DEPARTMENT OF TRANSPORTATION

Traffic Safety Evaluation at J-Turn Intersections in Minnesota

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Minnesota Department of Transportation

February 2024

Research Project
Final Report 2024-05

Technical Report Documentation Page

1. Report No.	2.	3. Recipients Accession No.
2024-05		

4. Title and Subtitle	5. Report Date
Traffic Safety Evaluation at J-turns in Minnesota	February 2024
	6.
7. Author(s) Max Moreland, PE, PTOE; Derek Leuer, PE; Ian Saari	8. Performing Organization Report No.
9. Performing Organization Name and Address Office of Traffic Engineering Minnesota Department of Transportation 1500 W. County Rd B2, MS 725 Roseville, Minnesota 55113	10. Project/Task/Work Unit No. 11. Contract (C) or Grant (G) No.
12. Sponsoring Organization Name and Address Minnesota Department of Transportation Office of Research & Innovation 395 John Ireland Boulevard, MS 330 St. Paul, Minnesota 55155-1899	13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code

15. Supplementary Notes
http://mdl.mndot.gov/

16. Abstract (Limit: 250 words)

Between 2010 and 2022, 83 J-turn intersections were installed on Minnesota Department of Transportation (MnDOT) roadways. The J-turn is an alternative intersection layout that is intended to provide safety benefits by limiting the number of points within an intersection that two or more vehicle paths might intersect. Before-after analyses at J-turns and control sites were conducted and compared. With the installation of a J-turn, the analyses found decreases in fatal and serious injury crashes, angle crashes, and fatal and serious injury angle crashes. The large decreases in severe crashes at J-turn locations indicate the J-turn can be an effective safety treatment. The analysis also found J-turns have lower crash rates for key crash types as compared to low-volume interchanges and rural, high-speed signalized intersections.

17. Document Analysis/Descriptors	18. Availability Statement
Restricted crossing U turn intersections, Traffic safety	

19. Security Class (this report)	20. Security Class (this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	51	

TRAFFIC SAFETY EVALUATION AT J-TURN INTERSECTIONS IN MINNESOTA

FINAL REPORT

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February 2024

Published by:

Minnesota Department of Transportation
Office of Research & Innovation
395 John Ireland Boulevard, MS 330
St. Paul, Minnesota 55155-1899

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LIST OF ABBREVIATIONS & DEFINITIONS OF TERMS

Acronym	**Meaning**
AADT	Average annual daily traffic volume
KA	Fatal and serious injury crash
KAB	Fatal, serious injury, and minor injury crashes
KABC	Fatal and all injury crashes
MEV	Million entering vehicles
MnDOT	Minnesota Department of Transportation
RCI	Reduced-conflict intersection
RCUT	Restricted crossing U-turn

Crash Severities

- K Crash: Fatal crash. At least one person involved in the crash died as a result of injuries sustained in the crash.
- A Crash: Suspected serious injury crash. The crash resulted in a suspected serious injury for at least one person involved in the crash.
- B Crash: Suspected minor injury crash. The crash resulted in a suspected minor injury for at least one person involved in the crash.
- C Crash: Possible injury crash. The crash resulted in a possible injury for at least one person involved in the crash.
- PDO Crash: Property damage only crash. The crash resulted in property damage with no injuries for anyone involved in the crash.

Crash Types:

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

Other Definitions:

- Site-Year: One year of data at a site.
- Treatment Sites: Intersections with a J-turn.
- Control Sites: Intersections with similar characteristics to J-turn sites, but without a J-turn.

EXECUTIVE SUMMARY

Between 2010 and 2022, 83 J-turn intersections were installed on Minnesota Department of Transportation (MnDOT) roadways. The J-turn is an alternative intersection layout that is intended to provide safety benefits by limiting the number of conflict points within an intersection where two or more vehicle paths might intersect. Specifically, the design of the intersection is intended to reduce the likelihood that vehicles travelling in different directions will collide at various angles thereby reducing the number of crashes that result in fatalities or serious injuries. This report includes the results of before-after analyses at J-turns and control sites, a comparison of those before-after analyses, a cross-sectional analysis comparing J-turns to rural signalized intersections and low-volume interchanges, and analyses of different J-turn features.

The results of the before-after analyses conducted show the J-turns in Minnesota are exhibiting their intended safety benefits. The analyses showed the following impacts of J-turns:

- Reductions in fatal and serious injury crashes
- Reductions in all injury crashes
- Reductions in angle crashes
- Reductions in fatal and serious injury angle crashes
- Increases in rear-end crashes

These results are consistent with the safety goals of J-turns as well as with the previous evaluation of J-turns in Minnesota. The large decreases in severe crashes at J-turn locations indicate the J-turn can be an effective safety treatment. J-turns have also seen a potential reduction in fatal and injury commercial vehicle crashes.

A cross-sectional analysis between J-turns, rural signals, and low-volume interchanges shows that J-turns have lower overall and injury crash rates than interchanges as well as fewer angle, rear-end, and intersection-related crashes than rural, high-speed signals.

Additional analyses between J-turns with different features found that:

- J-turns are performing well with various mainline traffic volumes
- J-turns without mainline left turns have lower crash rates than J-turns with mainline left turns
- J-turns that provide direct entry into the U-turn lane from the minor road have higher crash rates for some target crash types than J-turns that do not provide direct entry into the U-turn lane from the minor road
- J-turns that have U-turns that are 750 feet or less from the minor road have lower crash rates than J-turns with U-turns that are greater than 750 feet from the minor road

CHAPTER 1: INTRODUCTION

A J-turn, also known as a Reduced-Conflict Intersection (RCI) or a Restricted-Crossing U-Turn (RCUT), is an at-grade intersection design used on high-speed, multi-lane expressways. The goal of a J-turn is to improve safety by reducing the number and severity of angle crashes. From 2018 through 2022, 18% of all fatal and serious injury crashes in Minnesota were caused by angle crashes at intersections. Figure 1.1 shows the layout of a standard at-grade expressway intersection, Figure 1.2 shows the layout of a J-turn, and Figure 1.3 shows the layout of a J-turn with mainline left turn lanes. The channelized mainline left turns are not always provided at a J-turn.

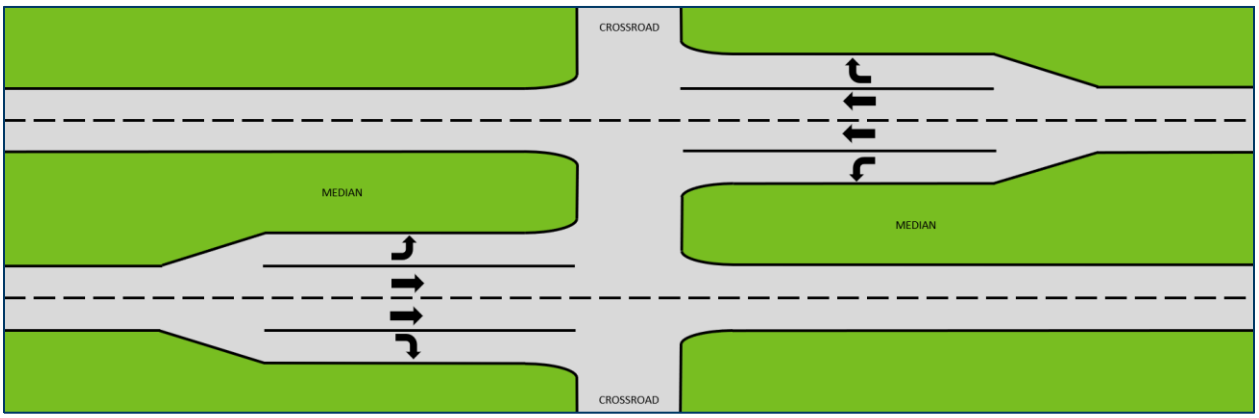

Figure 1.1 – Layout of Standard At-Grade Expressway Intersection

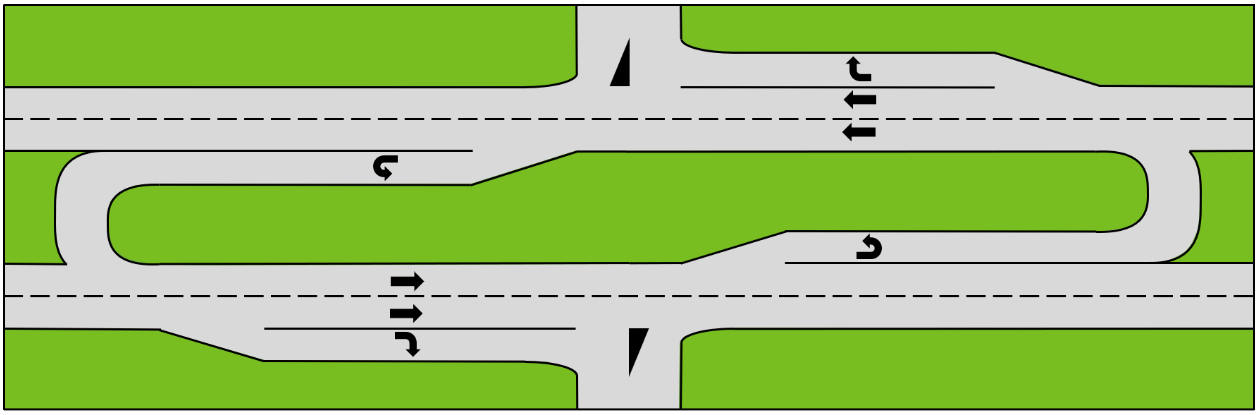

Figure 1.2 – Layout of J-turn

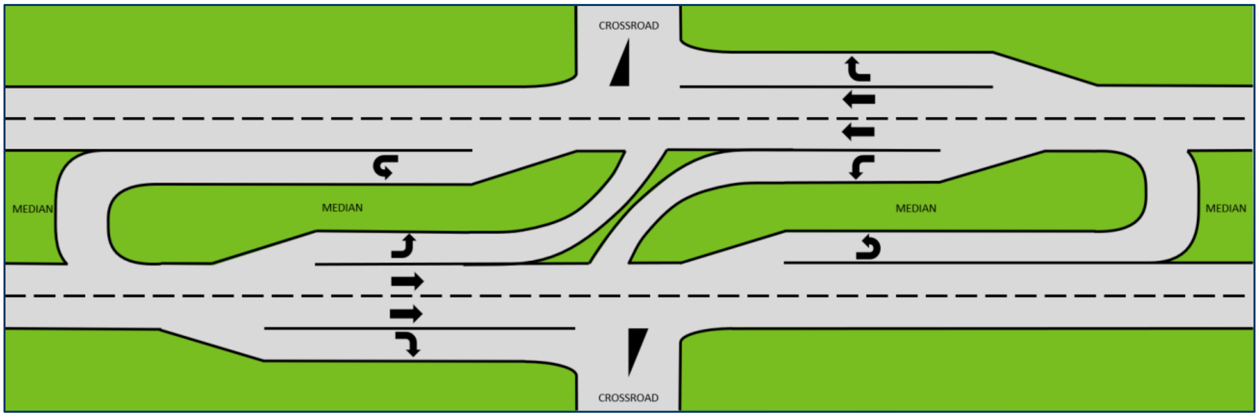

Figure 1.3 – Layout of J-turn with Mainline Left Turns

At a J-turn, vehicles on the mainline retain full access (if the channelized mainline left turns are provided) while those on the crossroad may only make right turns. Vehicles on the crossroad wishing to either turn left onto the mainline or continue straight through on the crossroad must make a right turn onto the mainline then make a U-turn to get onto the opposing direction of the mainline. Those vehicles can then turn right onto the crossroad or stay on the mainline. While the travel distance for those vehicles is increased, their travel time is less affected due to the need to only find gaps in one direction of opposing traffic at a time at a J-turn.

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

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

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

CHAPTER 2: HISTORY OF J-TURNS IN MINNESOTA

The first J-turn in Minnesota was installed during 2010 in Willmar. As of the end of 2023, there were 96 J-turns in Minnesota. There are several dozen more J-turns that are either already planned or under consideration for construction in the next few years. Table 2.1 lists the number of J-turns constructed each year in Minnesota.

Table 2.1 - Number of J-turns Constructed Each Year in Minnesota

Year	Number of J-turns Constructed
2010	1
2011	0
2012	4
2013	1
2014	3
2015	2
2016	2
2017	8
2018	7
2019	14
2020	7
2021	10
2022	24
2023	13 (preliminary count)

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

Many of the earlier J-turn locations were selected as reactive safety treatments due to high crash rates and/or frequent severe crashes. Some of the later J-turns were selected as proactive safety treatments.

CHAPTER 3: METHODOLOGY

3.1 LOCATIONS

As mentioned, there are 83 J-turns that have been constructed in Minnesota through the year 2022. Figure 3.1 shows those locations on a map.

