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
Minnesota Department of Transportation

Derek Leuer, P.E.
Katie Fleming, M.A.

3/9/2017

Executive Summary

The first Reduced Conflict Intersection (also known as J-Turns, Restricted Crossing U-Turns, RCUTs, etc.) was installed in Minnesota in 2010 in the City of Willmar. Since then, the Reduced Conflict Intersection (RCI) has been constructed at seven more locations in Minnesota. Several more are planned throughout the State, or have been completed since the end of 2015. Across the country, the RCI concept is being implemented in numerous states including Maryland, Mississippi, Missouri, North Carolina, and Wisconsin. Many other states are considering their use, or have them planned at specific locations. This report examines the safety performance of these intersections by comparing the before and after crash data. Overall, RCIs are performing well: preliminary analysis of RCIs in Minnesota have shown a 100% reduction in fatal and Serious-Injury right-angle crashes, a 77% reduction in all right-angle crashes, and over 50% reduction in injury crashes in Minnesota.

Statistical testing of the RCI sites with comparison to a representative control group showed that the intersection treatment was statistically significant for lowering the number of severe right-angle crashes, severe crashes, lowering the overall severity of crashes, and reducing the number of right-angle crashes. The testing also showed that there was an insignificant change in certain crash types, such as rear-end crashes, sideswipe crashes, and property-damage-only crashes.

Contents

Reduced Conflict Intersections

The Reduced Conflict Intersection (RCI) is an intersection control type that has been used on at-grade intersections of multi-lane high-speed (greater than 55 miles per hour) expressways. Standard at-grade intersections of multi-lane high-speed expressways typically allow drivers to make all movements (right, thru, and left) from the minor roadway onto the expressway. Historically, these intersections have experienced high-severity right-angle crashes, resulting in fatalities and serious injuries, with great frequency. Options such as traffic signals have not been effective, often increasing crashes. Other options, such as grade separation (interchanges), are extremely expensive and can only be done at limited locations.

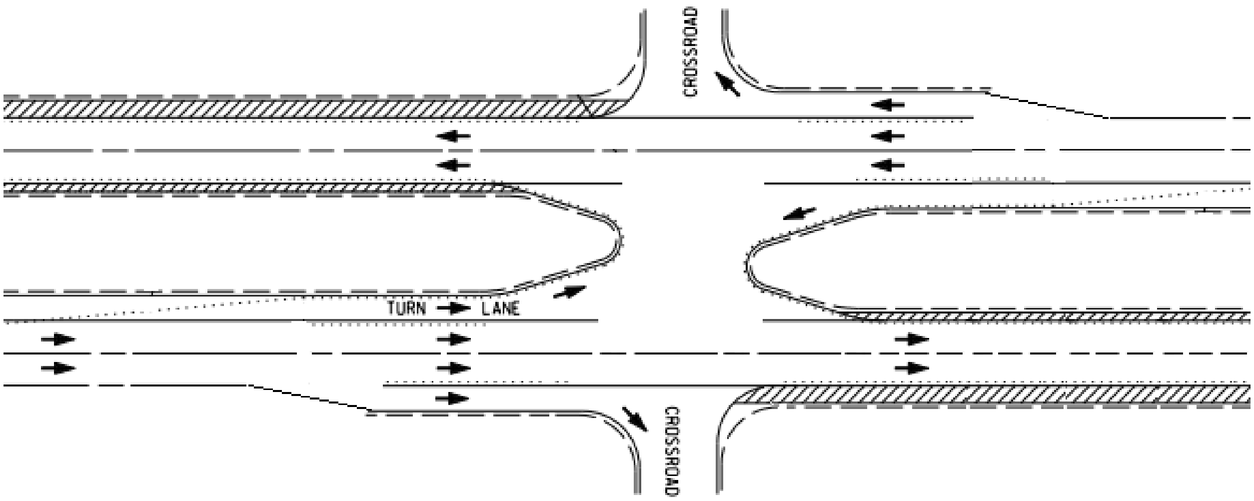


Figure 1: An illustration of a standard at-grade expressway intersection. All movements from the major road (going left and right) and the minor road (going up and down) are allowed. Modified from the Minnesota Road Design Manual, September 2016.

The RCI is a newer treatment where minor road drivers that want to go thru or turn left, will now take a different path. Minor-road drivers will turn right, drive to a designated U-turn, turn around, and then continue on their intended path. There are no changes for the expressway drivers. See Figure 2.

