.7%**	**0.0%**	**36.4%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Table 12a: *Crash data from the eight(8) sites with RCIs before and after construction with intersection-related crashes. Crashes are aggregated by crash diagram. The u-turn crashes have been placed into their original diagram codes. This is for statistical analysis purposes*

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle
Before	**31**	**7**	**3**	**4**	**5**	**3**	**48**
After	**7**	**12**	**11**	**8**	**3**	**4**	**33**
Reduction/ Increase (%)	**-77.4%**	**+71.4%**	**+267%**	**+100.0%**	**-40.0%**	**+33.3%**	**-31.3%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

When aggregated, the crash data for intersection-related crashes obtained has shown that RCIs have reduced all crashes by 15%. Right-angle crashes have been reduced by 77%. Most importantly, they have reduced fatal and injury crashes by over 50% (when comparing injury crashes with severity K, A, B, and C) and the most severe crashes (Fatal and A-injury) by 100%.

The target crash of the Reduced Conflict Intersection, which is the Fatal and Serious-Injury Right-angle Crash, has been reduced by 100%.

Comparative Site Analysis

The analysis completed above is defined as a simple before-after analysis. One of the weaknesses of the before-after analysis is that there is often no direct way to know if the crash frequency changed due to the changed site conditions, or from some other external factor. One way to check for this is to use a comparative group of similar intersections and to see how they performed during a similar time period. This comparative group can compensate for larger changes that have impacted the system as a whole, such as driver demographics, economic conditions, traffic growth, vehicle safety technology, etc.

To find a set of similar intersections, it was decided to use a measure of risk that has been defined in the 2016 Minnesota District Safety Plans. A data-driven process was used to develop the District Safety Plans, and it was found that six factors had an increased prevalence for risk of fatal and serious-injury right-angle crashes. These factors were:

Skew: Intersections where one or more of the minor roads was skewed greater than 10 degrees from perpendicular to the major road received a star (★).

On/Near Curve: Intersections that were on or near a horizontal curve on the major road received a star (★).

Adjacent Development: If one of the intersection quadrants had some type of commercial development (gas stations, bars, churches, businesses) the intersection received a star (★).

Previous Stop: If a driver on one of the minor road approaches had the possibility of travelling greater than 5 miles without needing to stop at a stop sign, there seemed to be increased risk once getting to the intersection. This received a star (★).

Volume Cross Product: This measure was found by taking the average of the major road and multiplying by the average of the minor road. An intersection with an average 10,000 vehicles/day on the major road, and an average of 700 vehicles/day on the minor road, would have a volume cross product of 7,000,000. Intersections with a volume cross product greater than six million (6,000,000) received a star (★).

Severe RA (Right-Angle) Density: Intersections that had a severe (K or A-Severity) right-angle crash density (number of crashes/number of years) above 0.022 within the crash history window (2009-2013) received a star (★).

Based on these characteristics, the treatment sites had the following risk characteristics.

Site Name	Cross Product	Cross Product	Skew	On/Near Curve	Development	"Before" Severe RA Density	Severe RA Density Risk	Previous STOP (>5mi)	Total Stars
Willmar	20,790,000	★	★	★	★	0.4	★		★★★★★
Cologne	32,700,000	★	★	★	★	0.6	★	★	★★★★★★
Cotton	5,060,000			★	★	0.3	★	★	★★★★
Ham Lake	43,500,000	★			★	0.6	★		★★★
Lake Elmo	39,937,500	★				0.1	★		★★
Vermillion	43,540,000	★	★			0.3	★	★	★★★★
St Peter/ Julien	67,875,000	★	★	★	★	0			★★★★
St Peter/ Dodd	54,020,000	★	★	★	★	0			★★★★

With most sites having 3 or more stars, the comparative group was selected to be similar to this. Using the 2016 District Safety Plans, 489 multi-lane at-grade intersections were reviewed. Only 52 sites were found to have 4 or more stars. After reviewing intersections and removing sites that would not be similar for various reasons (signalized, recent major construction, and other), a total of 34 sites were selected based on similar risk and geometric characteristics. The 34 sites are in the chart below.