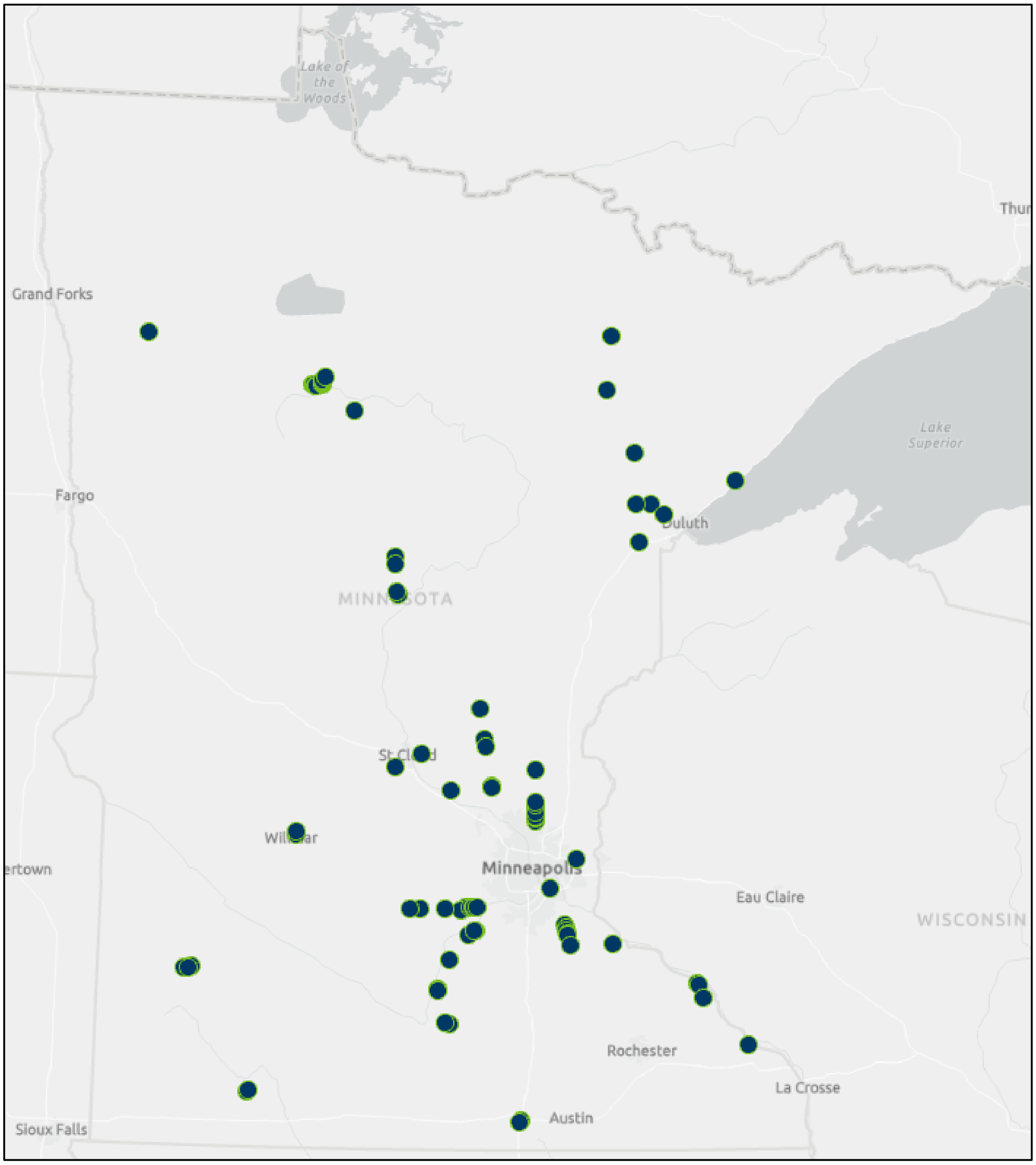

Figure 3.1 – J-turn Locations in Minnesota

Of the 83 J-turns in Minnesota at the time of this evaluation, 29 are not included in this evaluation for the following reasons:

- 24 J-turns were constructed in 2022. This evaluation was conducted in early 2023, so there was not enough crash data to conduct an “after” period analysis.
- Two J-turns are on new roadway alignments so there is no comparable “before” period data.
- One J-turn is signalized with dual right turn lanes and dual U-turn lanes. This is not included in the analysis because the layout and operations of this J-turn are significantly different from the other J-turn locations.
- One J-turn is located within 1/3 of a mile of signalized intersections on either side. After review of the crashes at this intersection, most, if not all, crashes are due to congestion/signal backups from the adjacent intersection. Because of the overwhelming influence of the adjacent signals on the crashes at this location, it is not included in the analysis.
- One J-turn allows for full movements of one of the minor approaches making it less comparable to the other J-turn locations.

3.2 CRASH DATA

For comparison purposes, all crash data in this evaluation is analyzed by site-year. The year of construction at each location is not included in the analysis. The analysis in this evaluation was conducted in 2023, so the most recent year of data analyzed was from 2022 as there was not a complete year of data for 2023 at the time of analysis.

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

Appendix A highlights all fatal and suspected serious injury crashes that occurred at locations with a J-turn. Appendix B highlights all fatal and suspected serious injury crashes that occurred in the year of construction at J-turns.

3.3 ANALYSIS OVERVIEW

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

A before-after analysis of locations with a J-turn.
This analysis focuses on existing J-turn locations comparing the crashes in a period before J-turn construction to a period after J-turn construction. The before and after periods for each site include the same number of site-years.

A comparison of before-after analyses between J-turn and control intersections.
This analysis compares before-after crash results at locations with J-turns (treatment) to similar locations without J-turns (control).

A cross-sectional comparison of J-turns to low-volume interchanges and rural signals.

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

A comparison between J-turns with different mainline volumes.

This analysis groups the J-turns from the before-after analysis into different groups based on the mainline traffic volumes and compares how J-turns are performing at different mainline traffic volume thresholds.

A comparison between J-turns with or without mainline left turns.

This analysis groups the J-turns from the before-after analysis into different groups based on whether or not direct left turn movements are provided off of the mainline and compares how J-turns are performing between the different groups.

A comparison between J-turns with different U-turn lane entry points.

This analysis groups the J-turns from the before-after analysis into different groups based on where the turn lane for the U-turns begin and compares how J-turns are performing between the different groups.

A comparison between J-turns with different U-turn distances.

This analysis groups the J-turns from the before-after analysis into different groups based on the distance from the minor road to the U-turn movement and compares how J-turns are performing between the different groups.

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

The first analysis (the before-after analysis) compares crash and traffic volume data from multiple years before and after their respective J-turn construction. After that initial test of the J-turn locations, the next two analyses complement the first analysis by comparing the J-turn sites with other types of comparable intersections. The remaining four analyses utilize the data from the before-after analysis but break it up in different ways to examine specific aspects of the J-turn intersections.

CHAPTER 4: ANALYSIS & RESULTS

4.1 BEFORE-AFTER ANALYSIS

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

4.1.1 Question Addressed

How do crashes change after a J-turn is installed at a location?

4.1.2 Locations

The analysis for this evaluation was conducted in the year 2023. Without having a full year of crash data for 2023, there is no after data for the J-turns constructed in 2022. Those locations are therefore not utilized in the analysis as treatment sites. Additionally, five other J-turn locations are not used in the analysis per the discussion in the previous section of this report.

This leaves 54 J-turn locations that have at least one site-year of before and one site-year of after data which totals to 225 site-years of before data and 225 site-years of after data. Figure 4.1 shows the locations of the included sites.

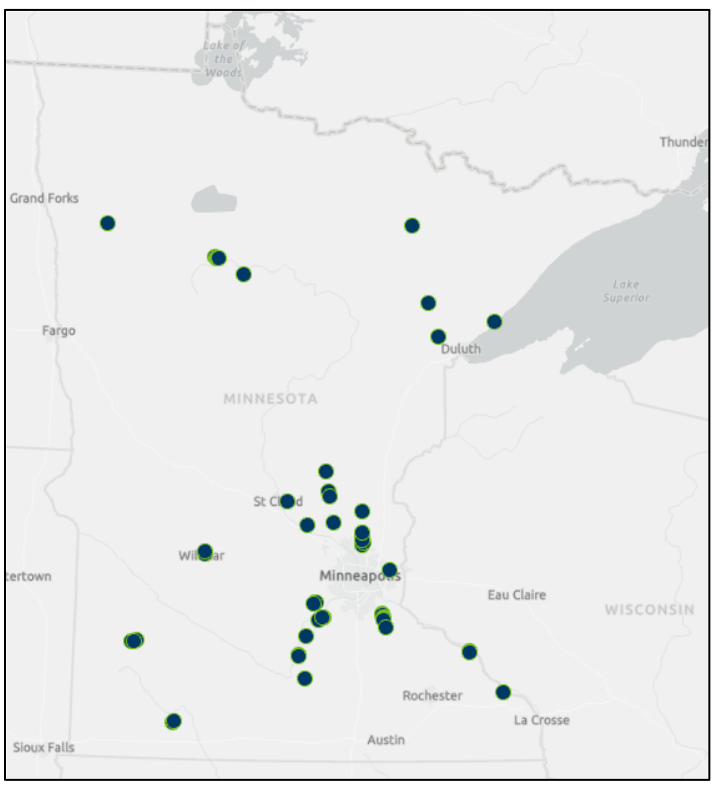

Figure 4.1 – Locations for Before-After Analysis

4.1.3 Crash Data

The before-after crash data at the 54 J-turn locations was collected and compiled. Table 4.1 shows that compiled crash data. The total entering volumes (sum of daily volumes at each site) were 1,639,495,223 vehicles in the before scenarios and 1,689,731,927 vehicles in the after scenarios. Crash rates, in units of crashes per million entering vehicles (MEV), for the before-after scenarios are also included in Table 4.1. A graphical breakdown showing the locations of the after crashes at J-turns for angle, rear-end, and sideswipe crashes can be seen in Appendix C.

The analysis and testing were focused on a number of crash severities/types. These are based on both the expected benefits of J-turns as well as commonly heard concerns about J-turns. Seven crash severities/types are focused on in this analysis and listed below.

- Fatal (K) and suspected serious injury (A) crashes. J-turns are an alternative intersection intended to improve safety by reducing crashes with these serious outcomes.
- Fatal and all injury crashes (severities KABC). J-turns are intended to improve safety and reduce injury severities of all types.
- Angle crashes. This is the target crash type J-turns are intended to reduce.
- K and A angle crashes. These are the most severe outcome types of the target crash type that J-turns are intended to reduce.
- Rear-end crashes. It is commonly heard that J-turns will contribute to an increase in rear-end crashes.
- Sideswipe crashes. It is commonly heard that J-turns will contribute to an increase in sideswipe crashes.
- Total crashes. J-turns are intended to reduce the most severe types of crashes at the intersections they are installed at, but not necessarily intended to reduce overall crashes.

Table 4.1 - Before-After Analysis Crash Counts and Rates

Crash Severity/Type	Before # of Crashes	After # of Crashes	Before Crash Rate	After Crash Rate
Total Crashes	733	677	0.447	0.401
K Crashes	15	3	0.009	0.002
A Crashes	27	16	0.016	0.009
KA Crashes	42	19	0.026	0.011
B Crashes	123	68	0.075	0.040
KAB Crashes	165	87	0.101	0.051
C Crashes	160	97	0.098	0.057
KABC Crashes	325	184	0.198	0.109
PDO Crashes	408	493	0.249	0.292
Angle Crashes	303	102	0.185	0.060
KA Angle Crashes	31	4	0.019	0.002
Rear-End Crashes	112	229	0.068	0.136
Sideswipe Crashes	75	79	0.046	0.047
Intersection Related Crashes	460	306	0.281	0.181

4.1.4 Crash Analysis

To compare the before-after crash data samples, a paired samples t-test was used. This test is used to compare two related (or dependent) samples with independent observations. This tests the assumptions of a null hypothesis and since this test takes all of the observed values, the measure we are using for each group's average will be its mean value. For this analysis, the null hypothesis being tested is that the mean difference between paired observations at the J-turn sites is equal to zero (i.e., the two distributions are the same). The alternative hypothesis being tested is that the mean difference between pairs of the sample observations is not equal to zero (i.e., the two distributions are different).

The paired sample t-test produces a test statistic with a corresponding p-value, which is then compared to a predetermined alpha level (in this case, alpha = 0.10) to evaluate the null hypothesis. If the test produces a result with a p-value that is less than that threshold alpha level, the null hypothesis is rejected, suggesting there is a significant difference in the before-after results. The results of these paired samples t-tests are shown in Table 4.2.

Table 4.2 - Before-After Analysis Results

Category	Change in Crash Rate	p-value	Significant?
K Crashes	**-81%**	**0.065**	**Yes**
A Crashes	-43%	0.821	No
KA Crashes	-56%	0.931	No
KABC Crashes	**-45%**	**0.097**	**Yes**
Angle Crashes	**-67%**	**<0.001**	**Yes**
KA Angle Crashes	**-87%**	**0.067**	**Yes**
Rear-End Crashes	**+98%**	**0.001**	**Yes**
Sideswipe Crashes	+2%	0.211	No
Total Crashes	-10%	0.773	No

As seen in Table 4.2, the conversion of these intersections to J-turns resulted in large decreases in fatal and serious injury crash rates (KA), all injury crash rates (KABC), angle crash rates, and fatal and serious injury angle crash rates. However, only the 67% reduction in angle crashes was found to be statistically significant at the 95th percent confidence level. At the 90th percent confidence level, fatal crash rates, KABC crash rates, as well as KA angle crash rates also had statistically significant decreases.

Additionally, there was found to be a statistically significant increase in rear-end crash rates as a result of the conversions to J-turns. Though there were increases in sideswipe crash rates and decreases in total crash rates, these changes were not found to be statistically significant.

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

Also as seen in Table 4.1, there were 12 less fatal crashes in the after period as compared to the before period. With 225 site-years in each period, it could be said that J-turns are related to reducing a fatal crash every 19 site-years. With 96 J-turn sites in Minnesota, that is equal to approximately five fatal crashes per year.

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

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

As the result of these label changes, Minnesota experienced a dramatic increase in A and B severity crashes from 2015 to 2016 (increasing by 83% and 51% for A and B crashes, respectively). Based on this change, some of the locations in the before-after analyses may have been impacted.

Additionally, Minnesota saw a large increase in the number of fatal and serious injury crashes in 2021 and 2022 compared to previous years. However, Table 4.1 shows that A and B severity crashes both experienced large decreases at the J-turn locations even when those years were included. This emphasizes the decreases seen at J-turn locations.

This analysis aimed to answer the question "How do crashes change after a J-turn is installed at a location?" which was posed in section 4.1.1. Based on this analysis, the answer is that after a J-turn is installed, there are reductions in fatal and serious injury crashes, reductions in all injury crashes, reductions in angle crashes, reductions in fatal and serious injury angle crashes, and increases in rear-end crashes.

4.2 COMPARATIVE TREATMENT-CONTROL BEFORE-AFTER ANALYSIS

The comparative before-after analysis takes a group of locations that have J-turns at them (treatment sites) and compares the before-after crash data there against the before-after crash data at a group of similar intersections without J-turns (control sites).