The concept for this intersection is that minor-road drivers are no longer able to expose themselves to the most common and severest crash type at these intersections: the right-angle crash (also called the T-bone, broadside, or perpendicular). Minor road drivers now complete a series of maneuvers that, if a crash does occur, have low severity and are low frequency.

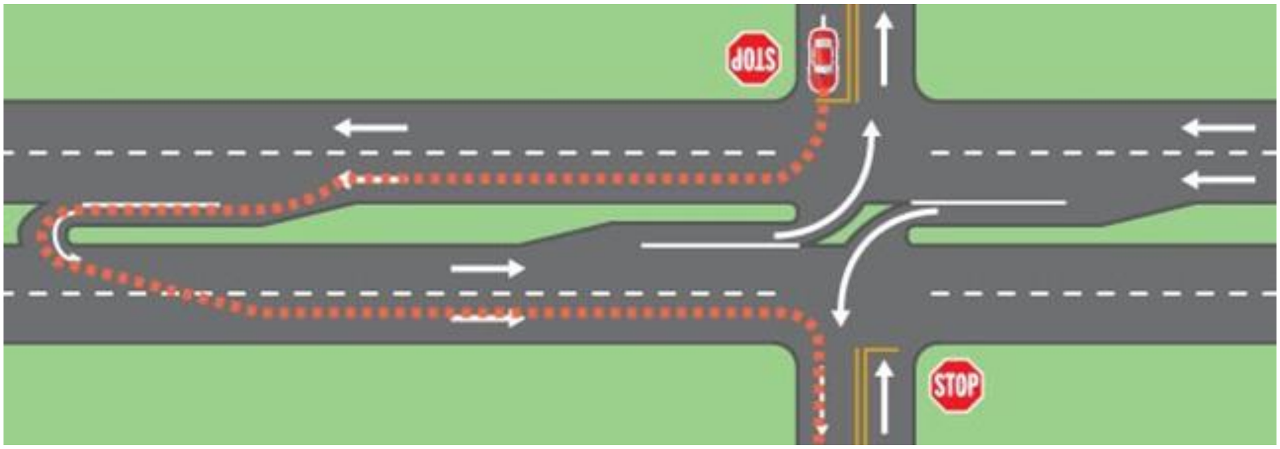


Figure 2: An illustration of a Reduced Conflict Intersection. All movements from the major road (going left and right) are unaltered. The minor-road (going up and down) drivers wanting to go thru or left, are still allowed, but now follow a different path. Source: “Mike on Traffic.” http://www.mikeontraffic.com/restricted-crossing-u-turn-rcut-intersections/ 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 than an interchange, and can be implemented on a much shorter time range than most interchange projects, which can take years to develop and fund.

More information can be found at: http://www.dot.state.mn.us/roadwork/rci/

Study Locations

Due to the limited number of sites, all eight (8) sites in Minnesota were selected. Sites were compared with a minimum of one year following the installation date and a minimum of one year before were selected.

The eight (8) sites are listed in the chart below:

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

The RCI has been becoming a more commonly-used intersection treatment. The treatment appears ideal on multi-lane high-speed expressways with at-grade intersections. These intersections have typically been problematic for transportation officials, as they can have severe right-angle crashes. The previous solutions for these intersections have been full closures, traffic signals, or interchanges. Full closures are often deeply unpopular and can “push” the problem to other intersections. Traffic signals have typically been shown not to work in these rural areas, often increasing the number of crashes, with severe crashes still occurring. Interchanges have worked well in the past, but due to the extremely high cost, the solution is a limited one, and these crash types are often occurring at many locations along a trunk highway, and across the entire network.

The RCI appears to be the best solution yet at high-speed at-grade intersections. The RCI eliminates the types of maneuvers that are most prone to fatal and serious-injury right-angle crashes, while retaining all movements (turning left, right, and going through) on the major and minor roads. The cost is significantly less than that of an interchange, and therefore can be implemented at multiple locations instead of just one location.

