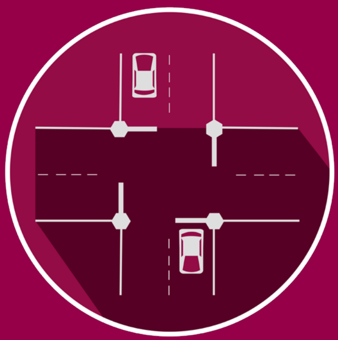
Field Evaluation of At-Grade Alternative Intersection Designs, Volume II—Safety Report

PUBLICATION NO. FHWA-HRT-24-155 OCTOBER 2024



U.S. Department of Transportation
Federal Highway Administration

Research, Development, and Technology
Turner-Fairbank Highway Research Center
6300 Georgetown Pike
McLean, VA 22101-2296

FOREWORD

The research documented in this report was conducted as part of a multiyear research project for the Federal Highway Administration. This study focuses on evaluating how converting from conventional intersections to alternative intersections can affect safety and operational performance. The report may be of interest to transportation practitioners conducting transportation design, safety, and operations.

This report is contained in two volumes. Volume I reviews site identification, data collection, and observed traffic operations at sites in Arizona, Minnesota, Texas, and Virginia. Volume II (this report) reviews the safety effects for the same volume I study sites to better understand the safety performance of alternative intersections. The alternative intersections included in the study were median U-turns, restricted crossing U-turns, displaced left turns, and hybrid intersections (locations with two or more of those elements). Where applicable, the analysis included bicycle and pedestrian safety performance for these study locations.

Shyuan-Ren (Clayton) Chen, P.E., Ph.D., PTOE
Acting Director, Office of Safety and Operations
Research and Development

Recommended citation: Federal Highway Administration, *Field Evaluation of At-Grade Alternative Intersection Designs, Volume II—Safety Report* (Washington, DC: 2024) https://doi.org/10.21949/1521599

TECHNICAL DOCUMENTATION PAGE

1. Report No. FHWA-HRT-24-155	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Field Evaluation of At-Grade Alternative Intersection Designs, Volume II—Safety Report		5. Report Date October 2024 6. Performing Organization Code
7. Author(s) Karen Dixon (ORCID: 0000-0002-8431-9304), Seyedeh Maryam Mousavi (ORCID: 0000-0001-8188-4466), and Kay Fitzpatrick (ORCID: 0000-0002-1863-5106)		8. Performing Organization Report No. HRDS30180007PRPR-DTFH6116D00039.
9. Performing Organization Name and Address Texas A&M Transportation Institute The Texas A&M University System College Station, TX 77843-3135		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DTFH6115C00005L
12. Sponsoring Agency Name and Address Office of Safety and Operations Research and Development Federal Highway Administration 6300 Georgetown Pike McLean, VA 22101-2296		13. Type of Report and Period Covered Final Report, August 2015–December 2022 14. Sponsoring Agency Code HRSO-10
15. Supplementary Notes Wei Zhang served as the Contracting Officer's Technical Representative; Technical Panel members include Jeffrey Shaw.		
16. Abstract This report reviews before and after crash data for nine alternative intersections located in four States along with comparison crash data for an additional two alternative intersections and one conventional two-way, stop-control intersection. Though the geometry and operations vary, each of the alternative intersections is characterized by redirecting the left-turn maneuver with a goal of enhancing operations without compromising safety.		
17. Key Words Alternative intersection, innovative intersection, reduced left-turn conflict intersection, reduced conflict intersection, median U-turn, displaced left, indirect left		18. Distribution Statement No restrictions. This document is available to the public through the National Technical Information Service, Springfield, VA 22161. https://www.ntis.gov
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 70 / 22. Price N/A

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1,000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2,000 lb)	0.907	megagrams (or “metric ton”)	Mg (or “t”)
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or “t”)	megagrams (or “metric ton”)	1.103	short tons (2,000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	2.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.
(Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS OR ACRONYMS