Site Name	Highway	Cross Product	Cross Product	Skew	On/Near Curve	Development	Severe RA Density Risk	Previous STOP (>5mi)	Total Stars
HATTRICK AV CSAH146M104/EVLTH	53	7,290,000	★		★	★	★	★	★★★★★
CSAH 25 LTT 740 RT/N WILLMAR	71	19,520,325	★	★	★	★		★	★★★★★
N JCT TH 65/NASHWAUK	169	6,510,000	★	★	★	★		★	★★★★★
CSAH 13	169	13,072,000	★	★		★		★	★★★★
W JCT CSAH10(OLD87)/BCKRCO	10	12,895,000	★	★	★		★		★★★★
190TH ST CSAH11	169	8,554,000	★	★	★	★		★	★★★★★
CSAH 7 LTCR 885 RT/TWIG	53	6,762,000	★	★	★	★		★	★★★★★
CSAH 16 LT1STST/KEEWATIN	169	6,000,000	★	★	★			★	★★★★
STEVENS RDCSAH 23/N OFONAMIA	169	6,630,000	★		★	★		★	★★★★
TH 228/LUCE	10	6,153,250	★	★	★			★	★★★★
CSAH 23/E LYON ST	23	12,787,500	★	★	★	★			★★★★
CSAH 18/KELLOGG	61	10,725,000	★	★	★	★			★★★★
CSAH 36 LTT 188/2MI STH 23	169	23,200,000	★	★				★	★★★
CSAH 23/67 S SARATOGA ST	23	15,207,500	★	★	★				★★★
CSAH 5 LT/N SIDE HIBBING	169	14,685,000	★		★			★	★★★
W JCT TH 194 CR 898RT M84LT	53	37,713,000	★	★		★		★	★★★★
CSAH 14/MORRISON CO	10	8,679,250	★	★	★			★	★★★★
N JCT CSAH16LT CR957RT	53	8,550,000	★	★		★		★	★★★★
CR 55 & T154	65	9,450,000	★	★	★	★			★★★★
CSAH 68 RTT 641 LT/N ZUMBRTA	52	17,735,250	★	★	★	★			★★★★
21ST AVE M822LT T730 RT/ROCH	14	24,989,250	★		★				★★
CSAH 6 RTCSAH138LT/NROCKVL	23	14,550,000	★		★				★★
CSAH 17/EOF EAGLELAKE	14	14,206,500	★		★				★★
CSAH 7/1.3MIW MARSHALL	23	11,490,000	★		★				★★
TH 42/S OFKELLOGG	61	9,225,375	★					★	★★
S JCT MNTH27/ONAMIA	169	16,385,000	★		★	★		★	★★★★
CSAH 9 LTT RDRT/WOF BEMIDJI	2	13,916,700	★	★		★		★	★★★★
TH 19 LT M330/W SIDE RED WING	61	38,463,600	★		★	★		★	★★★★
WASHINGTNAV CSAH16RT/CLOQUET	33	34,743,750	★	★	★	★			★★★★
CSAH 21 RT/1 MI N GR RAPIDS	169	11,685,000	★	★		★		★	★★★★
CSAH 36 LT/N OF MILACA	169	14,335,000	★	★	★	★		★	★★★★★
S JCT CSAH16RT	53	54,265,500	★		★	★		★	★★★★
CSAH 18 RTTREASUREISLAND	61	49,860,000	★		★			★	★★★
CSAH 25 LT/2 MI S ZIMMERMAN	169	26,000,000	★			★		★	★★★

Crash data was collected at these 34 sites and a “before” period and an “after” period was selected. Three of the treatment sites (Cologne, Cotton, and Ham Lake) were constructed in 2012, and this became the defined “construction year” for the comparative control site. This is also convenient since it gives 3 years of “after” construction data with 2013-2015 crash data. 2009-2011 was selected as the “before” period.

Table 13 and Table 14 shows the aggregated crash data by both the severity of injury, and the diagram of the crashes (the type/configuration of the vehicles at impact), respectively for all crashes that have been designated as intersection-related. For the comparative control sites, only intersection-related crashes were collected.

Table 13: *Crash data from the 34 control sites with similar risk to the built RCIs, “before” and “after” construction with intersection-related crashes. Crashes are aggregated by crash severity.*

Description	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	**152**	**6**	**3**	**28**	**37**	**78**
After	**173**	**5**	**9**	**28**	**37**	**97**
Reduction/ Increase (%)	**+20.5%**	**-16.7%**	**+200%**	**0.0%**	**0.0%**	**+20.5%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), September 2016. Minnesota Transportation Information System (TIS), September 2016.

Table 14: *Crash data from the 34 control sites with similar risk to the built RCIs, “before” and “after” construction with intersection-related crashes. Crashes are aggregated by crash diagram.*

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	**80**	**20**	**18**	**11**	**9**	**14**	**132**	**7**
After	**80**	**20**	**23**	**20**	**6**	**23**	**140**	**13**
Reduction/ Increase (%)	**0.0%**	**0.0%**	**+27.8%**	**+81.8%**	**-33.3%**	**+64.3%**	**+6.1%**	**+85.7%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), September 2016. Minnesota Transportation Information System (TIS), September 2016.

Table 15 and Table 16 compare the change in crashes (by percentage) of the treatment sites versus the control sites.

Table 15: *Percentage of change at the treatment sites versus the comparative control sites. Crashes percentages are aggregated by crash severity.*

Description	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Treatment–Reduction/ Increase (%)	**-15.1%**	**-100%**	**-100%**	**-66.7%**	**0.0%**	**+36.4%**
Control–Reduction / Increase (%)	**+13.8%**	**-16.7%**	**+200%**	**0.0%**	**0.0%**	**+20.5%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), September 2016. Minnesota Transportation Information System (TIS), September 2016.

Table 16: *Percentage of change at the treatment sites versus the comparative control sites. Crashes percentages are aggregated by crash diagram.*

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Treatment– Reduction/ Increase (%)	**-77.4%**	**+71.4%**	**+267%**	**+100%**	**-40.0%**	**+33.3%**	**-31.3%**	**-100%**
Control– Reduction/ Increase (%)	**0.0%**	**0.0%**	**+27.8%**	**+81.8%**	**-33.3%**	**+64.3%**	**+61.1%**	**+85.7%**

Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), September 2016. Minnesota Transportation Information System (TIS), September 2016.

Traffic volumes were also collected at the 34 sites. The results, along with the treatment sites, can be seen in Table 17.