Before Crash Data

The total number of site-years[1] totaled to 19 site-years "before construction" and 19 site-years "after construction". The year of construction was typically tossed out to simplify the analysis and remove any impacts due to construction or traffic detours. Table 1 highlights the number of crashes by the severity of the crash. The severity is described as:

> K-Severity: One or more people involved in the crash were killed due to injuries sustained in the crash
>
> A-Injury Severity: One or more people involved in the crash were severely injured and may have life altering consequences due to injuries sustained in the crash
>
> B-Injury Severity: One or more people involved in the crash were injured with visible injuries (blood, broken bones, etc.) sustained in the crash
>
> C-Injury Severity: One or more people involved in the crash were injured with non-visible or minor injuries sustained in the crash
>
> PDO-Injury Severity: No one involved in the crash was injured and only vehicular or personal property damage was sustained

It should be noted that the Minnesota Department of Transportation has adopted Fatal (K) and Serious-Injury (A) crashes as the performance measure for the State.

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

Table 1: Crash data from the eight(8) sites with RCIs before construction. These are all 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.

The crashes documented were those that took place at or near the intersection within 250', and included those on the mainline and the minor road.

The total number of vehicles entering these intersections before construction was 134.4 million vehicles in the 19 site-years. The reason for recording and using the total number of vehicles entering is a way to help equally compare different locations that may have different traffic conditions, or to compare a site over time as the traffic volume has changed.

[1] A site-year is a way to quantify the amount of exposure to traffic each site has had. A site with three years of data would have three site-years and another with four years would have four site-years. These can be additive; the two sites mentioned would have a total of 7 site-years.

To better understand the crashes at these intersections, crashes that were defined as “intersection-related” were looked at more specifically. The police officer completing a crash report can define if the crash was a result of the intersection, or not.

Table 2 highlights crashes that were coded as being “intersection-related” (defined by codes in “Relationship to Intersection/Junction” as 02 – 90, codes 00, 01, and 99 were excluded).

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

Table 2: Crash data from the eight(8) sites with RCIs before construction. 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.

Another important aspect to examine is the manner in which vehicle crash occurred. The diagram of the crashes (the type and configuration of the vehicles at impact), is shown in Table 3. The diagram codes are described briefly as:

Right-angle: When two vehicles collide perpendicular (broadside) to each other. This is often called a T-bone as well. This is one of the most deadly crash types in Minnesota.

Rear-End: When one vehicle collides into the vehicle in front of it. This is the most common type of crash in Minnesota.

Run-off-the-Road: 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.

Head-On/Sideswipe: Two vehicles either collide directly into each other while heading in opposite directions, or collide off-center and scrape each other. Sideswipe also includes vehicles heading in the same direction and impacts each other by maneuvering into the other.

Left-Turn-Into-Traffic: When one vehicle attempts to turn left (from either the major or minor road) and collides with a vehicle crossing its intended path.

Other/Unknown: Includes other crash code types such as “Right Turn Into Traffic”, “Other”, “Not Applicable”, and “Unknown”.

Multi-Vehicle: Crashes that involved two or more motor vehicles. This column is mutually exclusive of the other crash types, and is not additive to the total.

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

Table 3: Crash data from the eight(8) sites with RCIs before construction. 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 4 highlights crashes that were coded as being “intersection-related”.

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

Table 4: Crash data from the eight(8) sites with RCIs before construction. 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.

The intersection-related crashes before the RCI consisted of 58% right-angle crashes. When looking at severe crashes (K+A), 5 of the 7 were right-angle related (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.

After Crash Data

The RCIs at the sites mentioned above contained at least one year of after-crash data, and some had post-construction crash data up to 5 years (Willmar). The after-crash data included all crashes that extended to the new u-turn locations. This was done to ensure that any crashes which may have been a result of the new configuration were included in the analysis.

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
71	19	0	1*	8	16	46

Table 5: Crash data from the eight(8) sites with RCIs after construction. Crashes are aggregated by crash severity. Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

*The A-Injury was associated with the Vermillion intersection. After interviewing the state trooper who responded to the crash, the sideswipe crash appeared to be coincidently between the U-turn locations, and had not occurred due to any interaction or vehicles using the intersection.

Table 6 highlights crashes that were coded as being "intersection-related" and within the designated u-turn locations after the completion of the RCI.

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

Table 6: Crash data from the eight(8) sites with RCIs after construction. 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 7 highlights all crashes that were at the intersection, or within the designated u-turn locations by crash diagram.

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

Table 7: Crash data from the eight(8) sites with RCIs after construction. These are all crashes recorded at or near the intersection within the designated 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.