A	incapacitating injury (from KABCO scale)
B	nonincapacitating injury (from KABCO scale)
C	possible injury (from KABCO scale)
COVID-19	Coronavirus disease
DLT	displaced left turn
EB	eastbound
K	fatal injury (from KABCO scale)
KABC	injury crashes that involve K, A, B, and C severity injuries from the KABCO scale
KABCO	scale used to represent injury severity in crash reporting
MUT	median U-turn
NB	northbound
NE	northeast
O	property damage only (from KABCO scale)
PDO	property damage only (alternative for O)
RCUT	restricted crossing U-turn
RLTCI	reduced left-turn conflict intersection
SB	southbound
TWSC	two-way stop-controlled
WB	westbound

CHAPTER 1. INTRODUCTION

INTRODUCTION

In 2016, the Federal Highway Administration (FHWA) initiated an evaluation of recently implemented alternative intersections. The goal of this research effort was to assess the operational and safety impacts at up to 12 study sites. The study included field-data collection and assessment for intersections in Arizona, Minnesota, Texas, and Virginia. The operational effectiveness of these intersection is included in the report titled *Field Evaluation of At-Grade Alternative Intersection Designs, Volume I—Operations Report.*[(1)]

In general, alternative intersections include modified roadway features designed to optimize high-volume traffic locations while minimizing crashes. A transportation agency may elect to install alternative intersections that include a variety of features expected to enhance safety. For example, strategies that reduce the number of conflict points can be effective in reducing the number and severity of crashes. Strategies that separate conflict points can also be effective. This report is a companion to the volume I operations report and includes the safety analysis for the sites included in this field study.[(1)] The research team designed this effort as a longitudinal study with a goal of 3–5 yr of data for the before and after conditions following construction of alternative intersection configurations. The coronavirus disease (COVID-19) pandemic delayed the construction of some of the study sites; therefore, crash data for the after condition are limited. This report reviews the safety findings based on a simple before-after analysis.

REPORT SUMMARY FOR SAFETY ISSUES AT ALTERNATIVE INTERSECTIONS

This report summarizes the safety performance of constructed alternative intersections at the selected sites. Chapter 2 includes a brief literature review of known safety impacts based on converting more conventional intersections to alternative intersections. Chapter 3 provides a condensed summary of site data collection (an expanded summary is included in the companion operations report for this project).[(1)] Chapter 4 summarizes the safety analysis and results. Chapter 5 provides concluding comments.

CHAPTER 2. LITERATURE REVIEW—SAFETY PERFORMANCE

In recent years, transportation professionals have developed alternative intersections that modify conventional intersection configurations. One of the goals of developing these alternative intersections is to determine how the intersections can better accommodate operational and safety challenges, primarily at congested locations. Though the operational benefits are often the primary focus for considering an alternative intersection, the safety performance of these unique intersections should also be explored to confirm that the associated safety is maintained or enhanced. This report focuses on alternative intersection safety performance.[2] A companion operational report is also available for the study sites included in this report.[1]

A common safety assessment strategy for alternative intersections is determining the percentage of crash reduction (for locations with smaller sample sizes) or a statistically derived crash modification factor (for locations with larger sample sizes). The following summary documents the published safety impacts for a subset of alternative intersections represented by the sites in this research project.

SAFETY PERFORMANCE OF ALTERNATIVE INTERSECTIONS AND INTERCHANGES

Implementing a variety of alternative intersections has given transportation agencies options for enhancing intersection operational and safety performance. The need for these unique intersections is often inspired by transportation professionals evaluating congested maneuvers, such as oversaturated left-turn configurations, and several intersection feature options are available. For example, reducing the number of conflict points by restricting maneuvers or shifting access points are two ways to enhance safety performance.

The study sites for the research summarized in this report included several configurations and companion traffic control strategies. As alternative intersection configurations have evolved, the various agencies deploying these treatments have developed a variety of names that primarily describe the features of the intersection. FHWA has suggested consistent naming strategies for alternative intersections. This report primarily uses FHWA-recommended names. To minimize confusion, the following summary of alternative intersections identifies these alternative intersection names as cited in the literature review summary:

- Reduced conflict intersection and reduced left-turn conflict intersection (RLTCI):
    - Median U-turn (MUT).
    - Restricted crossing U-turn (RCUT) intersection, also referred to as a superstreet or J-turn.
- Displaced left turn (DLT).
- Hybrid alternative intersection.