Table 17: *Entering traffic volume and the percentage of change at the treatment sites versus the comparative control sites.*

Group	Before	After	+/- Change
Treatment	133,438,525	135,065,513	+1.2%
Control	514,220,213	512,492,850	-0.3%

Source: Minnesota Traffic Mapping Application. September 2016. Minnesota Transportation Information System (TIS), September 2016.

Comparative Control Sites Results

In order to measure the changes in crashes before and after the construction of a Reduced Conflict Intersections, in comparison to untreated sites, we used a two-by-two Chi Square analysis. This type of test works well for relatively small sample sizes and two-by-two comparisons of categorical data. This analysis included four categories of data: pre-construction, post construction, treated sites, and non-treated sites (control group). All of the tests were done on intersection-related crash data-sets (versus all crashes).

Hypothesis 1: Fewer fatal and serious injury right angle crashes are associated with the implementation of a Reduced Conflict Intersection compared to untreated locations from the pre-construction to the post construction period.

Null-hypothesis 1: There is no difference in the number of fatal and serious injury, right angle crashes associated with Reduced Conflict Intersections compared to untreated locations from the pre-construction to post construction period.

Table 13: Crosstab of Fatal and Serious Injury Right-angle Crashes, Treatment and Non-treatment Sites

	Pre-Construction	**Post Construction**
Non-Treatment	*7*	*13*
Treatment	*5*	*0*

$\chi^2 = 6.77$, $\rho < 0.01$

Result of Hypothesis 1: This analysis supports the hypothesis that fewer fatal and serious injury right angle crashes are associated with the construction of a Reduced Conflict Intersections compared to locations without a Reduced Conflict Intersection.

Hypothesis 2: Fewer fatal and serious injury crashes are associated with the implementation of a Reduced Conflict Intersection compared to untreated locations from the pre-construction to the post construction period.

Null-hypothesis 2: There is no difference in the number of fatal and serious injury crashes associated with Reduced Conflict Intersections compared to untreated locations from the pre-construction to post construction period.

Table 14: Crosstab of Fatal and Serious Injury Treatment and Non-treatment Sites

	Pre-Construction	**Post Construction**
Non-Treatment	*9*	*14*
Treatment	*6*	*0*

$\chi^2 = 7.06$, $\rho < 0.01$

Result of Hypothesis 2: This analysis supports the hypothesis that fewer fatal and serious injury crashes are associated with the construction of a Reduced Conflict Intersections compared to locations without a Reduced Conflict Intersection.

Hypothesis 3: Fewer intersection-related crashes are associated with the implementation of a Reduced Conflict Intersection compared to untreated locations from the pre-construction to the post construction period.

Null-hypothesis 3: There is no difference in the number of intersection-related crashes associated with Reduced Conflict Intersections compared to untreated locations from the pre-construction to post construction period.

Table 15: Crosstab of Intersection-related Crashes at Treatment and Non-treatment Sites

	Pre-Construction	**Post Construction**
Non-Treatment	*152*	*173*
Treatment	*53*	*45*

$\chi^2 = 1.612$, $\rho = 0.204$

Result of Hypothesis 3: This analysis does support the hypothesis that fewer intersection-related crashes are associated with the construction of a Reduced Conflict Intersections compared to locations without a Reduced Conflict Intersection. We fail to reject null hypothesis number three.

Hypothesis 4: A reduction of injury severity is associated with the implementation of a Reduced Conflict Intersection from the pre-construction to the post construction period.

Null-hypothesis 4: There is no reduction of injury severity associated with Reduced Conflict Intersections from the pre-construction to post construction period.

Table 16: Crosstab of Injury Severity at Treatment Sites

	Pre-Construction	Post Construction
PDO/C Injuries	32	40
B, A, and Fatal Crashes	21	5

$\chi^2 = 8.71$, $\rho = 0.0032$

Result of Hypothesis 4: This analysis supports the hypothesis that a reduction of injury severity is associated with the implementation of a Reduced Conflict Intersection from the pre-construction to the post construction period.

The same analysis conducted on non-treatment sites shows no statistically significant change in injury level associated with untreated intersections. This finding adds greater confidence to Hypothesis 4. A reduction of injury severity is associated with the Reduced Conflict Intersection.

Table 17: Crosstab of Injury Severity at Non-treatment Sites

	Pre-Construction	Post Construction
PDO/C Injuries	115	131
B, A, and Fatal Crashes	37	42

$\chi^2 = 0.0002$, $\rho = 0.99$

Hypothesis 5: The Reduced Conflict Intersection treatment is associated with a decrease of right angle, at intersections crashes, from the pre-construction to post construction period when compared to the non-treatment (control) sites for the same period.

Null-hypothesis 5: The Reduced Conflict Intersection treatment is not associated with a decrease of right angle, at intersections crashes, from the pre-construction to post construction period when compared to the non-treatment (control) sites for the same period.

Table 18: Fatal and Serious Injury, Right Angle at Intersection Crashes

	Pre-Construction	Post Construction
Treatment	**31**	**7**
Non-Treatment	**80**	**80**

$\chi^2 = 12.431$, $\rho = 0.0004$

Result of Hypothesis 5: This analysis supports the hypothesis that fewer right angle, at intersection crashes are associated with the construction of a Reduced Conflict

Intersections compared to locations without a Reduced Conflict Intersection. We fail to reject null hypothesis.