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

Table 8 highlights all intersection-related crashes that were at the intersection, or within the designated u-turn locations by crash diagram.

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

Table 8: Crash data from the eight(8) sites with RCIs after construction. 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.

The total number of vehicles entering after-construction was estimated to be 135.1 million vehicles entering in the 19 site-years after completion. 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

The RCIs have been built to reduce the number of severe right-angle crashes that are often prevalent at these types of intersections. Based on the limited after crash data, the RCI is reducing the target crashes (fatal, injury, and right-angle crashes). Table 9 and Table 10 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.

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%**

Table 9: Crash data from the eight(8) sites with RCIs before and after construction with all crashes. Crashes are aggregated by crash severity. Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

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%**

Table 10: Crash data from the eight(8) sites with RCIs before and after construction with all crashes. Crashes are 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 coded as originally as two sideswipes, one rear-end, and one other and have been highlighted separately for this analysis.

Table 11 and Table 12 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.

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%**

Table 11: Crash data from the eight(8) sites with RCIs before and after construction with intersection-related crashes. Crashes are aggregated by crash severity. Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

Description	Right-angle	Rear-end	Run Off Road	Head-On/ Sideswipe	Left Turn Into Traffic	Other/ Unknown	U-Turn Related	Multi-Vehicle
Before	31	7	3	4	5	3	0	48
After	7	11	11	6	3	3	4	33
Reduction/ Increase (%)	-77.4%	+57.1%	+267%	+50.0%	-40.0%	+0.0%	+100%	-31.3%

Table 12: Crash data from the eight(8) sites with RCIs before and after construction with intersection-related crashes. Crashes are aggregated by crash diagram. Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), May/June 2016. Minnesota Transportation Information System (TIS), June 2016.

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%

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. 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 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. For the comparative control sites, only intersection-related crashes were collected.

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%

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

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%

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. 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.

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%

Table 15: Percentage of change at the treatment sites versus the comparative control sites. Crashes percentages are aggregated by crash severity. Sources: Minnesota Crash Mapping Analyst Tool (MnCMAT), September 2016. Minnesota Transportation Information System (TIS), September 2016.

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%**

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

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

Table 17: Entering traffic volume and the percentage of change at the treatment sites versus the comparative control sites. Minnesota Traffic Mapping Application. September 2016. Minnesota Transportation Information System (TIS), September 2016.

Comparative Control Sites Results

Several statistical tests were conducted on the results to find if the change in crashes was statistically significant. This is important to find if the changes are due to the RCI treatment, or if the changes are due to the random variation in crashes and regression-to-the-mean. The following questions and statistical significance is listed below. The χ^2 (pronounced chi-squared) statistical test was used to find statistical significance. All of the tests were done of intersection-related crash data-sets (versus all crashes).

Hypothesis 1: The RCI treatment is responsible for the reduction in severe right-angle crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 1: There is no difference between the treatment sites and the non-treatment (control) sites.

Severe Right-angle Crashes

	Before Installation	**After Installation**
Non-Treatment	*7*	*13*
Treatment	*5*	*0*

The reduction is statistically significant. $\chi^2 = 6.77$, $\rho < 0.01$

Result of Hypothesis 1: RCIs reduced the number of severe right-angle crashes.

Hypothesis 2: The RCI treatment is responsible for the reduction in severe crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 2: There is no difference between the treatment sites and the non-treatment (control) sites.

Severe Crashes

	Before Installation	**After Installation**
Non-Treatment	*9*	*14*
Treatment	*6*	*0*

The reduction is statistically significant. $\chi^2 = 7.06$, $\rho < 0.01$

Result of Hypothesis 2: RCIs reduced the number of severe crashes.

Hypothesis 3: The RCI treatment is responsible for the reduction in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 3: There is no difference between the treatment sites and the non-treatment (control) sites.

All Crashes

	Before Installation	**After Installation**
Non-Treatment	*152*	*173*
Treatment	*53*	*45*

The reduction is not statistically significant. $\chi^2 = 1.612$, $\rho = 0.204$

Result of Hypothesis 3: RCIs did not reduced the number of total crashes.

Hypothesis 4: The RCI treatment is responsible for the shifting of injury severity from high severity to lower severities in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 4: There is no difference between the treatment sites and the non-treatment (control) sites.