The following sections describe the safety performance of these alternative intersections in more detail.

Safety Performance of an RLTCI

RLTCIs are intersections where left-turning vehicles are positioned at U-turn locations. The median openings can be signalized, stop controlled, or yield controlled. The RLTCI improves safety by reducing the number of conflict points at the intersection.(3) A variety of configurations can be classified as RLTCIs. This literature review focuses on intersection configurations included in the recently completed FHWA field study of alternative intersections.(1) Consequently, this summary of RLTCI safety performance highlights the MUT and the RCUT.

Signalized MUT and Unsignalized MUT

An MUT intersection is designed to redirect the left-turn maneuver on the roadway of interest (an MUT can be used on the major or the minor road).(4) Vehicles traversing the highway section of interest retain the ability to proceed straight or turn right at the primary intersection. The left-turning vehicles are relocated to a downstream median opening where they can then execute their left turn by completing a U-turn followed by a right turn. Relocating left turns can reduce the number of conflicts while also improving opportunities for pedestrian refuge at the primary intersection. Signalized intersections and unsignalized intersections are both candidates for converting to an MUT.

Convert Signalized and Unsignalized Corridor Intersections to MUTs

A Michigan study that extended from 1991 to 1997 evaluated the safety effect of converting bidirectional median crossovers to directional median crossovers.(5) The study focused on converting signalized and unsignalized conventional intersections into MUTs. The research team evaluated 54 bidirectional median crossovers that spanned 8 corridors. The analysis showed a reduction of approximately 31 percent in total crashes and injury crashes. The evaluated intersections had three or four legs, and Taylor, Lim, and Lighthizer found that four-legged intersections experienced an approximately 45-percent reduction in crashes, while three-legged intersections experienced an approximately 20-percent reduction in crashes, following an adjustment to compensate for increases in traffic volumes.

Convert Signalized Intersections to MUTs

Converting conventional intersections to signalized MUTs reduces the number of conflict points. For this reason, installing a signalized MUT can enhance safety for bicyclists and pedestrians at an intersection. In 2014, FHWA published two fact sheets that summarized the observed benefits of replacing conventional signalized intersections with MUTs.(6,7) East Lansing, MI, implemented a multistage project that included the installation of an MUT at the intersection of Michigan Avenue and South Harrison Road. The improvements reduced conflicts (particularly between pedestrians and turning vehicles) and provided refuge for pedestrians and bicyclists as they crossed the road, which enhanced safety for those nonmotorized users.(6) A second MUT installation at Woodward Avenue and East Maple Road in Birmingham, MI, further enhanced pedestrian safety by changing the traffic signal to a two-phase operation (a common benefit for all users at an MUT installation).(7)

As part of a 2020 study, Al-Omari et al. conducted a safety evaluation to assess how converting conventional intersections into signalized MUTs can influence safety performance.(8) This study considered the safety performance before and after 73 conventional intersections were converted to MUTs. The data spanned intersection conversions in the States of Michigan, North Carolina, and Ohio. The researchers also incorporated 171 conventional intersections to use for comparison. Al-Omari et al. evaluated type A MUTs (locations with U-turns located downstream of the main intersection and in both directions) and type B MUTs (similar to type A MUTs but with two additional reverse U-turns near the primary intersection). Al-Omari et al. evaluated changes in crash type and changes to crash severity and found the following trends:

- Crash severity was reduced at type A MUTs for the following crash types:
    - All crashes by 37 percent.
    - Fatal-and-injury crashes by 23 percent.
    - Property damage only (PDO) crashes by 40 percent.
- Crash severity was reduced at type B MUTs for the following crash types:
    - All crashes by 35 percent.
    - Fatal-and-injury crashes by 28 percent.
    - PDO crashes by 37 percent.
- Single-vehicle crashes increased at type A MUTs by 38 percent and at type B MUTs by 44 percent.
- Angle crashes were reduced at type A MUTs by 32 percent and at type B MUTs by 39 percent.
- Head-on crashes were reduced at type A MUTs by 74 percent and at type B MUTs by 67 percent.
- Rear-end crashes were reduced at type A MUTs by 47 percent and at type B MUTs by 48 percent.