These findings indicate that Reduced Conflict Intersections, compared to standard through stop intersections are associated with fewer severe crashes, fewer severe right angle crashes, fewer right angle crashes, and lower injury severity among crashes that do occur. Additionally, no statistically significant increase of total crashes, property damage crashes, run-off-the-road crashes, rear end crashes, head on crashes, or sideswipe crashes are associated with Reduced Conflict Intersections, meaning this strategy does not appear to 'trade off' one type of crash for another.

Table 19: Summary of the ten statistical tests comparing the treatment sites to the comparative control sites.

Hypothesis Number	Target Crash Type	Increase or Decrease?	χ^2	ρ	Result
1	**Severe Right-angle**	**Decrease**	**6.77**	**0.009**	**Significant**
2	**Severe (K+A)**	**Decrease**	**7.06**	**0.008**	**Significant**
3	Total Crashes	Decrease	1.61	0.204	Insignificant
4	**Crash Severity**	**Decrease**	**8.71**	**0.003**	**Significant**
5	Run-off-the-Road	Increase	NA	0.20 (Fisher)	Insignificant
6	Property Damage	Increase	0.15	0.699	Insignificant
7	**Right-angle**	**Decrease**	**12.43**	**0.0004**	**Significant**
8	Rear-end	Increase	0.90	0.343	Insignificant
9	HOSS	Increase	0.02	0.894	Insignificant
10	Multi-Vehicle	Decrease	**2.88**	0.090	Insignificant

Note. **Bold** typeface denote which statistical tests had significant results.

Conclusion

These findings indicate positive safety benefits associated with Reduced Conflict Intersections.

- Significantly fewer fatal and serious injury, right angle crashes are associated with the Reduced Conflict Intersection compared to a standard through stop intersection.
- Significantly fewer fatal and serious crashes are associated with the Reduced Conflict Intersection compared to a standard through stop intersection.
- Significantly fewer right angle crashes are associated with the Reduced Conflict Intersection compared to a standard through stop intersection.
- When crashes occur, the injury level is typically lower than at standard intersections. Significantly fewer high severity crashes are associated with Reduced Conflict Intersections

These findings are consistent with other evaluations throughout the United States. Nationwide, the RCI is associated with fewer injury crashes, and drastically fewer fatal and serious injury crashes. The Reduced Conflict Intersection is gaining in public acceptance and is more widely applied option for intersections at four-lane divided expressways.

Appendix A

This is a listing of the eight Reduced Conflict sites, along with a summary of pre-construction and post construction, intersection-related crashes.

Willmar, MN

Location: Old Highway 71 and CSAH 24/Golf Course Road

City of Willmar, Kandiyohi County, MN

Built: Summer, 2010

Aerial Photo from Google Maps, August 2015

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	5	17	1	1	5	3	7
After	5	2	0	0	0	0	2
Reduction/ Increase (%)	0%	-88.9%	-100%	-100%	-100%	-100%	-71.4%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	11	3	1	1	0	1	15	2
After	0	2	0	0	0	0	2	0
Reduction/ Increase (%)	-100%	-33.3%	-100%	-100%	0.0%	-100%	-100%	-100%

Cotton, MN

Location: US Highway 53 and CSAH 52

Township of Cotton, St Louis County, MN

Built: Summer, 2012

Aerial Photo from Google Maps, August 2015

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	3	3	0	0	1	1	1
After	3	7	0	0	2	0	5
Reduction/ Increase (%)	0.0%	+133%	0.0%	0.0%	+50%	-100%	+400%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	3	0	0	0	0	0	3	0
After	1	1	5	0	0	0	2	0
Reduction/ Increase (%)	-66.7%	+100%	+100%	0.0%	0.0%	0.0%	-33.3%	0.0%

Cologne, MN

Location: US Highway 212 and MN Highway 284/CSAH 53

City of Cologne, Carver County, MN

Built: Summer, 2012

Aerial Photo from Bolton and Menk, Inc. October 2013.

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	3	15	3	0	2	4	6
After	3	12	0	0	0	2	10
Reduction/ Increase (%)	0.0%	-20.0%	-100%	-100%	-100%	-50%	+66.7%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	11	0	2	1	1	0	13	3
After	0	3	4	4	0	1	8	0
Reduction/ Increase (%)	-100%	+100%	+50%	+400%	-100%	+100%	-38.5%	-100%

Ham Lake, MN

Location: MN Highway 65 and 169th Ave NE

City of Ham Lake, Anoka County, MN

Built: Summer, 2012

Aerial Photo from Google Maps, August 2015.

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	3	11	0	1	4	1	5
After	3	4	0	0	1	1	2
Reduction/ Increase (%)	0.0%	-63.6%	0.0%	-100%	-75.0%	0.0%	-60.0%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	4	1	0	1	3	2	10	0
After	1	0	0	1	1	1	3	0
Reduction/ Increase (%)	-75.0%	-100%	0.0%	0.0%	-66.7%	-50.0%	-70.0%	0.0%

Vermillion, MN

Location: US Highway 52 and CSAH 66/ 200th St E

Near the City of Vermillion, Dakota County, MN

Built: Completed June, 2014

Aerial Photo from Google Maps, August 2015.

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	1	3	0	0	1	0	2
After	1	3	0	0	0	1	2
Reduction/ Increase (%)	0.0%	0.0%	0.0%	0.0%	-100%	+100%	0.0%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	1	2	0	0	0	0	3	0
After	0	0	1	0	0	2	2	0
Reduction/ Increase (%)	-100%	-100%	+100%	0.0%	0.0%	+100%	-33.3%	0.0%

Demontreville Trail, Lake Elmo, MN

Location: MN Highway 36 and Demontreville Trail

City of Lake Elmo, Washington County, MN

Built: Completed June, 2013

Aerial Photo from Google Maps, August 2015.