4.2.1 Question Addressed

How much of the crash reduction can be attributed to J-turns?

4.2.2 Locations

For this comparison, only J-turns locations that had at least three years of "after" data were included. There are 38 locations that have J-turns during this 2020 through 2022 period.

For the control group, these locations should be similar to the treatment sites but cannot have had a J-turn at them during the entire 2020 through 2022 period. The sites that were included in this group are 61 locations where future J-turns have been planned or are under consideration.

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

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

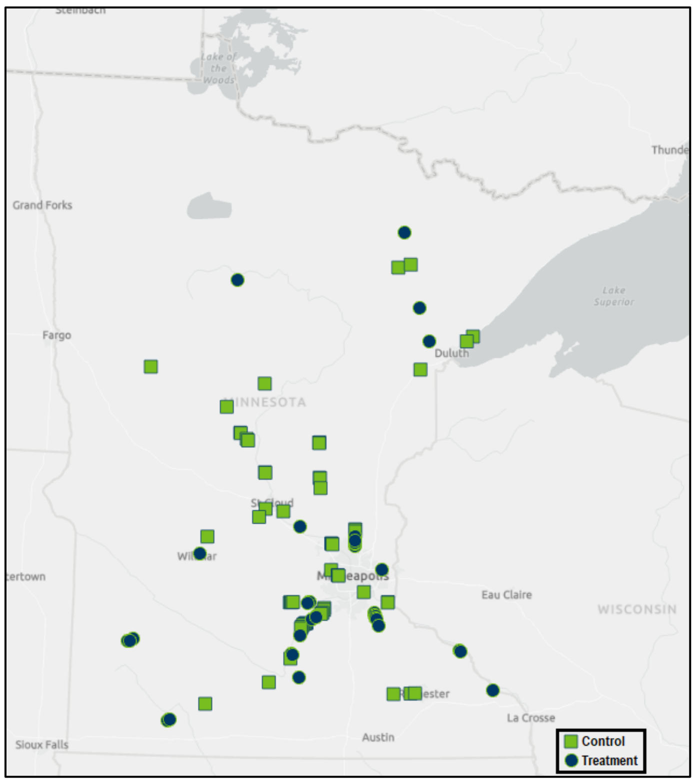

Figure 4.2 – Locations for Comparative Treatment-Control Analysis

4.2.3 Crash Data

The comparative treatment-control analysis involved a before period and an after period at the treatment and control sites. At the treatment sites, the before period was a three-year period before a J-turn was installed, and the after period was the three years from 2020 through 2022 where a J-turn was in place. At the control sites, the before period was the three years from 2017 through 2019 and the after period was the three years from 2020 through 2022. The change in crash rates from before to after at the treatment sites was compared to the change in crash rates from before to after at the control sites. As noted, fatal and serious injury crashes increased on Minnesota roadways in 2021 and 2022 making the need for a comparison to control sites even more important to see the impact of J-turns.

The comparative treatment-control analysis crash data at the 38 J-turn locations (treatment) and 61 non-J-turn locations (control) was collected and compiled. Table 4.3 shows the entering volumes for each scenario that were used in the analysis. Table 4.4 shows the compiled crash data. Crash rates, in units of crashes per million entering vehicles (MEV), for the before and after scenarios are shown in Table 4.5.

Table 4.3 – Comparative Treatment-Control Analysis Entering Volumes

	Treatment Before	Treatment After	Control Before	Control After
Total Entering Volume	819,387,147	834,397,546	1,343,400,020	1,274,055,747

Table 4.4 - Comparative Treatment-Control Analysis Crash Counts

Crash Severity/Type	Treatment Before # of Crashes	Treatment After # of Crashes	Control Before # of Crashes	Control After # of Crashes
Total Crashes	342	284	341	306
K Crashes	8	2	6	8
A Crashes	16	6	12	9
KA Crashes	24	8	18	17
B Crashes	68	36	50	48
KAB Crashes	92	44	68	65
C Crashes	69	32	57	64
KABC Crashes	161	76	125	129
PDO Crashes	181	208	216	176
Angle Crashes	137	47	136	136
KA Angle Crashes	17	2	12	14
Rear-End Crashes	59	101	56	42
Sideswipe Crashes	36	27	40	38
Intersection Related Crashes	216	123	227	203

Table 4.5 - Comparative Treatment-Control Analysis Crash Rates

Crash Severity/Type	Treatment Before Crash Rate	Treatment After Crash Rate	Control Before Crash Rate	Control After Crash Rate
Total Crashes	0.417	0.340	0.254	0.240
K Crashes	0.010	0.002	0.004	0.006
A Crashes	0.020	0.007	0.009	0.007
KA Crashes	0.029	0.010	0.013	0.013
B Crashes	0.083	0.043	0.037	0.038
KAB Crashes	0.112	0.053	0.051	0.051
C Crashes	0.084	0.038	0.042	0.050
KABC Crashes	0.196	0.091	0.093	0.101
PDO Crashes	0.221	0.249	0.161	0.138
Angle Crashes	0.167	0.056	0.101	0.107
KA Angle Crashes	0.021	0.002	0.009	0.011
Rear-End Crashes	0.072	0.121	0.042	0.033
Sideswipe Crashes	0.044	0.032	0.030	0.030
Intersection Related Crashes	0.264	0.147	0.169	0.159

4.2.4 Crash Analysis

For the comparative treatment-control crash data analysis, an independent sample t-test was used. This test is used to compare two related (or dependent) samples with independent observations. This tests the assumptions of a null hypothesis and since this test takes all of the observed values, the measure we are using for each group's average will be its mean value. For this analysis, the null hypothesis being tested is that the mean difference between pairs of observations from the two groups (J-turn treatment and control) is equal to zero. The alternative hypothesis being tested is that the mean difference between pairs of observations from the two groups is not equal to zero. Here, the observations being compared are the sites' crash reduction factors, or the observed percentage decrease in crashes at the treatment and control sites.

The independent sample t-test produces a test statistic with a corresponding p-value, which is then compared to a predetermined alpha level (in this case, alpha = 0.10) to evaluate the null hypothesis. If the test produces a result with a p-value that is less than that threshold alpha level, the null hypothesis is rejected in favor of the alternative hypothesis suggesting there is a significant difference between the results of the two groups. The results are shown in Table 4.6.

Table 4.6 - Comparative Treatment-Control Analysis Results

Category	Treatment Change in Crash Rate	Control Change in Crash Rate	p-value	Significant?	Result Interpretation
KA Crashes	**-67%**	**0%**	**0.013**	**Yes**	**KA crash rates at J-turns decreased more than at controls**
KABC Crashes	**-54%**	**+9%**	**0.001**	**Yes**	**KABC crash rates at J-turns decreased more than at controls**
Angle Crashes	**-66%**	**+5%**	**0.001**	**Yes**	**Angle crash rates at J-turns decreased more than at controls**
KA Angle Crashes	**-88%**	**+23%**	**0.010**	**Yes**	**KA angle crash rates at J-turns decreased more than at controls**
Rear-End Crashes	**+68%**	**-21%**	**0.005**	**Yes**	**Rear-end crash rates at J-turns increased more than at controls**
Sideswipe Crashes	-26%	0%	0.414	No	Sideswipe crash rates at J-turns did not change more than at controls
Total Crashes	**-18%**	**-5%**	**0.100**	**Yes**	**Total crash rates at J-turns decreased more than at controls**

As seen in Table 4.6, the J-turn sites showed decreases in fatal and serious injury (KA) crash rates, all injury (KABC) crash rates, angle crash rates, and fatal and serious injury (KA) angle crash rates that were statistically significantly larger than changes at the control sites. These results line up with the goals of J-turns and are similar to what was seen in the before-after analysis. The installation of J-turns also showed a statistically significant increase in rear-end crash rates with no statistically significant changes at the 0.05 significance level for sideswipe or total crash rates. However, at the 0.10 significance level the decrease in total crash rates at J-turns was larger than that of the control intersections suggesting that not only are J-turns reducing severe crashes, but they may also be reducing total overall crashes.

This analysis aimed to answer the question "How much of the crash reduction can be attributed to J-turns?" which was posed in section 4.2.1. Based on this analysis the answer is that the changes seen in the before-after analysis for KA, KABC, angle, KA angle, and rear-end crash rates can be attributed to J-turns. Additionally, a reduction in total crashes can be attributed to J-turns.

4.3 CROSS-SECTIONAL J-TURN, LOW-VOLUME INTERCHANGE, AND RURAL SIGNAL ANALYSIS

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

This analysis compares the crash data at interchanges with volumes similar to what would be found at a J-turn as well as at signalized intersections with volumes and characteristics similar to what would be found at a J-turn to the crash data at J-turns.

4.3.1 Question Addressed

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

4.3.2 Locations

There are over 700 interchanges in Minnesota including many that serve very high volumes of traffic. To be able to get a set of interchanges that would be able to be meaningfully compared to J-turns, the volumes had to be considered. High volume interchanges, such as those that serve the meeting of two Interstate Highway System routes, would not be locations where a J-turn would ever be considered. Because of that, only low-volume interchanges were selected. Low volume, in this case, means daily volumes of 45,000 or less on the mainline with average daily volumes of 7,500 or less on the minor approaches. These volumes represent the upper end of the volumes seen at J-turns in Minnesota. Using those filters, 202 interchanges were selected and crash data from 2020 through 2022 was used.

Signalized intersections are utilized on a wide variety of intersection types, so to get a meaningful comparison site for J-turns, only signalized intersections that are on high-speed, rural roadways with the same volume constraints as the low-volume interchanges were used. Signalized intersections that include interchange ramps were not included. Using those filters, 24 intersections were selected and crash data from 2020 through 2022 was used. MnDOT has been working to convert these types of intersections that have poor crash history away from signal control, typically to low volume interchanges. Those that remain tend to be the signalized intersections that operate within crash parameters that can be deemed acceptable.

Like in the comparative treatment-control analysis from section 4.2 of this report, the 38 J-turn locations that were fully in place from 2020 through 2022 were used for this comparison. Using only 2020 through

2022 data avoids any inconsistencies between the pre-2016 and post-2016 crash data due to the statewide changes previously discussed.

4.3.3 Crash Data

The area included when gathering crash data at J-turns was previously discussed. For low-volume interchanges, all crashes that were located within 100 feet of the physical gore or curb at the outermost connection of the interchange were included. For rural, high-speed signals, all crashes that were within 50 feet of the bounds of the turn lanes on all approaches were included.

The following tables show the total entering volumes, the number of crashes, and crash rates (crashes per MEV) from 2020 through 2022 at the selected locations.

Table 4.7 - 2020-2022 Cross-Sectional Analysis Entering Volumes

	J-turn (38 sites)	Rural Signals (24 sites)	Low-Volume Interchanges (202 sites)
Total Entering Volume	834,397,546	458,877,664	2,328,795,048

Table 4.8 - 2020-2022 Cross-Sectional Analysis Crash Counts

Crash Type/Severity	J-turn (38 sites)	Rural Signals (24 sites)	Low-Volume Interchanges (202 sites)
Total Crashes	284	342	1,662
K Crashes	2	1	6
A Crashes	6	2	29
KA Crashes	8	3	35
B Crashes	36	36	144
KAB Crashes	44	39	179
C Crashes	32	59	153
KABC Crashes	76	98	332
PDO Crashes	208	244	1,328
Angle Crashes	47	92	215
KA Angle Crashes	2	1	9
Rear-End Crashes	101	169	232
Sideswipe Crashes	27	25	171
Intersection Related Crashes	123	296	271

Table 4.9 - 2020-2022 Cross-Sectional Analysis Crash Rates

Crash Type/Severity	J-turn (38 sites)	Rural Signals (24 sites)	Low-Volume Interchanges (202 sites)
Total Crashes	0.340	0.745	0.714
K Crashes	0.002	0.002	0.003
A Crashes	0.007	0.004	0.012
KA Crashes	0.010	0.007	0.015
B Crashes	0.043	0.078	0.062
KAB Crashes	0.053	0.085	0.077
C Crashes	0.038	0.129	0.066
KABC Crashes	0.091	0.214	0.143
PDO Crashes	0.249	0.532	0.570
Angle Crashes	0.056	0.200	0.092
KA Angle Crashes	0.002	0.002	0.004
Rear-End Crashes	0.121	0.368	0.100
Sideswipe Crashes	0.032	0.054	0.073
Intersection Related Crashes	0.147	0.645	0.116