Convert Unsignalized Intersections to MUTs

Kay et al. evaluated converting unsignalized conventional intersections into MUTs.(9) The authors included 39 study sites and 56 reference sites for unsignalized, lower volume, two-lane highways and unsignalized, four-lane highways in Michigan. Sites with two-lane, undivided highways and four-lane, divided or undivided highways were also included in the sample. Each of these three categories was separately evaluated. Kay et al. observed a 56.2-percent reduction in crashes when a two-lane, conventional-lane highway was converted to a two-lane MUT at the associated intersection. Kay et al. observed a 56.2-percent reduction for all crashes in rural, two-lane, uncontrolled intersections. Similarly, Kay et al. observed a 31.4-percent reduction for K, A, B, and C crashes; however, the number of O crashes increased by 32.5 percent.

Signalized and Unsignalized RCUT

An RCUT permits traffic along the main highway to proceed straight, turn left, or turn right. All traffic on the minor road, however, must turn right. These vehicles can then execute a U-turn at a downstream median opening where the vehicle can complete the minor road maneuver of turning left (accomplished by a U-turn at the median opening) or by continuing to the opposing minor road leg (accomplished by a U-turn at the median opening followed by a right turn at the primary intersection). Islands at the primary intersection location reinforce that the minor-leg traffic must turn right. The replacement of the high-risk, minor-leg through movements with the MUT provides fewer conflicts and a safer configuration.

Safety assessment for RCUTs has primarily occurred over the last decade. A 2012 FHWA report contains a commonly cited statistic that converting a conventional intersection to an RCUT can reduce injury crashes by 40 percent and fatal crashes by 70 percent.[(10)]

The safety assessment is generally based on converting a conventional intersection to an alternative intersection. Common conventional intersections include higher speed, two-way stop-controlled (TWSC) intersections in rural areas. In urban areas, the conversion is often based on signalized conventional intersections. However, suburban regions often include both types of conventional intersections for the before condition. For the after condition, the RCUT may be unsignalized or signalized. Studies of common RCUT scenarios generally focus on either converting TWSC intersections to RCUTs or converting conventional signalized intersections to RCUTs. When the intersections are constructed along a corridor and the MUTs are signalized with two-phase traffic signals, the traffic flow can be synchronized. This scenario is referred to as a superstreet.

The following sections summarize the related safety performance literature for each of these scenarios.

Convert TWSC Intersections to RCUT

A 2013 Maryland case study for U.S. 15 in Frederick County evaluated converting six TWSC intersections into unsignalized RCUTs.[(11)] The researchers observed a 40-percent reduction in ABC injury crashes and a 70-percent reduction in K. PDO crashes were reduced by approximately 20 percent.

In a 2013 study, Edara, Sun, and Breslow used a combination of field studies, public surveys, crash analysis, and conflict-point assessment to evaluate the safety effects of converting a TWSC to RCUTs (referred to as J-turns by the Missouri research team).[(12)] The research team considered all crash types for the various crash severity levels and reached the following conclusions about converting a TWSC to an RCUT:

- All crashes were reduced by 34.8 percent.
- The following crash injury severities were reduced:
    - ABC crashes by 53.7 percent.
    - O crashes by 43 percent.
    - B crashes by 50 percent
    - A crashes by 86 percent.
    - K crashes by 100 percent.

- The following crash types were reduced:
  - Angle crashes by 80 percent.
  - Left-turn crashes by 100 percent.
  - Rear-end crashes by 58.8 percent.
  - All other crash types by 58.8 percent.