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	1	1	0	0	1	0	0
After	1	8	0	0	2	1	5
Reduction/ Increase (%)	0.0%	+700%	0.0%	0.0%	+100%	+100%	+100%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	0	0	0	0	1	0	1	0
After	2	1	1	2	2	0	7	0
Reduction/ Increase (%)	+100%	+100%	+100%	+100%	+100%	0.0%	+600%	0.0%

Julien Street, St Peter, MN

Location: US 169 and Julien Street

City of Saint Peter, Nicollet County, MN

Built: Completed Summer, 2014

Aerial Photo from Google Maps, September 2016.

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	1	2	0	0	1	1	0
After	1	6	0	0	0	3	3
Reduction/ Increase (%)	0.0%	+200%	0.0%	0.0%	-100.0%	+200%	+100%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	1	1	0	0	0	0	2	0
After	2	3	0	1	0	0	6	0
Reduction/ Increase (%)	+100%	+200%	0.0%	+100%	0.0%	0.0%	+200%	0.0%

Dodd Street, St Peter, MN

Location: US 169 and Dodd Street

City of Saint Peter, Nicollet County, MN

Built: Completed Summer, 2014

Aerial Photo from Google Maps, August 2016

Description	Number of Years	Total Crashes	K-Severity	A-Injury Severity	B-Injury Severity	C-Injury Severity	PDO-Injury Severity
Before	1	1	0	0	0	0	1
After	1	3	0	0	0	2	1
Reduction/ Increase (%)	0.0%	+200.0%	0.0%	0.0%	0.0%	+100%	0.0%

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	Multi-Vehicle	Severe Right-angle
Before	0	0	0	1	0	0	1	0
After	1	2	0	0	0	0	3	0
Reduction/ Increase (%)	+100%	+100%	0.0%	-100%	0.0%	0.0%	+200%	0.0%

Appendix B

Reviewing and Analyzing Selected After Crash Types

It is important to understand that no countermeasure, including the RCI, is a 100% effective tool for reducing all crashes. Reviewing crashes from after the completion of an RCI can help to better understand issues and make improvements. In total, 45 crashes have occurred at the eight RCIs in this study that are intersection-related. Due to concerns about rear-end, sideswipe, and u-turning crashes, this section will discuss these types of crashes.

Rear-End Crashes

The before-construction conditions had a total of 3 rear-end crashes. The after-condition had a total of 12 rear-end crashes. One of these is U-turn related (see below).

a. Two crashes were due to a distracted driver on the major highway.
b. Six of the crashes occurred on the minor roadway, while waiting for a gap to turn right.
c. Two of the crashes occurred when drivers pulled out in front of mainline traffic. One driver stated they were attempting to get to the U-turn. The other crash is unknown if they were attempting to complete a U-turn. Both resulted in no injuries.
d. One crash was from a driver slowing down in the mainline through-lane while approaching the intersection.

Of these eleven crashes, only two (see item c) are related to vehicles maneuvering for the RCI. Both crashes were property-damage-only and no injuries were recorded.

Sideswipe Crashes

The before construction conditions had a total of four sideswipe crashes. The after-condition had a total of 8 sideswipe crashes. Two of these are u-turn related (see below).

a. One crash was a “sideswipe” with a deer.
b. One crash was weather related and lost control, sideswiping the adjacent vehicle.
c. One crash was from vehicles sideswiping to avoid a vehicle on the shoulder.
d. One crash was from vehicles sideswiping to avoid a vehicle turning onto the highway. The crash severity was property-damage-only.
e. One crash was from a vehicle maneuvering over (unknown why; the other driver fled).
f. One crash was from a vehicle attempting to move over to get to the U-turn. The crash severity was property-damage-only.

Of these six crashes, only two (see items d and f) are related to vehicles maneuvering for the RCI. Both crashes were property-damage-only and no injuries were recorded.

U-Turn Crashes

The before-construction conditions had a total of zero U-turn crashes. The after condition had a total of four U-turn crashes.

a. Two of the u-turning crashes
b. were attributed to weather/icy conditions.
c. One crash attributed the through-driver to merging into the u-turner.
d. One crash attributed the u-turner to merging into the through -driver.

Of the u-turning crashes, three were property-damage-only, and one resulted in a minor C-injury.

All four of the after-crashes are either directly or indirectly related to a driver using the RCI intersection.

Considering the concern regarding these crashes, it appears that only eight crashes are directly attributed to these maneuvers in the after-condition. Seven of the eight resulted in no injuries, while one crash resulted in a minor C-injury.

Based on the after-crash data, the overall concerns of increased crashes

due to these maneuvers appears to be an acceptable trade-off, and that the after-crashes related to the RCI are infrequent and low severity. This is an acceptable alternative compared to the high-severity and fatal right-angle crashes the RCI is installed to prevent.