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

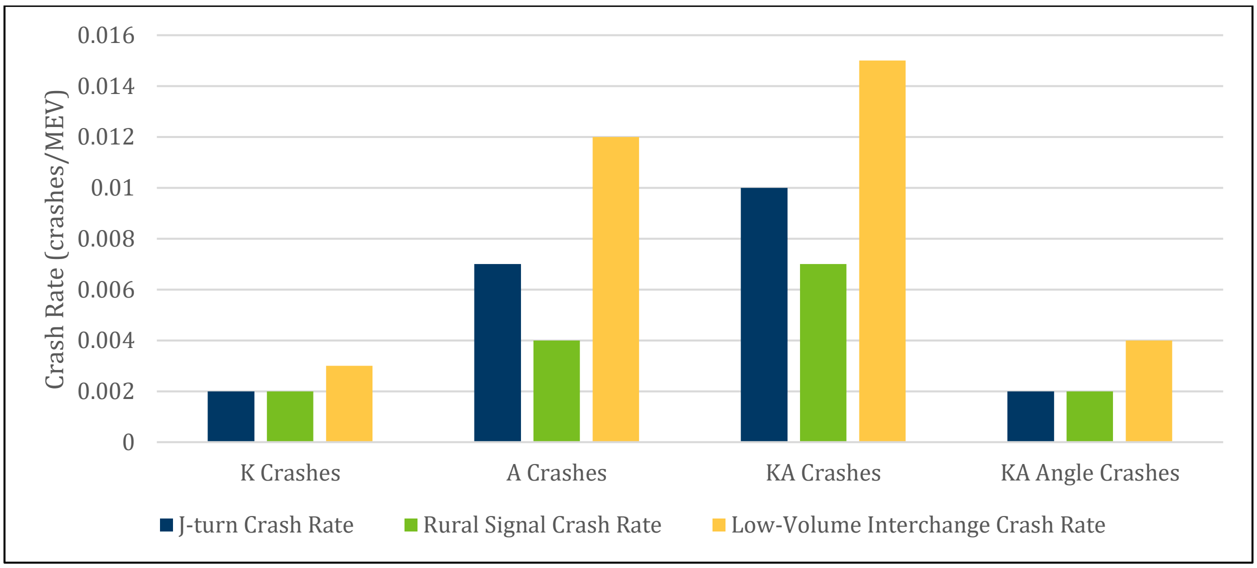

Figure 4.3 – Cross-Sectional Analysis Severe Crash Rates

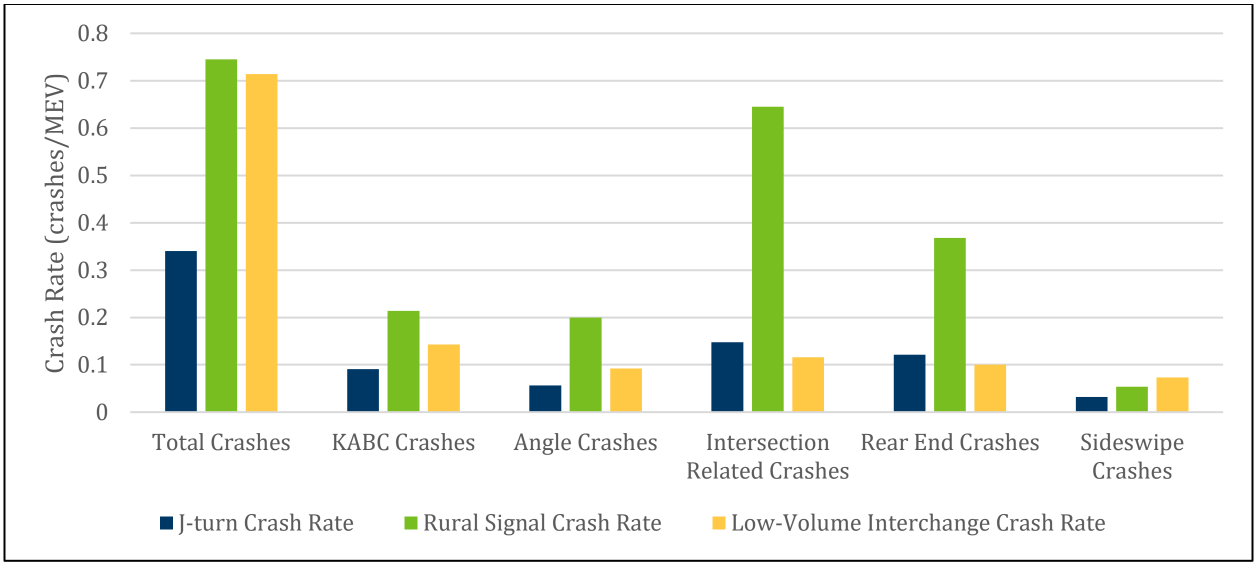

Figure 4.4 – Cross-Sectional Analysis Other Crash Rates

4.3.4 Crash Analysis

Using the crash and traffic volume data, any statistically significant differences between crash rates for these three intersection types were assessed. To test for any differences between these three types of intersection designs an independent samples t-test was conducted for each combination of two subgroups. Each of these comparisons tested the null hypothesis, which in this case was that there was zero difference between how much the two groups' crash rates decreased (or increased) on average. The results of this testing are shown in Table 4.10. Any crash types or severities that did not have a statistical significance difference between the intersection types are not included in Table 4.10.

Table 4.10 - 2020-2022 Cross-Sectional Analysis Results

Crash Type/Severity	J-turns vs Interchanges p-value	J-turns vs Signals p-value	Signals vs Interchanges p-value	Result Interpretation
B Crashes	**0.087***	0.288	0.906	Interchange crash rate > J-turn crash rate
C Crashes	**0.064***	**0.040**	0.329	Interchange crash rate > J-turn crash rate & Signal crash rate > J-turn crash rate
PDO Crashes	**<0.001**	0.154	0.170	Interchange crash rate > J-turn crash rate
Total Crashes	**<0.001**	0.103	0.290	Interchange crash rate > J-turn crash rate
Angle Crashes	0.133	**0.014**	**0.082***	Signal crash rate > J-turn crash rate & Signal crash rate > Interchange crash rate
Intersection Related Crashes	0.634	**<0.001**	**<0.001**	Signal crash rate > J-turn crash rate & Signal crash rate > Interchange crash rate
Rear-End Crashes	0.794	**0.002**	**0.001**	Signal crash rate > J-turn crash rate & Signal crash rate > Interchange crash rate
Sideswipe Crashes	**0.007**	0.362	0.259	Interchange crash rate > J-turn crash rate
KAB Crashes	**0.051***	0.362	0.617	Interchange crash rate > J-turn crash rate
KABC Crashes	**0.020**	**0.074***	0.798	Interchange crash rate > J-turn crash rate & Signal crash rate > J-turn crash rate

*Statistically significant at $\alpha = 0.10$

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

- The average crash rate for property damage only crashes, total crashes, sideswipe crashes, and KABC crashes at low volume interchanges are higher than at J-turns.
- The average crash rate for C crashes, angle crashes, intersection related crashes, and rear-end crashes at rural high-speed signals are higher than at J-turns.

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

- The average crash rate for B crashes, C crashes, and KAB crashes at low volume interchanges is higher than at J-turns.
- The average crash rate for KABC crashes at rural high-speed signals is higher than at J-turns.

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

J-turns tend to have lower crash rates compared to low-volume interchanges when it comes to overall crashes and injury crashes, and lower crash rates compared to signals when it comes to angle crashes. The low rate of angle crashes at J-turns is in line with the other results from this study. Though the before-after and comparative treatment-control analyses showed increases in rear-end crashes at J-turns, they are statistically significantly lower than at signals.

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

This analysis aimed to answer the question "How do J-turns compare with alternative strategies for high-speed expressway intersections?" which was posed in section 4.3.1. Based on this analysis the answer is that J-turns have favorable safety results with lower overall and injury crash rates than interchanges as well as lower angle, rear-end, and intersection-related crashes than rural, high-speed signals.

4.4 J-TURN MAINLINE AADT ANALYSIS

The mainline average annual daily traffic (AADT) at the existing J-turns in Minnesota range from as low as approximately 3,000 to 41,000 vehicles per day. Overall, J-turns have had good safety performance in Minnesota, but this analysis aims to see if the safety performance of J-turns differs with different mainline AADTs.

4.4.1 Question Addressed

How do crashes at J-turns differ based on the mainline AADTs?

4.4.2 Locations

Upon review of the average mainline traffic volumes of the 54 J-turns from the before-after analysis, it was determined that there was a relatively even distribution of site traffic volumes, which made it possible to create three similar-sized J-turn subgroups based on their mainline AADTs:

- 15 J-turns with less than 10,000 AADT
- 19 J-turns with 10,000 to 20,000 AADT
- 20 J-turns with more than 20,000 AADT

4.4.3 Crash Data

The same years and crash data utilized in the before-after analysis were utilized in this analysis. The following tables show the total entering volumes, the number of crashes, and the crash rates (crashes per MEV) for each category.

Table 4.11 – Mainline AADT Analysis Entering Volumes

	Mainline AADT <10k Before (15 sites)	Mainline AADT <10k After (15 sites)	Mainline AADT 10k – 20k Before (19 sites)	Mainline AADT 10k – 20k After (19 sites)	Mainline AADT >20k Before (20 sites)	Mainline AADT >20k After (20 sites)
Total Entering Volume	221,392,252	194,656,033	418,997,982	431,848,423	999,104,989	1,063,227,471

Table 4.12 – Mainline AADT Analysis Crash Volumes

Crash Severity/Type	Mainline AADT <10k Before Crash Count (15 sites)	Mainline AADT <10k After Crash Count (15 sites)	Mainline AADT 10k – 20k Before Crash Count (19 sites)	Mainline AADT 10k – 20k After Crash Count (19 sites)	Mainline AADT >20k Before Crash Count (20 sites)	Mainline AADT >20k After Crash Count (20 sites)
Total Crashes	155	71	230	248	348	358
K Crashes	2	0	8	2	5	1
A Crashes	11	2	4	5	12	9
KA Crashes	13	2	12	7	17	10
B Crashes	29	9	33	29	61	30
KAB Crashes	42	11	45	36	78	40
C Crashes	39	13	48	27	73	57
KABC Crashes	81	24	93	63	151	97
PDO Crashes	74	47	137	185	197	261
Angle Crashes	86	10	107	45	110	47
KA Angle Crashes	11	0	10	3	10	1
Rear-End Crashes	10	21	42	91	60	117
Sideswipe Crashes	11	6	25	25	39	48
Intersection Related	124	38	166	152	170	116

Table 4.13 – Mainline AADT Analysis Crash Rates

Crash Severity/Type	Mainline AADT <10k Before Crash Rate (15 sites)	Mainline AADT <10k After Crash Rate (15 sites)	Mainline AADT 10k – 20k Before Crash Rate (19 sites)	Mainline AADT 10k – 20k After Crash Rate (19 sites)	Mainline AADT >20k Before Crash Rate (20 sites)	Mainline AADT >20k After Crash Rate (20 sites)
Total Crashes	0.700	0.365	0.549	0.574	0.348	0.337
K Crashes	0.009	0.000	0.019	0.005	0.005	0.001
A Crashes	0.050	0.010	0.010	0.012	0.012	0.008
KA Crashes	0.059	0.010	0.029	0.016	0.017	0.009
B Crashes	0.131	0.046	0.079	0.067	0.061	0.028
KAB Crashes	0.190	0.057	0.107	0.083	0.078	0.038
C Crashes	0.176	0.067	0.115	0.063	0.073	0.054
KABC Crashes	0.366	0.123	0.222	0.146	0.151	0.091
PDO Crashes	0.334	0.241	0.327	0.428	0.197	0.245
Angle Crashes	0.388	0.051	0.255	0.104	0.110	0.044
KA Angle Crashes	0.050	0.000	0.024	0.007	0.010	0.001
Rear-End Crashes	0.045	0.108	0.100	0.211	0.060	0.110
Sideswipe Crashes	0.050	0.031	0.060	0.058	0.039	0.045
Intersection Related Crashes	0.560	0.195	0.396	0.352	0.170	0.109

Figures 4.5 and 4.6 illustrate the after crash rates of some of the target crash types from Table 4.13. The crash rates from the before portion of the before-after analysis are also included in the figures for reference. These are the crash rates at intersections before a J-turn was installed.

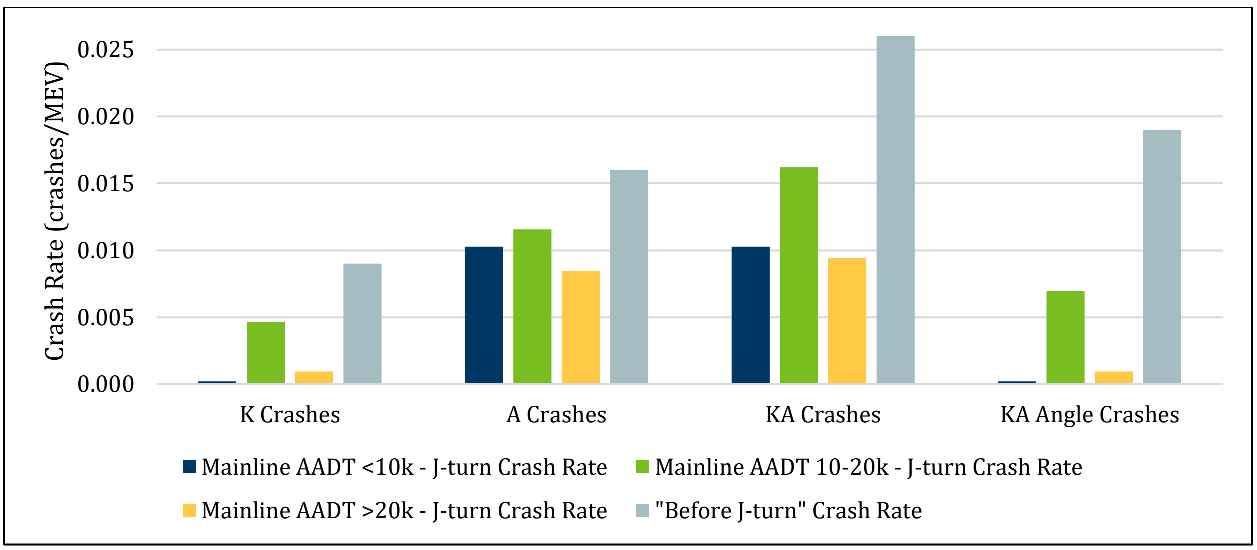

Figure 4.5 – Mainline AADT Analysis Severe Crash Rates

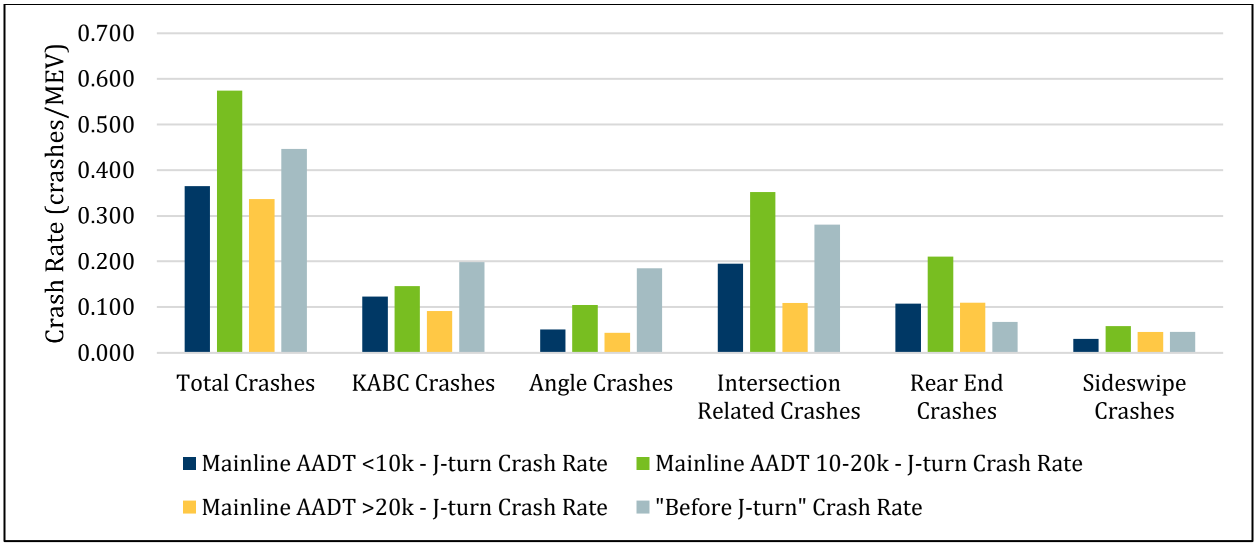

Figure 4.6 – Mainline AADT Analysis Other Crash Rates

4.4.4 Crash Analysis

Using the crash and traffic volume data, any statistically significant differences between crash rates for these three groups were checked. Using the sample crash and traffic volume data, any statistically significant differences between crash rates for these three subgroups based on daily vehicle traffic were assessed. To test for any differences in crash rates, an independent samples t-test was conducted for each combination of two subgroups. Each of these comparisons tested the null hypothesis, which in this case was that there was zero difference between how much any two groups' crash rates decreased (or increased) on average.