Edara et al. conducted a 2015 study that further evaluated converting TWSC rural, higher speed RCUT intersection performance (conflict measures and crashes) for an unsignalized RCUT in Missouri and an additional control site. The authors evaluated the effectiveness of using field studies, crash analysis, and traffic-conflict analysis, and included before-after Empirical Bayes analysis of five RCUT (referred to as J-turn) sites. The researchers made the following observations:(13)

- Crash frequency was reduced by 31.2 percent for all crashes and by 63.8 percent for injury and fatal crashes. Disabling and minor injury crashes decreased by 91.5 percent and 67.9 percent, respectively.

- Right-angle crashes decreased from 8.6 to 0.8 crashes per year (a 90.2-percent reduction).

- Left-turn, right-angle crashes were eliminated following the treatment.

- Average time-to-collision conflict measure was four times higher at the J-turn site than at the TWSC site.

A 2021 North Carolina study by Mishra and Pulugurtha evaluated safety performance for RCUTs located in rural and suburban areas.(14) Their study included 42 RCUT intersections that were converted from TWSC intersections or from signalized intersections. Their findings are summarized as follows:

- Converting TWSC intersections to RCUTs at unsignalized rural locations reduced total crashes by 73.3 percent and reduced fatal and injury crashes by 79.4 percent.

- Converting TWSC intersections to RCUTs at unsignalized suburban locations reduced the total number of crashes by 64.9 percent and reduced fatal and injury crashes by 73.4 percent.

- Converting conventional intersections to signalized RCUTs in rural areas reduced the total number of crashes by 10.2 percent and reduced fatal and injury crashes by 84.3 percent.

- Converting conventional intersections to signalized RCUTs in suburban areas reduced all crashes by 31.1 percent and reduced fatal and injury crashes by 31.1 percent.

Mishra and Pulugurtha noted that unsignalized RCUTs in rural areas can provide the greatest safety benefits.(14)

Convert Conventional Intersections to RCUT

A 2011 FHWA report, Inman and Hass reviewed a study of nine Maryland intersections where unsignalized conventional intersections were converted to unsignalized RCUTs.(15) This study observed a 49-percent reduction in intersection crashes compared to control group crash reductions of 28 percent. The Maryland study also observed a 70-percent decrease in fatal crashes and a 42-percent decrease in injury crashes during the 3-yr period following implementation. Ultimately the authors determined that total rural crashes were reduced by approximately 44 percent.

A 2017 study by Hummer and Rao evaluated conversion of conventional suburban signalized intersections to signalized superstreets.(16) Their findings were based on before and after data for 11 intersection conversions. The associated streets were four- and six-lane arterials located in Alabama, North Carolina, Ohio, and Texas. The researchers identified a 15-percent reduction for all crashes and a 22-percent reduction for injury crashes at signalized superstreet conversions.

A 2019 study by Sun and Rahman evaluated the safety benefits of converting signalized and stop-controlled intersections to RCUTs (referred to as J-turns by study authors).(17) The authors used the empirical Bayes analysis approach to determine that traffic professionals can expect crashes to decrease by approximately 20 percent at the converted intersection locations.

In 2020, Al-Omari et al. investigated the safety performance for RCUTs in Michigan, North Carolina, and Ohio.(18) Their research effort focused on converting urban and suburban conventional signalized intersections to signalized RCUTs. The authors conducted an analysis for crash severity and crash type. The authors' findings related to injury crashes are as follows:

- Converting the conventional signalized intersections to signalized RCUTs can reduce the total number of crashes by approximately 23.7 percent.
- KABC (injury crashes that involve fatal injury (K), incapacitating injury (A), nonincapacitating injury (B), and possible injury (C) severity injuries from the KABCO scale) crashes can be reduced by approximately 31.1 percent.
- Injury crashes (ABC) should be reduced by approximately 42.7 percent, and KABC crashes can be reduced by 43.3 percent.
- Property damage-only crashes should be reduced by approximately 15.9 percent.