Appendix C Statistical Equation

Crosstab Algorithm Notes

Distinct value of rows variable arranged in ascending order:

X_i $\quad X_1 < X_2 < \cdots < X_R$

Distinct values of column variable arranged in ascending order:

Y_j $\quad Y_1 < Y_2 < \cdots < Y_C$

Sum of cell weights for cases in cell (*i,f)*:

f_{ij}

The *j*th column subtotal

$$C_j \sum_{i=1}^{R} f_{ij}$$

The *i*th row subtotal

$$r_i \sum_{j=1}^{C} f_{ij}$$

The grand total

$$W \sum_{j=1}^{C} c_j = \sum_{i=1}^{R} r_i$$

Marginal and cell statistics

Count:

$$f_{ij}$$

Expected Count:

$$E_{ij} = \frac{r_i\, c_j}{W}$$

Row Percent:

$$Row\ Percent = 100 \times (f_{ij}/r_i)$$

Column Percent:

$$Column\ Percent = 100 \times (f_{ij}/c_i)$$

Total Percent:

$$Total\ Percent = 100 \times (f_{ij}/W)$$

Residual:

$$R_{ij} = f_{ij} - E_{ij}$$

Standardized Residual:

$$SR_{ij} = \frac{R_{ij}}{\sqrt{E_{ij}}}$$

Adjusted Residual:

$$AR_{ij} = \frac{R_{ij}}{\sqrt{E_{ij}\,(1 - \frac{r_i}{W})(1 - \frac{C_j}{W})}}$$

Chi-Square Statistics

Pearson's Chi-Square:

$$X_p^2 = \sum_{ij} \frac{(f_{ij} - E_{ij})^2}{E_{ij}}$$

Appendix D

Control Site Crash Data. “Pre” construction, 2009-2011.

Site Name	Highway	County	Cross Product	Cross Product Risk	Skew	On/Near Curve	Development	Severe RA Density Risk	Previous STOP (>5mi)	Total Stars	Numerical Risk Rating	Before Time Period	Before # of Years	Before PDO	Before C Injury	Before B Injury	Before A Injury	Before K	Before Right Angle	Before Rear End	Before ROR	Before HOSS	Before LTIT	Before Other	Before MV	Before Severe RA
HATTRICK AV CSAH146M104/EVLTH	53	St Louis	7,290,000	★		★	★	★	★	★★★★★	5	2009-2011	3	2	0	0	0	1	2	0	0	1	0	0	3	1
CSAH 25 LTT 740 RT/N WILLMAR	71	Kandiyohi	19,520,325	★	★	★	★		★	★★★★★	5	2009-2011	3	5	0	0	0	0	3	1	1	0	0	0	4	0
N JCT TH 65/NASHWAUK	169	Itasca	6,510,000	★	★	★	★		★	★★★★★	5	2009-2011	3	1	1	0	0	1	2	0	0	0	1	0	3	1
CSAH 13	169	Mille Lacs	13,072,000	★	★		★		★	★★★★	4	2009-2011	3	1	3	1	0	0	5	0	0	0	0	0	5	0
W JCT CSAH10(OLD87)/BCKRCO	10	Becker	12,895,000	★	★	★		★		★★★★	4	2009-2011	3	0	0	0	1	0	1	0	0	0	0	0	1	1
190TH ST CSAH11	169	Mille Lacs	8,554,000	★	★	★	★		★	★★★★★	5	2009-2011	3	3	4	3	1	1	10	1	1	0	0	0	11	1
CSAH 7 LTCR 885 RT/TWIG	53	St Louis	6,762,000	★	★	★	★		★	★★★★★	5	2009-2011	3	4	0	0	0	0	2	0	1	1	0	0	3	0
CSAH 16 LT1STST/KEEWATIN	169	Itasca	6,000,000	★	★	★			★	★★★★	4	2009-2011	3	0	0	0	0	0	0	0	0	0	0	0	0	0
STEVENS RDCSAH 23/N OFONAMIA	169	Mille Lacs	6,630,000	★		★	★		★	★★★★	4	2009-2011	3	0	1	1	0	0	2	0	0	0	0	0	2	0