Table 4.14 - Mainline AADT Analysis Results

Crash Severity/Type	Mainline AADT <10k Change in Crash Rate	Mainline AADT 10k – 20k Change in Crash Rate	Mainline AADT >20k Change in Crash Rate
Total Crashes	-48%	+5%	-3%
K Crashes	-100%	-76%	-81%
A Crashes	-79%	+21%	-30%
KA Crashes	-83%	-43%	-45%
B Crashes	-65%	-15%	-54%
KAB Crashes	-70%	-22%	-52%
C Crashes	-62%	-45%	-27%
KABC Crashes	-66%	-34%	-40%
PDO Crashes	-28%	+31%	+24%
Angle Crashes	**-87%***	-59%	-60%
KA Angle Crashes	**-100%****	-71%	-91%
Rear-End Crashes	+139%	+110%	+83%
Sideswipe Crashes	-38%	-3%	+16%
Intersection Related Crashes	-65%	-11%	-36%

*Statistically significantly larger decrease than AADT 10k-20k at $\alpha = 0.10$, and AADT >20k at $\alpha = 0.05$.
**Statistically significantly larger decrease than other categories at $\alpha = 0.10$

As can be seen in Table 4.14, each of the three groups saw large reductions in injury and angle crashes indicating that J-turns are performing well at each of these volume thresholds. Comparing the changes in crash rates of the three groups against each other, the J-turns with mainline AADT of less than 10,000 vehicles had statistically significantly larger decreases in angle crash rates and KA angle crash rates than the other two groups.

This analysis aimed to answer the question "How do crashes at J-turns differ based on the mainline AADTs?" which was posed in section 4.4.1. Based on this analysis the answer is that J-turns are seeing positive safety benefits on roads with a wide range of AADTs. Intersections with mainline AADTs of less than 10,000 vehicles a day saw the biggest reductions in angle and KA angle crashes when a J-turn was installed.

4.5 J-TURN MAINLINE LEFT TURN ANALYSIS

Most of the J-turns in Minnesota have at least one channelized left turn lane for mainline traffic to turn directly onto the minor road. This mainline left turn movement still presents the opportunity for an angle crash at the intersection, and as can be seen in Figure C.2 in Appendix C, approximately one third of angle crashes at J-turns are caused by this mainline left turning movement. Mainline vehicles wanting to turn left can use the U-turn, so the mainline left turn is not necessary for the intersection to serve all movements, though it does provide a level of convenience for drivers. This analysis aims to see if J-turns that provide one or two mainline left turns (as shown in Figure 1.3) see a different safety performance compared to J-turns that do not have any mainline left turns (as shown in Figure 1.2).

4.5.1 Question Addressed

How do crashes at J-turns differ when comparing J-turns with mainline left turn lanes vs J-turns without mainline left turn lanes?

4.5.2 Locations

Using the 54 J-turns from the before-after analysis, J-turns were grouped into two categories based on if they had a mainline left turn present or not:

- 45 J-turns have mainline left turns
- 9 J-turns do not have mainline left turns

4.5.3 Crash Data

The same years and crash data utilized in the before-after analysis were utilized in this analysis. The following tables show the total entering volumes, the number of crashes, and the crash rates (crashes per MEV) for each category.

Table 4.15 – Mainline Left Turn Analysis Entering Volumes

	With Mainline Left Turns Before (45 sites)	With Mainline Left Turns After (45 sites)	Without Mainline Left Turns Before (9 sites)	Without Mainline Left Turns After (9 sites)
Total Entering Volume	1,411,331,074	1,434,254,949	228,164,149	255,476,978

Table 4.16 – Mainline Left Turn Analysis Crash Volumes

Crash Severity/Type	With Mainline Left Turns Before Crash Count (45 sites)	With Mainline Left Turns After Crash Count (45 sites)	Without Mainline Left Turns Before Crash Count (9 sites)	Without Mainline Left Turns After Crash Count (9 sites)
Total Crashes	692	616	41	61
K Crashes	14	3	1	0
A Crashes	26	16	1	0
KA Crashes	40	19	2	0
B Crashes	122	64	1	4
KAB Crashes	162	83	3	4
C Crashes	148	88	12	9
KABC Crashes	310	171	15	13
PDO Crashes	382	445	26	48
Angle Crashes	290	95	13	7
KA Angle Crashes	31	4	0	0
Rear-End Crashes	107	214	5	15
Sideswipe Crashes	68	71	7	8
Intersection Related Crashes	438	287	22	19

Table 4.17 – Mainline Left Turn Analysis Crash Rates

Crash Severity/Type	With Mainline Left Turns Before Crash Rate (45 sites)	With Mainline Left Turns After Crash Rate (45 sites)	Without Mainline Left Turns Before Crash Rate (9 sites)	Without Mainline Left Turns After Crash Rate (9 sites)
Total Crashes	0.490	0.429	0.180	0.239
K Crashes	0.010	0.002	0.004	0.000
A Crashes	0.018	0.011	0.004	0.000
KA Crashes	0.028	0.013	0.009	0.000
B Crashes	0.086	0.045	0.004	0.016
KAB Crashes	0.115	0.058	0.013	0.016
C Crashes	0.105	0.061	0.053	0.035
KABC Crashes	0.220	0.119	0.066	0.051
PDO Crashes	0.271	0.310	0.114	0.188
Angle Crashes	0.205	0.066	0.057	0.027
KA Angle Crashes	0.022	0.003	0.000	0.000
Rear-End Crashes	0.076	0.149	0.022	0.059
Sideswipe Crashes	0.048	0.050	0.031	0.031
Intersection Related Crashes	0.310	0.200	0.096	0.074

Figures 4.7 and 4.8 illustrate the after crash rates of some of the target crash types from Table 4.17. The crash rates from the before portion of the before-after analysis are also included in the figures for reference. These are the crash rates at intersections before a J-turn was installed.

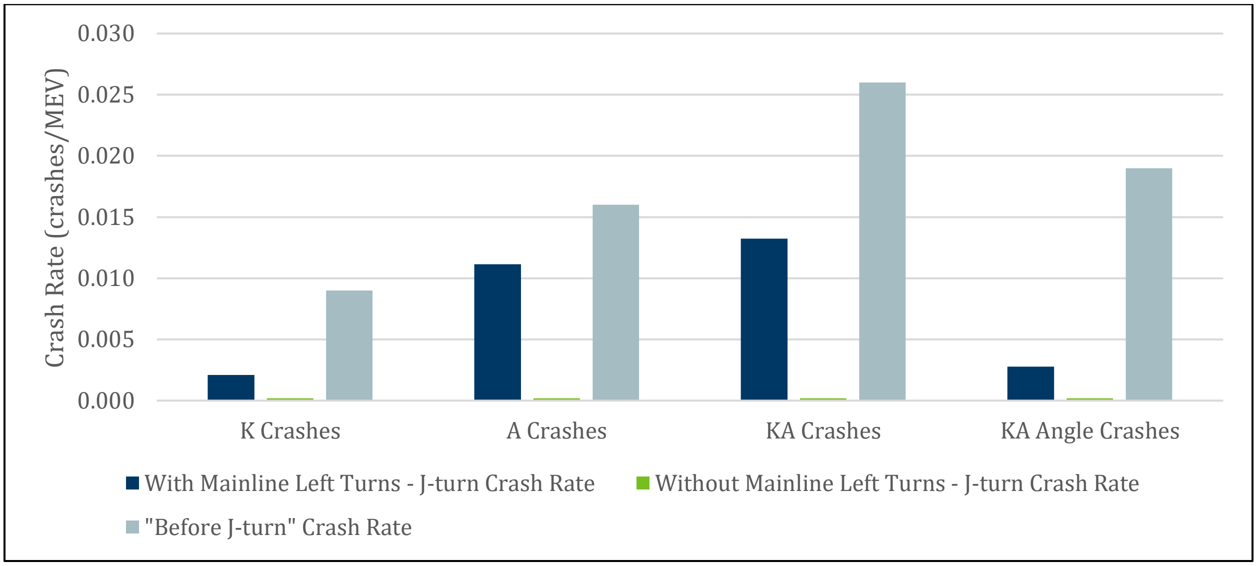

Figure 4.7 – Mainline Left Turn Analysis Severe Crash Rates

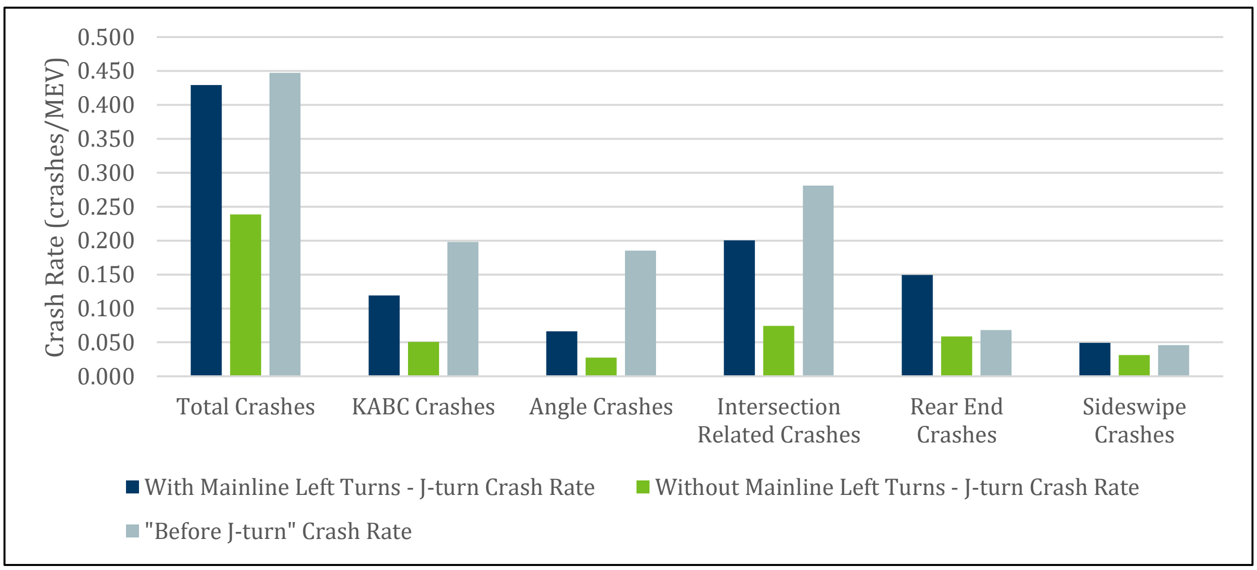

Figure 4.8 – Mainline Left Turn Analysis Other Crash Rates

4.5.4 Crash Analysis

Using the sample crash data, any statistically significant differences between crash rates for these two subgroups based on U-turn distance were assessed. To test for any differences in crash rates, an independent samples t-test was conducted to compare the two subgroups. The comparison tests the observed crash rates from the two subgroups against the null hypothesis, which in this case was that there was zero difference between how much the two groups' crash rates decreased (or increased) on average.

Table 4.18 - Mainline Left Turn Analysis Results

Crash Severity/Type	With Mainline Left Turns Change in Crash Rate	Without Mainline Left Turns Change in Crash Rate
Total Crashes	-12%	33%
K Crashes	-79%	-100%
A Crashes	-39%	-100%
KA Crashes	-53%	-100%
B Crashes	-48%	257%
KAB Crashes	-50%	19%
C Crashes	-41%	-33%
KABC Crashes	-46%	-23%
PDO Crashes	15%	65%
Angle Crashes	**-68%***	-52%
KA Angle Crashes	-87%*	n/a
Rear-End Crashes	97%	168%
Sideswipe Crashes	3%	2%
Intersection Related Crashes	-36%	-23%

*Statistically significantly larger decrease than other categories at $\alpha = 0.10$

As can be seen in Table 4.18, both of the groups saw large reductions in injury and angle crashes indicating that J-turns are performing well with both layout types. J-turns with mainline left turns had statistically significantly larger decreases in angle crash rates and KA angle crash rates than J-turns without mainline left turns, however there were no KA angle crashes at J-turns without mainline left turns. Additionally, J-turns with mainline left turns have historically been put at locations with higher turning volumes so there were more angle crashes in the before period leading to the ability to have greater reductions.