For crash type, Al-Omari et al. observed the following changes for the signalized intersection conversion:(18)

- Single-vehicle crashes may increase by up to 30.8 percent.
- Angle crashes may decrease by approximately 41.5 percent.
- Head-on crashes can be reduced by up to 93.3 percent.
- Rear-end crashes should be reduced by 24.9 percent.
- Other crash-type reductions will vary.

The increase in single vehicle crashes may merit future evaluation to determine if this finding is consistent for all RCUT configurations. Al-Omari et al. similarly included 10 RCUTs in the analysis, but due to the small sample size, the results were inconclusive; however, their findings did continue the trend of single vehicle crashes increasing while all other crash types decrease.(18)

In 2020, Ulak et al. developed a series of safety performance functions and crash modification factors to evaluate the safety performance of RCUTs for urban and suburban roadways in multiple States.(19) The authors of this study evaluated both signalized and unsignalized intersections with a focus on all crashes and fatal and injury crashes separately. The safety performance functions largely depended on the traffic volume on the major and minor street coupled with the ratio of these traffic volumes. Ulak et al. noted that the selection of candidate intersections should include consideration of the traffic volume thresholds. Though the authors' findings varied for the different crash severity types, crashes were increasing at some locations and decreasing at others. The researchers noted that RCUTs do have the potential to reduce the number of fatal and injury crashes at converted intersections and should be considered at locations with this problem.

Safety Performance of a DLT

Traffic professionals commonly use a DLT at locations where the high left-turn volume will benefit (by crossing left-turning traffic to the opposing direction so that the turning traffic can bypass the primary intersection). Though only limited information about the safety performance of DLTs is available, agencies have used information about the number of conflict points, the associated human factor responses, and the number of reduced crashes as ways to explore expected safety performance.

A human factors study conducted at Dowling College, Oakdale, NY, in 1995 evaluated how easily users understood traversing through the DLT intersection. Approximately 80 percent of the subjects indicated that the intersection was easy to understand and navigate. After 1 wk, this number increased to positive feedback for 100 percent of the users.(20) In 2014, Steyn et al. indicated that in lieu of crash information, a reduction in the number of conflict points could be a good indicator of improved safety performance.(21) The authors noted that, depending on the intersection design, the number of conflict points associated with implementing a DLT could range from a 6- to a 12-percent decrease in conflict points.

In 2014, FHWA published several case studies that explored safety or operational performance for DLT configurations. An overview brochure FHWA assembled for this effort indicated that converting a conventional intersection to a full DLT can reduce the number of conflict points from 32 to 28.(22) The DLT constructed at Missouri SR–30 and Summit Drive in Fenton, MO, resulted in a notable reduction in property damage-only crashes.(23) The Bangerter corridor study from Salt Lake County in Utah noted that before implementation of the DLT, the corridor experienced more than 1 crash per week.(24) The study determined that installation of DLTs reduced crashes by as much as 60 percent at some installation locations. The study also observed that the 60-percent decrease extended to within approximately 4,000 ft of the initial intersection location.

A recent study conducted by researchers at the University of Central Florida, Orlando, FL, identified 13 intersections with suitable before and after crash data that enabled additional safety evaluations.[(25)] The analysis included sites from the States of Utah, Colorado, Louisiana, and Ohio. The researchers also included two comparison sites for each of the DLT study sites. All the sites were in urban or suburban regions. The researchers evaluated safety performance based on crash severity and crash type and determined that all crashes increased by 1.2 percent. KABC crashes increased by 22.4 percent, and property damage-only crashes increased by 6.9 percent. Abdelrahman et al. observed that single-vehicle crashes increased by 51.9 percent and angle crashes increased by 24.4 percent. Their research team determined that rear-end crash types decreased by 5.4 percent and head-on crash types decreased by 28.7 percent. Assessment of crash types labeled Other varied.

Hybrid

Many agencies have started developing alternative intersections that combine features of other treatments; however, due to the unique characteristics of each individual hybrid configuration, little is known about the expected overall safety performance at these hybrid locations.