All Crashes by Severity – Treatment Sites

	Before Installation	**After Installation**
PDO/C Injuries	*32*	*40*
B, A, and Fatal Crashes	*21*	*5*

The change is statistically significant. $\chi^2 = 8.71$, $\rho = 0.0032$

All Crashes – Non-Treatment (Control) Sites

	Before Installation	**After Installation**
PDO/C Injuries	*115*	*131*
B, A, and Fatal Crashes	*37*	*42*

The change is not statistically significant. $\chi^2 = 0.0002$, $\rho = 0.99$

Result of Hypothesis 4: RCIs reduced the severity of crashes.

Hypothesis 5: The RCI treatment is responsible for the increase in run-off-the-road (ROR) crashes in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 5: There is no difference between the treatment sites and the non-treatment (control) sites.

Run-off-the-Road Crashes

	Before Installation	**After Installation**
Treatment	*3*	*11*
Non-Treatment	*18*	*23*

The change is not statistically significant. Fisher Exact = 0.204

Result of Hypothesis 5: RCIs did not increase the frequency of run-off-the-road crashes.

Hypothesis 6: The RCI treatment is responsible for the increase in property-damage-only (PDO) severity crashes in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 6: There is no difference between the treatment sites and the non-treatment (control) sites.

Property-damage-only Crashes

	Before Installation	**After Installation**
Treatment	*22*	*30*
Non-Treatment	*78*	*94*

The change is not statistically significant. $\chi^2 = 0.149$, $\rho = 0.699$

Result of Hypothesis 6: RCIs did not increase the frequency of property-damage-only crashes.

Hypothesis 7: The RCI treatment is responsible for the decrease in right-angle crashes in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 7: There is no difference between the treatment sites and the non-treatment (control) sites.

Right-Angle Crashes

	Before Installation	**After Installation**
Treatment	*31*	*7*
Non-Treatment	*80*	*80*

The reduction is statistically significant. $\chi^2 = 12.431$, $\rho = 0.0004$

Result of Hypothesis 7: RCIs decreased the frequency of right-angle crashes.

Hypothesis 8: The RCI treatment is responsible for the increase in rear-end crashes in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 8: There is no difference between the treatment sites and the non-treatment (control) sites.

Rear-End Crashes

	Before Installation	**After Installation**
Treatment	*7*	*12*
Non-Treatment	*20*	*20*

The change is not statistically significant. $\chi^2 = 0.899$, $\rho = 0.3432$

Result of Hypothesis 8: RCIs did not increase the frequency of rear-end crashes.

Hypothesis 9: The RCI treatment is responsible for the decrease in head-on and sideswipe (HOSS) crashes in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 9: There is no difference between the treatment sites and the non-treatment (control) sites.

Head-On and Sideswipe Crashes

	Before Installation	**After Installation**
Treatment	*4*	*8*
Non-Treatment	*11*	*20*

The change is not statistically significant. $\chi^2 = 0.018$, $\rho = 0.8944$

Result of Hypothesis 9: RCIs did not increase the frequency of head-on and sideswipe crashes.

Hypothesis 10: The RCI treatment is responsible for the decrease in multi-vehicle (MV) crashes (two or more motor vehicles in transport) in intersection-related crashes from before the installation to after the installation when compared to the non-treatment (control) sites for the same time period.

Null-hypothesis 9: There is no difference between the treatment sites and the non-treatment (control) sites.

Multi-Vehicle Crashes

	Before Installation	**After Installation**
Treatment	*48*	*33*
Non-Treatment	*132*	*140*

The reduction is not statistically significant. $\chi^2 = 2.875$, $\rho = 0.0899$

Result of Hypothesis 9: RCIs likely did not decrease the frequency of mutli-vehicle crashes.

Based on these results, the RCI has shown a statistically significant result in reducing severe crashes, right-angle severe crashes, right-angle crashes, and lowering the severity of crashes at these intersections. This has occurred while also showing no statistically significant increase in total crashes, property damage crashes, run-off-the-road crashes, rear-end, or HOSS crashes. Multi-vehicle crashes may have been reduced by the RCI, but the statistical test did not have a strong enough outcome. The results can be summed up in Table 18.

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*

Table 18: Summary of the ten statistical tests comparing the treatment sites to the comparative control sites. **Bold** numbers denote which statistical tests had significant results.

Common Concerns

One of the main concerns with the motoring public tends to be involved with the following issues.