TH 228/LUCE	10	Otter Tail	6,153,250	★	★	★			★	★★★★	4	2009-2011	3	3	0	0	0	0	1	1	0	0	0	1	2	0
CSAH 23/E LYON ST	23	Marshall	12,787,500	★	★	★	★			★★★★	4	2009-2011	3	0	1	0	0	0	1	0	0	0	0	0	1	0
CSAH 18/KELLOGG	61	Wabasha	10,725,000	★	★	★	★			★★★★	4	2009-2011	3	0	0	0	0	0	0	0	0	0	0	0	0	0
CSAH 36 LTT 188/2MI STH 23	169	Mille Lacs	23,200,000	★	★				★	★★★	3	2009-2011	3	2	1	0	0	0	0	0	2	1	0	0	1	0
CSAH 23/67 S SARATOGA ST	23	Marshall	15,207,500	★	★	★				★★★	3	2009-2011	3	7	4	3	0	0	9	0	1	1	0	3	13	0
CSAH 5 LT/N SIDE HIBBING	169	St Louis	14,685,000	★		★			★	★★★	3	2009-2011	3	1	0	0	0	0	0	1	0	0	0	0	1	0
W JCT TH 194 CR 898RT M84LT	53	St Louis	37,713,000	★	★		★		★	★★★★	4	2009-2011	3	7	0	0	0	0	1	4	0	1	0	1	6	0
CSAH 14/MORRISON CO	10	Morrison	8,679,250	★	★	★			★	★★★★	4	2009-2011	3	1	2	1	0	0	3	0	1	0	0	0	4	0
N JCT CSAH16LT CR957RT	53	St Louis	8,550,000	★	★		★		★	★★★★	4	2009-2011	3	0	2	1	0	0	2	1	0	0	0	0	3	0
CR 55 & T154	65	Isanti	9,450,000	★	★	★	★			★★★★	4	2009-2011	3	1	0	1	0	0	0	0	2	0	0	0	0	0
CSAH 68 RTT 641 LT/N ZUMBRTA	52	Goodhue	17,735,250	★	★	★	★			★★★★	4	2009-2011	3	1	0	1	0	0	0	1	0	0	0	1	1	0
21ST AVE M822LT T730 RT/ROCH	14	Olmsted	24,989,250	★		★				★★	2	2009-2011	3	3	0	1	0	0	1	2	0	0	0	1	4	0
CSAH 6 RTCSAH138LT/NROCKVL	23	Stearns	14,550,000	★		★				★★	2	2009-2011	3	3	0	0	0	0	0	0	1	0	2	0	1	0
CSAH 17/EOF EAGLELAKE	14	Blue Earth	14,206,500	★		★				★★	2	2009-2011	3	4	2	1	0	1	8	0	0	0	0	0	8	1
CSAH 7/1.3MIW MARSHALL	23	Lyon	11,490,000	★		★				★★	2	2009-2011	3	2	5	1	0	0	3	2	1	0	1	1	7	0
TH 42/S OFKELLOGG	61	Wabasha	9,225,375	★					★	★★	2	2009-2011	3	3	3	1	0	1	3	2	1	1	0	1	8	1
S JCT MNTH27/ONAMIA	169	Mille Lacs	16,385,000	★		★	★		★	★★★★	4	2009-2011	3	1	0	1	0	1	2	0	1	0	0	0	2	1
CSAH 9 LTT RDRT/WOF BEMIDJI	2	Beltrami	13,916,700	★	★		★		★	★★★★	4	2009-2011	3	2	0	0	0	0	1	0	0	1	0	0	2	0
TH 19 LT M330/W SIDE RED WING	61	Goodhue	38,463,600	★		★	★		★	★★★★	4	2009-2011	3	2	0	0	0	0	0	0	2	0	0	0	0	0
WASHINGTNAV CSAH16RT/CLOQUET	33	Carlton	34,743,750	★	★	★	★			★★★★	4	2009-2011	3	2	0	0	0	0	2	0	0	0	0	0	2	0
CSAH 21 RT/1 MI N GR RAPIDS	169	Itasca	11,685,000	★	★		★		★	★★★★	4	2009-2011	3	2	2	1	0	0	2	2	0	0	1	0	5	0
CSAH 36 LT/N OF MILACA	169	Mille Lacs	14,335,000	★	★	★	★		★	★★★★★	5	2009-2011	3	0	0	0	0	0	0	0	0	0	0	0	0	0
S JCT CSAH16RT	53	St Louis	54,265,500	★		★	★		★	★★★★	4	2009-2011	3	1	1	0	0	0	2	0	0	0	0	0	2	0
CSAH 18 RTTREASUREISLAND	61	Goodhue	49,860,000	★		★			★	★★★	3	2009-2011	3	12	3	7	1	0	9	2	1	3	4	4	21	0
CSAH 25 LT/2 MI S ZIMMERMAN	169	Sherburne	26,000,000	★			★		★	★★★	3	2009-2011	3	2	2	3	0	0	3	0	2	1	0	1	6	0