CHAPTER 3. STUDY SITES AND DATA COLLECTION

Volume I, chapter 3 of the companion report provides an overview of the most common alternative intersection configurations.[1] Volume I, chapter 4 includes a summary of the sites selected for this analysis. The goal for this study was to evaluate up to 12 alternative intersection configurations and determine how the conversion from a conventional intersection to an alternative intersection influenced operational and safety performance. The research team used the same sites for both the operational and safety analysis. The operational evaluation is included in volume I. This volume II of the report summarizes the data used for the safety analysis. Ideally, a before-after study should include 3–5 yr of crash data following construction, but due to construction delays and traffic and construction disruptions related to COVID-19, the analysis included in this report focuses on the crashes that were available within the time limits for this research.

STUDY SITES

The team initially identified 12 unique sites to study. Selected sites had the following characteristics:

- The construction did not occur before data collection efforts.
- The proposed construction was expected within 1–3 yr of before data collection.
- The local transportation agency was confident that the alternative intersection would be constructed in a timely manner.
- The local transportation agency supported the research project.

As shown in table 1, the team collected crash data before and after construction at 9 of the 12 study sites initially selected. The companion operations report provides detailed information about the physical parameters for each site.[1] Because construction at three of the sites (located in College Station, TX) is still not completed, the team was unable to acquire after crash data for those three sites. Consequently, the research team identified two additional sites along the Minnesota study corridor and one additional site along the Arizona Grant Road corridor. These three additional sites were used to identify any unexpected crash or operational trends in the region that could influence subsequent analysis. For the safety analysis, the team collected crash data and physical site data (used for both the operational and safety analysis).

Table 1. Before and after site configurations.