1. With everyone turning right, and the increased exposure to thru-traffic, won't 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 the section "Reviewing and Analyzing After Crashes".

2. 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 section "Reviewing and Analyzing After Crashes".

3. How will heavy 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

Another 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

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 thru-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 were attributed to weather/icy conditions.
b. One crash attributed the thru-driver to merging into the u-turner.
c. One crash attributed the u-turner to merging into the thru-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.

Conclusion

The RCIs in Minnesota appears to be matching what has happened on the national level. RCIs nationwide have continuously shown to decrease the number of injury crashes, and drastically reduce the number of fatal and serious-Injury crashes. Minnesota's crash data have typically shown only a small decrease/increase in Property-Damage-Only (PDO) type crashes after opening. This could be due to the community adjusting to a new intersection type. After the initial opening, these crashes typically drop down to a lower level. The fatal and injury-crash reductions appear to be sustained over the life of the RCI.

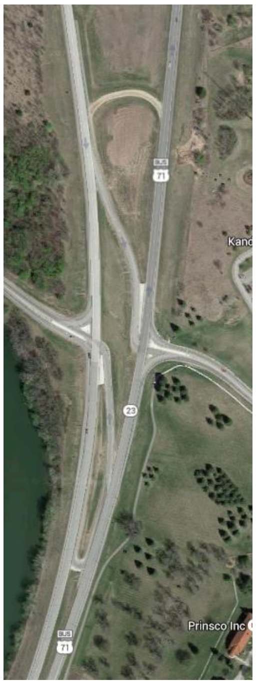
The crash data obtained has shown that RCIs have reduced intersection-related right-angle crashes by over 77%. RCIs have reduced injury crashes by over 50% and the most severe crashes (fatal and A-injury) by 100%.

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

Appendix A

This is a listing of the eight sites, along with the “before and after” intersection-related crash data.

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

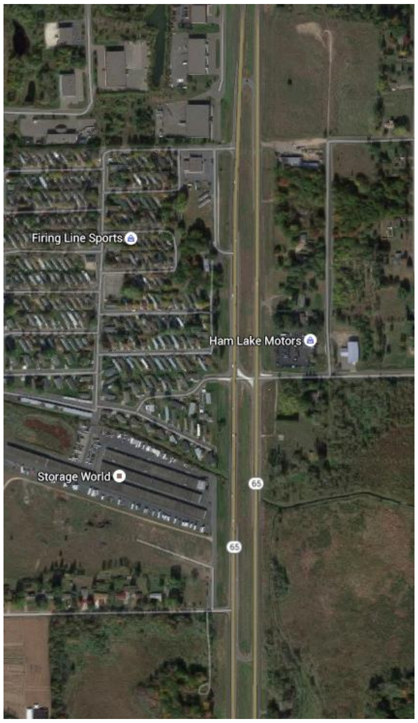
Built: Summer, 2012

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

Control Site Crash Data. “Before” 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

Definitions

Cross Product = Average Major Road Daily Entering Traffic multiplied by Average Minor Road Daily Entering Traffic

Cross Product Risk = Site with great then Six Million (6,000,000) received a star (★)

Severe RA Density Risk = Severe Right-angle Crashes / Number of Years

PDO = Property-damage-only

“K,A,B,C” Injury = a scale of the severity of the injury

ROR = Run off the Road Crash (Road Departure to the right or left)

HOSS = Head On or Sideswipe Crash

LTIT = Left Turn Into Traffic

MV = Multi-Vehicle Crash, two or more motor vehicles in transport

Before Severe RA = number of fatal or incapacitating (K+A) right-angle crashes in the before study period

Control Site Crash Data. “After” 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

Definitions

Cross Product = Average Major Road Daily Entering Traffic multiplied by Average Minor Road Daily Entering Traffic

Cross Product Risk = Site with great then Six Million (6,000,000) received a star (★)

Severe RA Density Risk = Severe Right-angle Crashes / Number of Years

PDO = Property-damage-only

“K,A,B,C” Injury = a scale of the severity of the injury

ROR = Run off the Road Crash (Road Departure to the right or left)

HOSS = Head On or Sideswipe Crash

LTIT = Left Turn Into Traffic

MV = Multi-Vehicle Crash, two or more motor vehicles in transport

Before Severe RA = number of fatal or incapacitating (K+A) right-angle crashes in the before study period