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Control Site Crash Data. “Post” construction, 2012-2015.

Site Name	Highway	County	Cross Product	Cross Product Risk	Skew	On/Near Curve	Development	Severe RA Density Risk	Previous STOP (>5mi)	Total Stars	Numerical Risk Rating	After Time Period	After # of Years	After PDO	After C Injury	After B Injury	After A Injury	After K	After Right Angle	After Rear End	After ROR	After HOSS	After LTIT	After Other	After MV	After Severe RA
HATTRICK AV CSAH146M104/EVLTH	53	St Louis	7,290,000	★		★	★	★	★	★★★★★	5	2013-2015	3	0	2	0	0	0	1	0	0	0	0	1	2	0
CSAH 25 LTT 740 RT/N WILLMAR	71	Kandiyohi	19,520,325	★	★	★	★		★	★★★★★	5	2013-2015	3	4	0	0	0	0	0	1	2	0	0	1	2	0
N JCT TH 65/NASHWAUK	169	Itasca	6,510,000	★	★	★	★		★	★★★★★	5	2013-2015	3	3	2	0	1	0	2	0	2	1	0	1	4	0
CSAH 13	169	Mille Lacs	13,072,000	★	★		★		★	★★★★	4	2013-2015	3	2	1	4	1	0	7	0	0	1	0	0	8	1
W JCT CSAH10(OLD87)/BCKRCO	10	Becker	12,895,000	★	★	★		★		★★★★	4	2013-2015	3	1	0	1	0	0	1	0	1	0	0	0	1	0
190TH ST CSAH11	169	Mille Lacs	8,554,000	★	★	★	★		★	★★★★★	5	2013-2015	3	3	1	1	0	1	5	0	1	0	0	0	5	1
CSAH 7 LTCR 885 RT/TWIG	53	St Louis	6,762,000	★	★	★	★		★	★★★★★	5	2013-2015	3	1	1	0	1	0	2	0	0	1	0	0	2	1
CSAH 16 LT1STST/KEEWATIN	169	Itasca	6,000,000	★	★	★			★	★★★★	4	2013-2015	3	0	0	0	0	0	0	0	0	0	0	0	0	0
STEVENS RDCSAH 23/N OFONAMIA	169	Mille Lacs	6,630,000	★		★	★		★	★★★★	4	2013-2015	3	2	1	0	0	0	2	0	0	1	0	0	3	0
TH 228/LUCE	10	Otter Tail	6,153,250	★	★	★			★	★★★★	4	2013-2015	3	2	0	0	1	0	2	1	0	0	0	0	3	1
CSAH 23/E LYON ST	23	Marshall	12,787,500	★	★	★	★			★★★★	4	2013-2015	3	1	1	0	0	0	1	0	0	1	0	0	2	0
CSAH 18/KELLOGG	61	Wabasha	10,725,000	★	★	★	★			★★★★	4	2013-2015	3	1	0	1	0	0	1	1	0	0	0	0	2	0
CSAH 36 LTT 188/2MI STH 23	169	Mille Lacs	23,200,000	★	★				★	★★★	3	2013-2015	3	2	2	1	0	0	3	0	2	0	0	0	3	0
CSAH 23/67 S SARATOGA ST	23	Marshall	15,207,500	★	★	★				★★★	3	2013-2015	3	8	3	3	1	2	11	0	2	0	0	4	15	3
CSAH 5 LT/N SIDE HIBBING	169	St Louis	14,685,000	★		★			★	★★★	3	2013-2015	3	4	0	0	0	0	1	1	1	1	0	0	3	0
W JCT TH 194 CR 898RT M84LT	53	St Louis	37,713,000	★	★		★		★	★★★★	4	2013-2015	3	6	3	2	1	0	3	8	0	0	0	1	11	0
CSAH 14/MORRISON CO	10	Morrison	8,679,250	★	★	★			★	★★★★	4	2013-2015	3	2	2	0	0	1	3	0	0	0	1	1	5	1
N JCT CSAH16LT CR957RT	53	St Louis	8,550,000	★	★		★		★	★★★★	4	2013-2015	3	1	0	0	0	0	0	0	1	0	0	0	0	0
CR 55 & T154	65	Isanti	9,450,000	★	★	★	★			★★★★	4	2013-2015	3	1	0	0	0	0	0	0	0	1	0	0	1	0
CSAH 68 RTT 641 LT/N ZUMBRTA	52	Goodhue	17,735,250	★	★	★	★			★★★★	4	2013-2015	3	2	0	0	0	0	0	1	0	1	0	0	1	0
21ST AVE M822LT T730 RT/ROCH	14	Olmsted	24,989,250	★		★				★★	2	2013-2015	3	3	0	0	0	0	0	0	0	0	0	3	0	0
CSAH 6 RTCSAH138LT/NROCKVL	23	Stearns	14,550,000	★		★				★★	2	2013-2015	3	3	2	3	0	0	3	1	0	2	0	2	7	0
CSAH 17/EOF EAGLELAKE	14	Blue Earth	14,206,500	★		★				★★	2	2013-2015	3	0	2	2	0	1	3	1	0	0	0	1	5	1
CSAH 7/1.3MIW MARSHALL	23	Lyon	11,490,000	★		★				★★	2	2013-2015	3	6	3	1	0	0	2	2	1	0	1	4	8	0
TH 42/S OFKELLOGG	61	Wabasha	9,225,375	★					★	★★	2	2013-2015	3	4	3	3	1	0	7	0	1	2	0	0	10	1
S JCT MNTH27/ONAMIA	169	Mille Lacs	16,385,000	★		★	★		★	★★★★	4	2013-2015	3	5	1	1	0	0	4	0	0	2	1	0	7	0
CSAH 9 LTT RDRT/WOF BEMIDJI	2	Beltrami	13,916,700	★	★		★		★	★★★★	4	2013-2015	3	2	1	1	0	0	4	0	0	0	0	0	4	1
TH 19 LT M330/W SIDE RED WING	61	Goodhue	38,463,600	★		★	★		★	★★★★	4	2013-2015	3	1	0	0	0	0	0	0	1	0	0	0	0	0
WASHINGTNAV CSAH16RT/CLOQUET	33	Carlton	34,743,750	★	★	★	★			★★★★	4	2013-2015	3	1	0	0	0	0	0	0	0	0	0	1	1	0
CSAH 21 RT/1 MI N GR RAPIDS	169	Itasca	11,685,000	★	★		★		★	★★★★	4	2013-2015	3	4	4	1	0	0	6	0	1	1	0	1	8	0
CSAH 36 LT/N OF MILACA	169	Mille Lacs	14,335,000	★	★	★	★		★	★★★★★	5	2013-2015	3	0	0	0	0	0	0	0	0	0	0	0	0	0
S JCT CSAH16RT	53	St Louis	54,265,500	★		★	★		★	★★★★	4	2013-2015	3	6	0	1	0	0	0	0	4	1	2	0	2	0
CSAH 18 RTTREASUREISLAND	61	Goodhue	49,860,000	★		★			★	★★★	3	2013-2015	3	7	2	2	2	0	5	2	1	2	1	2	11	2
CSAH 25 LT/2 MI S ZIMMERMAN	169	Sherburne	26,000,000	★			★		★	★★★	3	2013-2015	3	6	0	0	0	0	1	1	2	2	0	0	4	0

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