Looking at Table 4.17 as well as Figures 4.5 and 4.6, it is illustrated that J-turns without mainline left turns have lower crash rates across the board than J-turns with mainline left turns. In Figure C.2 in Appendix C, it is shown that 36% of angle crashes happening at J-turns involve mainline left turning vehicles. Based on these findings, though not statistically significant, J-turns without mainline left turns appear to be a safer choice than J-turns with mainline left turns.

This analysis aimed to answer the question "How do crashes at J-turns differ when comparing J-turns with mainline left turn lanes vs J-turns without mainline left turn lanes?" which was posed in section 4.5.1. Based on this analysis the answer is that J-turns with and without mainline left turn lanes both show positive safety benefits when installed, though J-turns without mainline left turn lanes have lower crash rates for all crash types studied.

4.6 J-TURN U-TURN LANE ENTRY LOCATION ANALYSIS

Vehicles on the minor road wishing to make a through or left turning movement at a J-turn need to turn right onto the mainline and utilize the U-turn to head in their desired direction. There is a dedicated turn lane for each U-turn at J-turns. At some J-turns, this U-turn turn lane is extended all the way back to the minor road which allows minor road vehicles to turn directly into the U-turn lane. At some other J-turns, the taper for the U-turn lane begins close to the minor road, within 100 feet or so, which allows minor road vehicles to merge over rather quickly into the U-turn lane. Lastly, at other J-turns the U-turn lane begins further downstream of the minor road, so those vehicles need to turn onto the mainline through lanes and then merge over into the turn lane. This analysis aims to see if the safety performance of J-turns differs when the U-turn lane is extended to the minor road compared to when it is not.

4.6.1 Question Addressed

How do crashes at J-turns differ when comparing J-turns with the U-turn lane extended to the minor road vs J-turns with the U-turn lane beginning close to the minor road vs J-turns with the U-turn lane beginning downstream of the minor road?

4.6.2 Locations

Using the 54 J-turns from the before-after analysis, J-turns were grouped into four categories based on where the U-turn lane begins:

- 24 J-turns have the U-turn lane extended to the minor road.
- 20 J-turns have the taper for the U-turn lane extended nearly to the minor road.
- 6 J-turns have the start of the U-turn lane downstream of the minor road.
- 4 J-turns have a different scenario for each minor road to U-turn. These were not used in the analysis.

4.6.3 Crash Data

The same years and crash data utilized in the before-after analysis were utilized in this analysis. The following tables show the total entering volumes, the number of crashes, and the crash rates (crashes per MEV) for each category.

Table 4.19 – U-turn Lane Entry Location Analysis Entering Volumes

	Direct to U-Turn Before (24 sites)	Direct to U-Turn After (24 sites)	Nearly direct to U-Turn Before (20 sites)	Nearly direct to U-Turn After (20 sites)	Not direct to U-Turn Before (6 sites)	Not direct to U-Turn After (6 sites)
Total Entering Volume	576,175,926	586,247,683	457,490,502	494,400,383	398,558,215	378,625,644

Table 4.20 – U-turn Lane Entry Location Analysis Crash Volumes

Crash Severity/Type	Direct to U-Turn Before Crash Count (24 sites)	Direct to U-Turn After Crash Count (24 sites)	Nearly direct to U-Turn Before Crash Count (20 sites)	Nearly direct to U-Turn After Crash Count (20 sites)	Not direct to U-Turn Before Crash Count (6 sites)	Not direct to U-Turn After Crash Count (6 sites)
Total Crashes	229	275	188	153	223	125
K Crashes	9	1	2	1	4	1
A Crashes	5	6	9	4	10	2
KA Crashes	14	7	11	5	14	3
B Crashes	31	30	30	17	47	14
KAB Crashes	45	37	41	22	61	17
C Crashes	46	34	45	17	44	24
KABC Crashes	91	71	86	39	105	41
PDO Crashes	138	204	102	114	118	84
Angle Crashes	92	51	87	22	94	18
KA Angle Crashes	11	2	9	1	10	1
Rear-End Crashes	37	110	30	42	30	32
Sideswipe Crashes	30	25	15	16	21	18
Intersection Related Crashes	164	156	142	66	108	45

Table 4.21 – U-turn Lane Entry Location Analysis Crash Rates

Crash Severity/Type	Direct to U-Turn Before Crash Rate (24 sites)	Direct to U-Turn After Crash Rate (24 sites)	Nearly direct to U-Turn Before Crash Rate (20 sites)	Nearly direct to U-Turn After Crash Rate (20 sites)	Not direct to U-Turn Before Crash Rate (6 sites)	Not direct to U-Turn After Crash Rate (6 sites)
Total Crashes	0.397	0.469	0.411	0.309	0.560	0.330
K Crashes	0.016	0.002	0.004	0.002	0.010	0.003
A Crashes	0.009	0.010	0.020	0.008	0.025	0.005
KA Crashes	0.024	0.012	0.024	0.010	0.035	0.008
B Crashes	0.054	0.051	0.066	0.034	0.118	0.037
KAB Crashes	0.078	0.063	0.090	0.044	0.153	0.045
C Crashes	0.080	0.058	0.098	0.034	0.110	0.063
KABC Crashes	0.158	0.121	0.188	0.079	0.263	0.108
PDO Crashes	0.240	0.348	0.223	0.231	0.296	0.222
Angle Crashes	0.160	0.087	0.190	0.044	0.236	0.048
KA Angle Crashes	0.019	0.003	0.020	0.002	0.025	0.003
Rear-End Crashes	0.064	0.188	0.066	0.085	0.075	0.085
Sideswipe Crashes	0.052	0.043	0.033	0.032	0.053	0.048
Intersection Related Crashes	0.285	0.266	0.310	0.133	0.271	0.119

Figures 4.9 and 4.10 illustrate the after crash rates of some of the target crash types from Table 4.21. The crash rates from the before portion of the before-after analysis are also included in the figures for reference. These are the crash rates at intersections before a J-turn was installed.

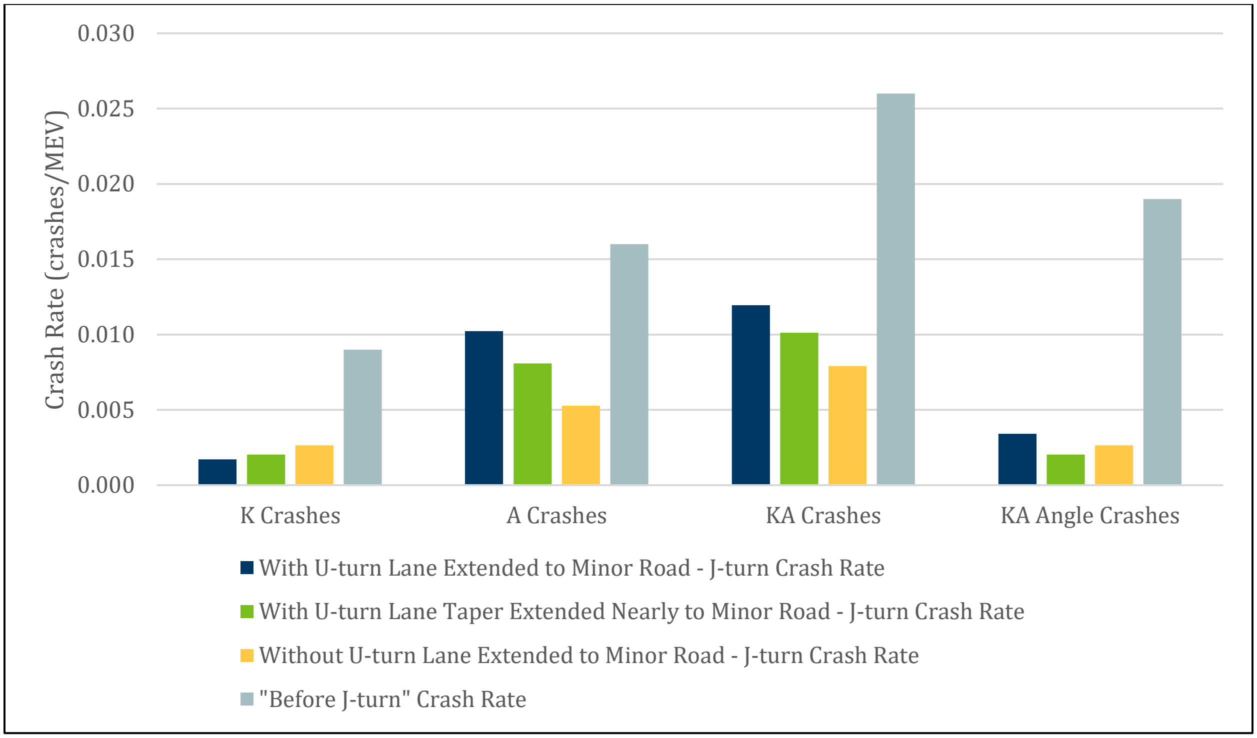

Figure 4.9 – U-turn Entry Location Analysis Severe Crash Rates

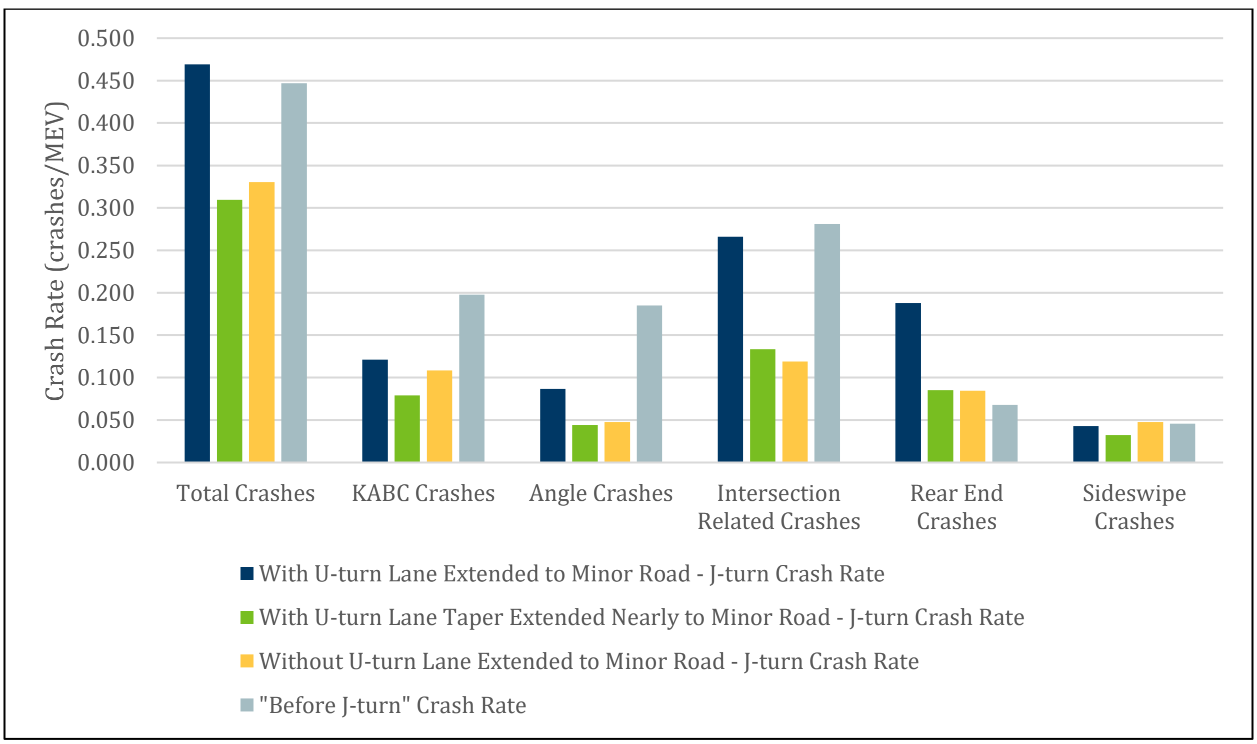

Figure 4.10 – U-turn Entry Location Analysis Other Crash Rates

4.6.4 Crash Analysis

Using the crash data for the three site subgroups, any statistically significant differences between crash rates for these three J-turn configurations were assessed. To test for any differences between the three possible designs of the U-turn lane entry points, an independent samples t-test was conducted for each combination of two subgroups. Each of these comparisons tested the null hypothesis, which in this case was that there was zero difference between how much the two groups' crash rates decreased (or increased) on average.

Table 4.22 - U-turn Lane Entry Location Analysis Results

Crash Severity/Type	Direct to U-Turn Change in Crash Rate	Nearly direct to U-Turn Change in Crash Rate	Not direct to U-Turn Change in Crash Rate
Total Crashes	+18%	-25%	-41%
K Crashes	-89%	-54%	-74%
A Crashes	+18%	-59%	-79%
KA Crashes	-51%	-58%	-77%
B Crashes	-5%	-48%	-69%
KAB Crashes	-19%	-50%	-71%
C Crashes	-27%	**-65%***	-43%
KABC Crashes	-23%	-58%	-59%
PDO Crashes	+85%	+3%	-25%
Angle Crashes	-46%	**-77%***	-80%
KA Angle Crashes	-82%	-90%	-89%
Rear-End Crashes	+192%	+30%	+12%
Sideswipe Crashes	-18%	-1%	-10%
Intersection Related Crashes	-7%	-57%	-56%

*Statistically significantly larger decrease than Direct to U-turn at $\alpha = 0.10$

As can be seen in Table 4.22, all three groups saw large reductions in injury and angle crashes indicating that J-turns are performing well with all of the different layout types. The J-turns with nearly direct access to the U-turn lane had statistically significantly larger decreases in C crash rates and angle crash rates than the J-turns with direct access to the U-turn lane. This is possible due to drivers perceiving they need a larger gap in traffic to get to the U-turn lane from the minor road when there is not direct access to it.

It is noted there were not significant differences between KA or KA angle crash rates, though the J-turns with direct access to the U-turn lane had the highest KA, angle, and KA angle crash rates. The J-turns with direct access to the U-turn lane from the minor road saw a jump in the number of rear-end crashes, mostly driven by low speed, PDO crashes on the minor road as shown in Figure C.1 in Appendix C.

This analysis aimed to answer the question "How do crashes at J-turns differ when comparing J-turns with the U-turn lane extended to the minor road vs J-turns with the U-turn lane beginning close to the minor road vs J-turns with the U-turn lane beginning downstream of the minor road?" which was posed in section 4.6.1. Based on this analysis the answer is that each of these groups of J-turns saw large reductions in injury and angle crashes, though J-turns that provide direct entry into the U-turn lane from the minor road have higher crash rates for some target crash types than J-turns that do not provide direct entry into the U-turn lane from the minor road.

4.7 J-TURN U-TURN DISTANCE ANALYSIS

The location of the U-turn can vary at J-turns. Some are very close, just a few hundred feet away from the minor road, while others are more than a quarter mile away. There are a number of reasons why the location of the U-turn may differ including roadway curvature, the presence of a bridge, or other natural features. This analysis aims to see if the safety performance of J-turns differs depending on the distance of the U-turn from the minor road.

4.7.1 Question Addressed

How do crashes at J-turns differ when comparing J-turns with varying distances between the U-turns and the minor road?

4.7.2 Locations

Using the 54 J-turns from the before-after analysis, J-turns were grouped into two categories based on the distance from the minor road to the U-turn:

- 32 J-turns have U-turns at or closer than 750 feet to the minor road.
- 22 J-turns have U-turns more than 750 feet from the minor road.

4.7.3 Crash Data

The same years and crash data utilized in the before-after analysis were utilized in this analysis. The following tables show the total entering volumes, the number of crashes, and the crash rates (crashes per MEV) for each category.

Table 4.23 – U-turn Distance Analysis Entering Volumes

	U-Turn <=750’ Before (32 sites)	U-Turn <=750’ After (32 sites)	U-Turn >750’ Before (22 sites)	U-Turn >750’ After (22 sites)
Total Entering Volume	755,083,083	778,021,204	884,412,141	911,710,723

Table 4.24 – U-turn Distance Analysis Crash Volumes

Crash Severity/Type	U-Turn <=750' Before Crash Count (32 sites)	U-Turn <=750' After Crash Count (32 sites)	U-Turn >750' Before Crash Count (22 sites)	U-Turn >750' After Crash Count (22 sites)
Total Crashes	262	235	471	442
K Crashes	2	1	13	2
A Crashes	11	3	16	13
KA Crashes	13	4	29	15
B Crashes	43	22	80	46
KAB Crashes	56	26	109	61
C Crashes	57	25	103	72
KABC Crashes	113	51	212	133
PDO Crashes	149	184	259	309
Angle Crashes	115	35	188	67
KA Angle Crashes	10	0	21	4
Rear-End Crashes	45	75	67	154
Sideswipe Crashes	26	30	49	49
Intersection Related Crashes	177	116	283	190

Table 4.25 – U-turn Distance Analysis Crash Rates

Crash Severity/Type	U-Turn <=750' Before Crash Rate (32 sites)	U-Turn <=750' After Crash Rate (32 sites)	U-Turn >750' Before Crash Rate (22 sites)	U-Turn >750' After Crash Rate (22 sites)
Total Crashes	0.347	0.302	0.533	0.485
K Crashes	0.003	0.001	0.015	0.002
A Crashes	0.015	0.004	0.018	0.014
KA Crashes	0.017	0.005	0.033	0.016
B Crashes	0.057	0.028	0.090	0.050
KAB Crashes	0.074	0.033	0.123	0.067
C Crashes	0.075	0.032	0.116	0.079
KABC Crashes	0.150	0.066	0.240	0.146
PDO Crashes	0.197	0.236	0.293	0.339
Angle Crashes	0.152	0.045	0.213	0.073
KA Angle Crashes	0.013	0.000	0.024	0.004
Rear-End Crashes	0.060	0.096	0.076	0.169
Sideswipe Crashes	0.034	0.039	0.055	0.054
Intersection Related Crashes	0.234	0.149	0.320	0.208

Figures 4.11 and 4.12 illustrate the after crash rates of some of the target crash types from Table 4.25. The crash rates from the before portion of the before-after analysis are also included in the figures for reference. These are the crash rates at intersections before a J-turn was installed.

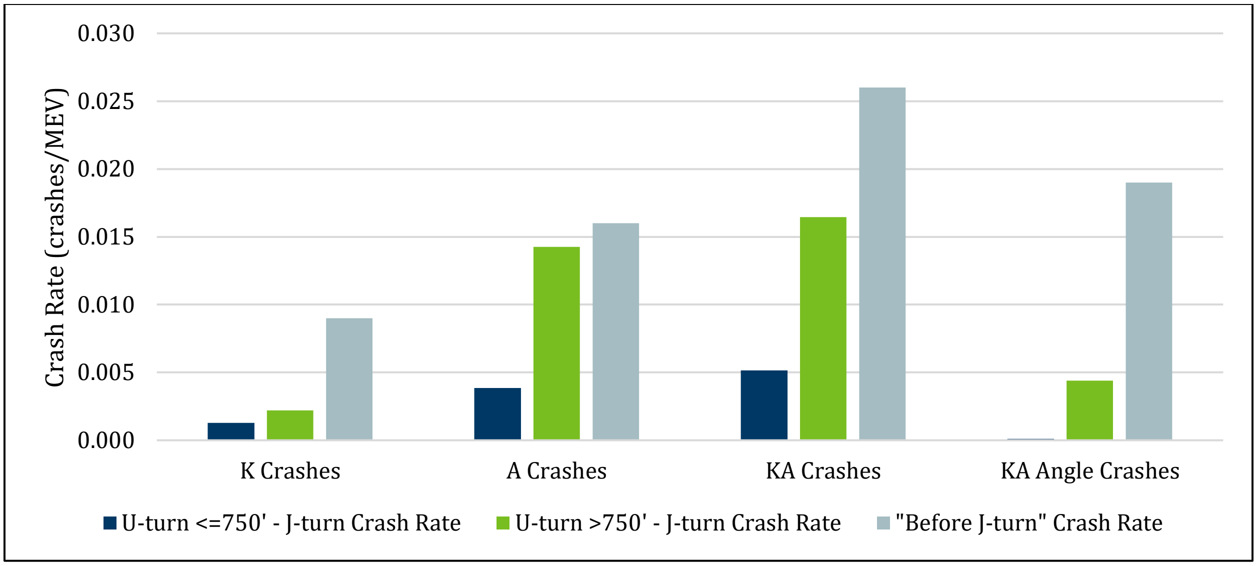

Figure 4.11 – U-turn Distance Analysis Severe Crash Rates

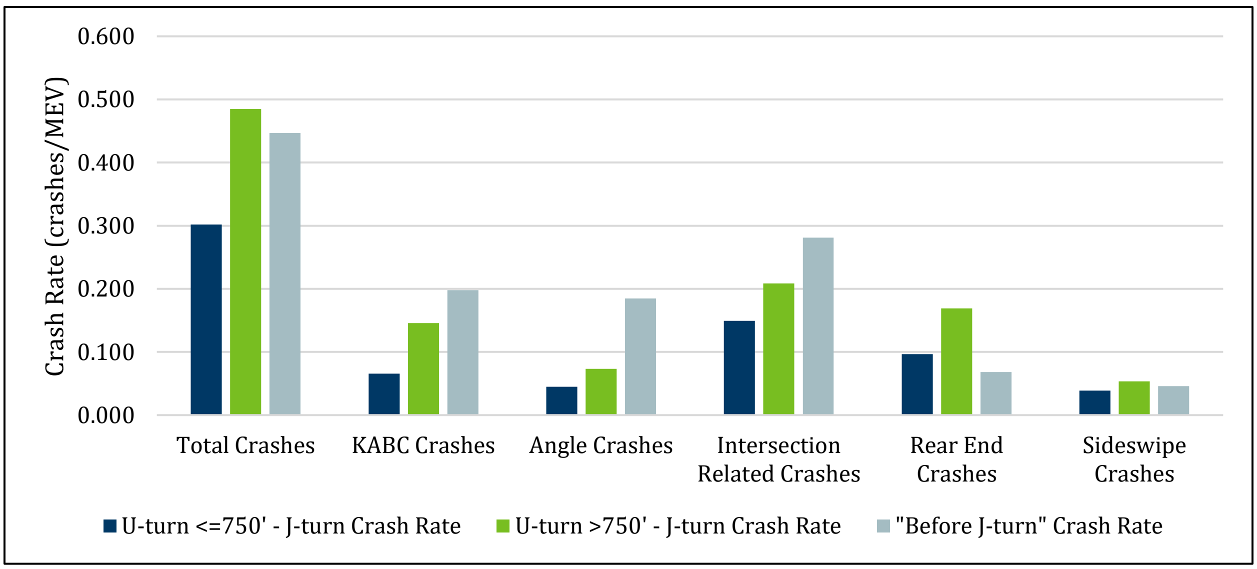

Figure 4.12 – U-turn Distance Analysis Other Crash Rates

4.7.4 Crash Analysis

Using the sample crash data, any statistically significant differences between crash rates for these two subgroups based on U-turn distance were assessed. To test for any differences in crash rates, an independent samples t-test was conducted to compare the two subgroups. The comparison tests the observed crash rates from the two subgroups against the null hypothesis, which in this case was that there was zero difference between how much the two groups' crash rates decreased (or increased) on average.

Table 4.26 - U-turn Distance Analysis Results

Crash Severity/Type	U-Turn <=750' Change in Crash Rate	U-Turn >750' Change in Crash Rate
Total Crashes	-13%	-9%
K Crashes	-51%	-85%
A Crashes	-74%	-21%
KA Crashes	-70%	-50%
B Crashes	-50%	-44%
KAB Crashes	-55%	-46%
C Crashes	-57%	-32%
KABC Crashes	-56%	-39%
PDO Crashes	20%	16%
Angle Crashes	-70%	-65%
KA Angle Crashes	-100%	-82%
Rear-End Crashes	62%	123%
Sideswipe Crashes	12%	-3%
Intersection Related Crashes	-36%	-35%

As can be seen in Table 4.26, both of the groups saw large reductions in injury and angle crashes indicating that J-turns are performing well with both layout types. There were no statistically significant differences in crash rate changes between the two groups, though J-turns where the U-turn was 750 feet or less from the minor road had lower crash rates across the board than when the U-turn was greater than 750 feet away. This could be due to the smaller intersection footprint, but these results indicate J-turns with a U-turn 750 feet or less from the minor road have a better safety performance than J-turns with a U-turn more than 750 feet from the minor road.

This analysis aimed to answer the question "How do crashes at J-turns differ when comparing J-turns with varying distances between the U-turns and the minor road?" which was posed in section 4.7.1. Based on this analysis the answer is that there are positive safety benefits when a J-turn is installed no matter where the U-turn is located, though J-turns where the U-turn was 750 feet or less from the minor road had lower crash rates across the board than when the U-turn was greater than 750 feet away.

4.8 J-TURN COMMERCIAL VEHICLE ANALYSIS

The operations of commercial vehicles at J-turns have been previously studied by MnDOT and it has been found that large vehicles have similar exposure time and reduced conflicts at J-turns than at similar control intersections. However, questions and concerns continue to be expressed by some regarding commercial vehicle safety at J-turns. The analysis compares crash data involving commercial vehicles at J-turn locations before the J-turn was installed and after the J-turn was installed as well as comparing before-after results with a control group. These are subsets of the analyses in sections 4.1 and 4.2 of this report.

4.8.1 Question Addressed

How do commercial vehicle crashes change after a J-turn is installed at a location and how much of that change is attributable to the J-turn?

4.8.2 Locations

This analysis is broken into two parts. First, using the 54 J-turns from the before-after analysis from section 4.1 of this report, a before-after analysis focused on commercial vehicle crashes was conducted. Second, using the 38 J-turns and 61 control intersections from the comparative analysis from section 4.2 of this report, a comparative treatment-control before-after analysis focused on commercial vehicle crashes was conducted.

4.8.3 Crash Data

The same years and crash data utilized in the previous analyses were utilized in this analysis with the exception that only crashes that involved a commercial vehicle were selected. For the before-after analysis that included the full 225 site years of before data and 225 site years of after data. For the treatment-control comparative before-after analysis that included the three years of before and three years of after data for each site. The following tables show the crash counts and crash rates for commercial vehicle crashes.

Table 4.27 – Commercial Vehicle Before-After Crash Volumes and Rates at J-turns

Crash Severity/Type	Commercial Vehicle Before Crash Count (54 sites)	Commercial Vehicle After Crash Count (54 sites)	Commercial Vehicle Before Crash Rate (54 sites)	Commercial Vehicle After Crash Rate (54 sites)
Total Crashes	66	83	0.040	0.049
KA Crashes	5	4	0.003	0.002
KABC Crashes	28	26	0.017	0.015

Table 4.28 – Commercial Vehicle Treatment-Control Comparative Before-After Crash Volumes

Crash Severity/Type	Treatment Before Crash Count (38 sites)	Treatment After Crash Count (38 sites)	Control Before Crash Count (61 sites)	Control After Crash Count (61 sites)
Total Crashes	35	37	37	31
KA Crashes	4	1	1	5
KABC Crashes	17	14	14	17

Table 4.29 – Commercial Vehicle Treatment-Control Comparative Before-After Crash Rates

Crash Severity/Type	Treatment Before Crash Rate (38 sites)	Treatment After Crash Rate (38 sites)	Control Before Crash Rate (61 sites)	Control After Crash Rate (61 sites)
Total Crashes	0.043	0.044	0.028	0.024
KA Crashes	0.005	0.001	0.001	0.004
KABC Crashes	0.021	0.017	0.010	0.013

4.8.4 Crash Analysis

Using the commercial vehicle crash data, comparisons were made between the crash rates. A paired samples t-test similar to what was described in section 4.1.4 of this report was used for the commercial vehicle before-after analysis, and an independent samples t-test similar to what was described in section 4.2.4 of this report was used for the commercial vehicle comparative treatment-control analysis. The results are shown in the tables below.

Table 4.30 – Commercial Vehicle Before-After Analysis Results

Category	Change in Crash Rate	p-value	Significant?
Total Crashes	+22%	0.543	No
KA Crashes	-22%	0.676	No
KABC Crashes	-10%	0.550	No

Table 4.31 – Commercial Vehicle Comparative Treatment-Control Analysis Results

Category	Treatment Change in Crash Rate	Control Change in Crash Rate	p-value	Significant?	Result Interpretation
Total Crashes	+4%	-12%	0.592	No	Total commercial vehicle crash rates at J-turns increased but not significantly more than at controls
KA Crashes	-75%	+427%	0.147	No	KA commercial vehicle crash rates at J-turns decreased but not significantly more than at controls
KABC Crashes	-19%	+28%	0.553	No	KABC commercial vehicle crash rates at J-turns decreased but not significantly more than at controls

As can be seen in Table 4.30, with the installation of J-turns, there has been an increase in total crashes involving commercial vehicles, but a decrease in crashes involving fatalities and injuries. Those trends stay true in Table 4.31 but with the opposite results for commercial vehicle crashes at the control intersections with a decrease in overall commercial vehicle crashes but an increase in those involving fatalities and injuries. These results echo the overall crash results of J-turns in that crashes involving fatalities and injuries have decreased with the installation of a J-turn. However, due to the low crash numbers, none of the changes found here are statistically significant.

This analysis aimed to answer the question "How do commercial vehicle crashes change after a J-turn is installed at a location and how much of that change is attributable to the J-turn?" which was posed in section 4.8.1. Based on this analysis the answer is that commercial vehicle crash rates do increase for with the installation of a J-turn, but severe crashes and all injury crashes decrease, though in limited numbers.

CHAPTER 5: CONCLUSIONS

The results of the before-after and comparative treatment-control analyses conducted show the J-turns in Minnesota are exhibiting their intended safety benefits. The analyses show the following impacts of J-turns:

- Reductions in fatal and serious injury crashes
- Reductions in all injury crashes
- Reductions in angle crashes
- Reductions in fatal and serious injury angle crashes
- Increases in rear-end crashes

These results are consistent with the safety goals of J-turns as well as with the previous evaluation of J-turns in Minnesota. The large decreases in severe crashes at J-turn locations indicate the J-turn can be an effective safety treatment. J-turns have also seen a potential reduction in fatal and injury commercial vehicle crashes.

A cross-sectional comparison between J-turns, rural signals, and low-volume interchanges show that J-turns have lower overall and injury crash rates than interchanges as well as lower angle, rear-end, and intersection-related crashes than rural, high-speed signals.

Additional analyses comparing J-turns with different features were also conducted and are listed below with their results. All the subgroups analyzed in these additional analyses saw reductions in target crash types when a J-turn was installed, and the results below specifically described the differences between the subgroups.

- A comparison between J-turns with different mainline AADTs.
    - Intersections with mainline AADTs of less than 10,000 vehicles a day saw the biggest reductions in angle and KA angle crashes when a J-turn was installed.
- A comparison between J-turns with and without mainline left turns.
    - J-turns without mainline left turns have lower crash rates than J-turns with mainline left turns.
- A comparison between J-turns with different U-turn lane entry points.
    - J-turns with direct access to the U-turn lane from the minor road had the higher KA, angle, and KA angle crash rates than J-turns that do not provide direct entry into the U-turn lane from the minor road.
- A comparison between J-turns with different distances between the U-turn and the minor road.
    - J-turns that have U-turns that are 750 feet or less from the minor road have lower crash rates than J-turns with U-turns that are greater than 750 feet from the minor road.

APPENDIX A
J-TURN SEVERE CRASH DETAILS

As seen in the before-after analysis, the locations with J-turns saw a decrease in K and A severity crashes after installation of the J-turns. However, there have still been K and A severity crashes at these locations. Details about those crashes are included in Table A.1. Also included in Table A.1 are K and A severity crashes at J-turns not included in the before-after analysis.

Table A.1: K & A Severity Crashes at J-turn Locations After Construction Year

Location	J-turn Construction Year	Crash Year	Crash Severity	Description	Location Included in Analysis?
US 212 & MN 284/CR 53	2012	2017	A	Rear end on US 212	Yes
US 52 & CR 66	2014	2015	A	Sideswipe on US 52	Yes
US 52 & CR 66	2014	2017	A	Rear end on US 52 (lane closure)	Yes
US 52 & CR 66	2014	2018	A	Rear end on US 52 (ice)	Yes
US 169 & MN 22/Dodd Ave	2014	2017	A	Run off road on TH 169	Yes
US 61 & Orin St/Gilmore Ave	2016	2019	K	Run off road on TH 61	Yes
US 169 & Park Blvd & CR 66	2018	2019	A	Rear end into snowplow on US 169	Yes
MN 65 & 157th Ave NE	2018	2020	A	Run off road on mainline	Yes
MN 65 & 153rd Ave NE	2019	2020	A	Rear end on mainline	Yes
MN 23 & Saratoga St	2015	2021	A	Rear end on mainline	Yes
MN 65 & 187th Ave NE	2018	2021	A	Rear end on mainline	Yes
MN 65 & 169th Ave	2012	2021	A	Mainline sideswipe same direction	Yes
US 14 & CR 17	2016	2022	K	Mainline left turn fail to yield	Yes
US 169 & CR 59/Delaware Ave	2018	2022	K	Wrong way driver on mainline	Yes
MN 65 & 181st Ave NE	2019	2022	A	Minor road fail to yield	Yes
US 169 & CR 11	2020	2022	A	Run off road on minor road	Yes
MN 23 & CR 8	2020	2022	A	Mainline left turn fail to yield	Yes
US 2 & MN 32	2021	2022	A	Minor road fail to yield (ice)	Yes
US 2 & Eckles Rd	2021	2022	A	Vehicle turning onto mainline collided with ATV crossing minor road	Yes
MN 65 & Viking Blvd	2019	2020	K	Minor road fail to yield	No
MN 371 & CR 168/107	2017	2021	A	Mainline left turn fail to yield	No

Of these 21 crashes, a majority of them do not appear to be directly related to the J-turn itself. Of crashes related to the J-turn, there have been three severe crashes at J-turns involving mainline left turning traffic failing to yield to oncoming mainline traffic, and three severe crashes at J-turns involving minor road traffic failing to yield to oncoming mainline traffic. None of these crashes have been associated with mainline U-turning movements.

APPENDIX B
J-TURN CONSTRUCTION YEAR SEVERE CRASHES

As mentioned, crashes during the construction years were not included in the analysis. Table B.1 lists the K and A severity crashes that occurred during the construction year of all J-turn locations in Minnesota, including the locations not used in the before-after analysis.

Table B.1: K & A Severity Crashes at J-turn Locations After Construction Year

Location	Construction & Crash Year	Crash Severity	Before or After Construction of J-turn	Description of Crash at J-turn
MN 23 & Saratoga St	2015	K	Before	--
MN 23 & Saratoga St	2015	K	Before	--
US 10 & CR 23/Sherburne Ave	2018	K	After	Pedestrian on mainline
MN 65 & 157th Ave	2018	K	Before	--
MN 65 & 187th Ave	2018	A	Before	--
MN 65 & 153rd Ave	2019	A	Before	--
MN 65 & 181st Ave	2019	A	After	Sideswipe heading to median U-turn
US 61 & MN 60	2019	K	Before	--
MN 65 & Viking Blvd (signalized J-turn)	2019	A	Before	--
MN 65 & Viking Blvd (signalized J-turn)	2019	K	After	Mainline run off road
US 61 & TH 42	2022	K	Before	--
US 61 & TH 42	2022	K	Before	--

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

APPENDIX C
J-TURN TARGET CRASH TYPE BREAKDOWNS

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

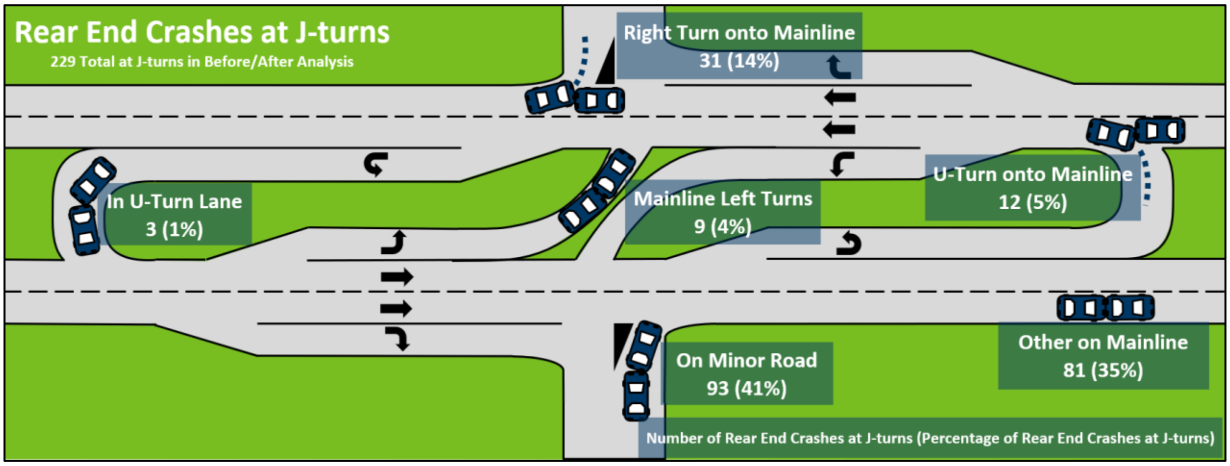

Figure C.1 - Breakdown of Rear-End Crashes at J-turns

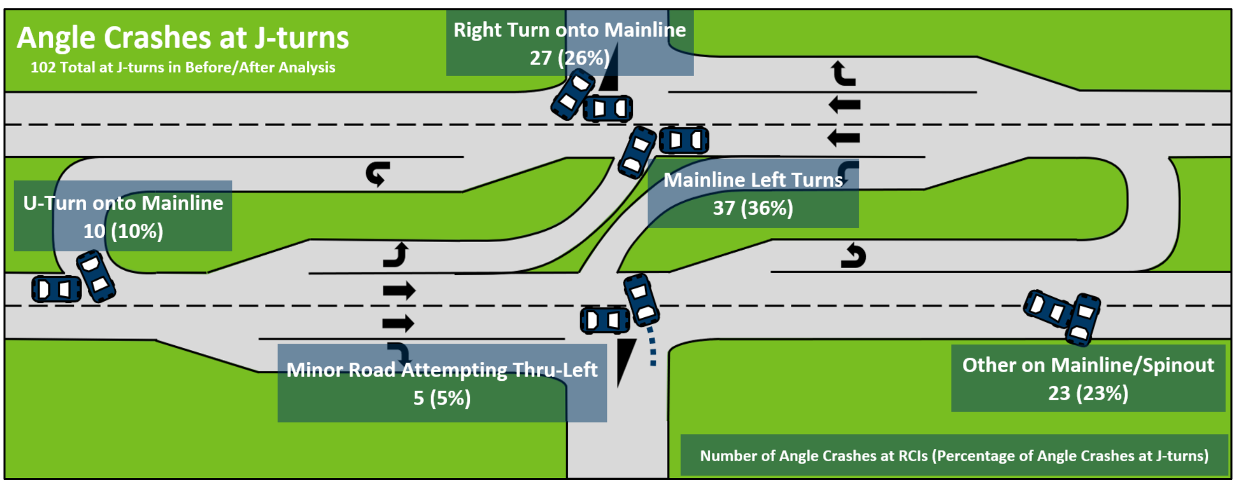

Figure C.2 - Breakdown of Angle Crashes at J-turns

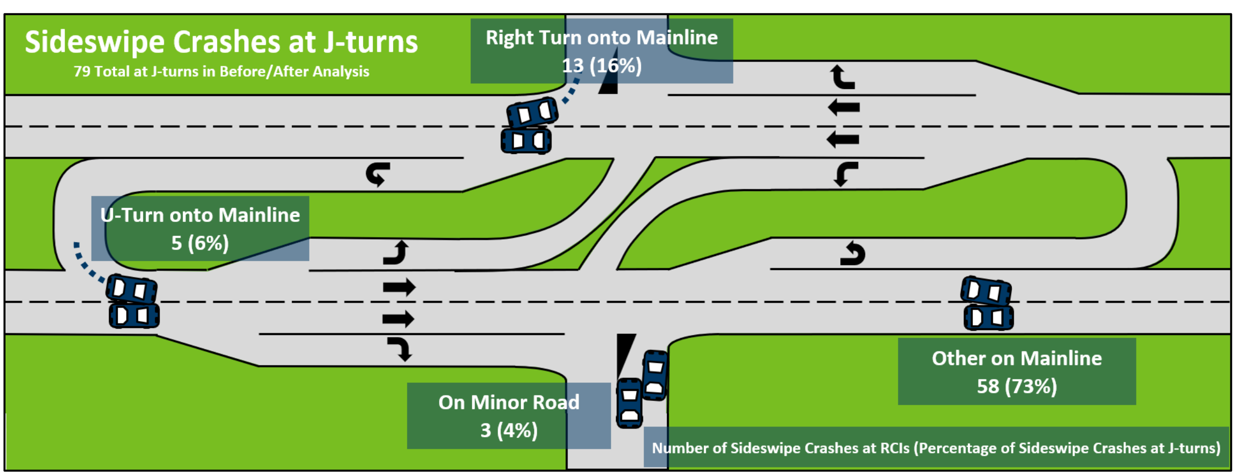

Figure C.3 - Breakdown of Sideswipe Crashes at J-turns