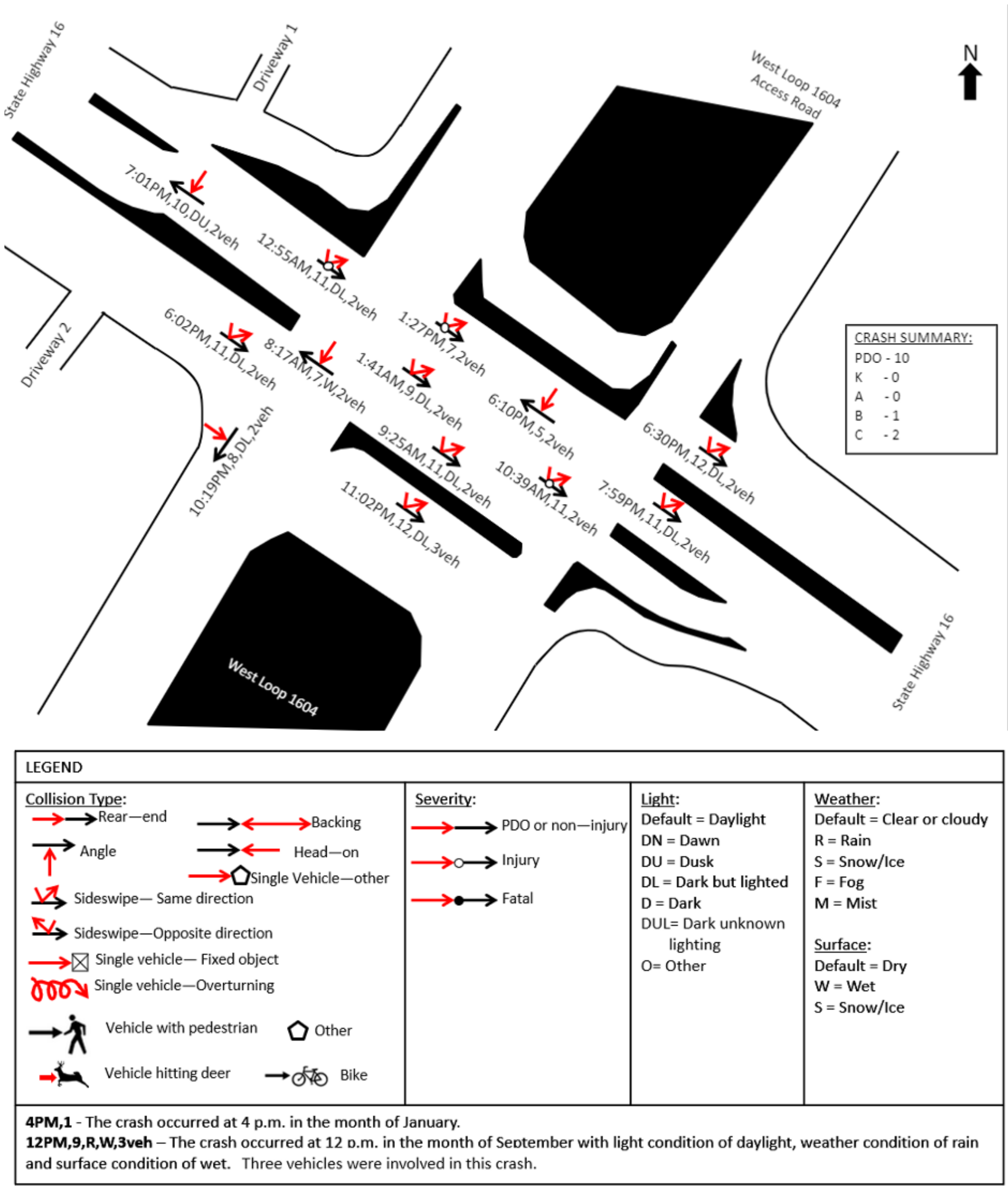
State	Intersection, City	Before Configuration	After Configuration
AZ	Grant Road at First Avenue, Tucson	Conventional signalized	Signalized MUTs (also known as indirect left turn, or ThruU in AZ)
AZ	Grant Road at Oracle Road North, Tucson*	Conventional signalized	Signalized MUTs
AZ	Grant Road at Stone Avenue, Tucson	Reduced left-turn conflict signalized	Signalized MUTs
AZ	Valencia Road at Kolb Road, Tucson	Conventional signalized	Signalized MUTs
MN	MN–65 at 157th Avenue Northeast, Ham Lake	Conventional two-way, stop-controlled	Unsignalized RCUT
MN	MN–65 at 181st Avenue Northeast (Baltimore Street Northeast), East Bethel*	Unsignalized RCUT	Unsignalized RCUT
MN	MN–65 at 187th Lane Northeast, East Bethel	Conventional two-way stop	Unsignalized RCUT
MN	MN–65 at 209th Avenue Northeast, East Bethel*	Conventional two-way stop	Conventional TWSC intersection
MN	MN–65 at Viking Boulevard Northeast, East Bethel	Conventional signalized	Signalized RCUT
TX	FM–2818 at George Bush Drive West, College Station**	Conventional signalized	Signalized RCUT (future)
TX	FM–2818 at Luther West Street, College Station**	Conventional signalized	Signalized RCUT (future)
TX	FM–2818 at Holleman Drive South, College Station**	Conventional signalized	Signalized RCUT (future)
TX	SH–16 (Bandera Road) at West Loop 1604 Access Road, San Antonio	Conventional signalized access road with turnaround	Signalized DLT interchange
VA	Military Highway at Northampton Boulevard (East Princess Anne Road) (U.S. 13 at VA SR–165), Norfolk	Conventional signalized	Signalized intersection with DLT on north and south approaches
VA	Indian River Road at Kempsville Road, Virginia Beach	Conventional signalized	Signalized hybrid intersection (DLT on two approaches and MUTs on two approaches)

*Replacement sites to use for comparison purposes.
**Original sites delayed but under construction at time of research project completion.

DATA COLLECTION

The overall data collection plan included operational data, field data, and crash data. The companion volume I report provides details about intersection locations and operational performance.[1] The research team also acquired crash data from the individual agencies responsible for the study sites and then plotted this crash data on collision diagrams that extended over multiple years. Figure 1 is an example of one of these diagrams, and includes the diagram key. Members of the research team reviewed these collision diagrams to identify patterns or trends in crashes. Developing collision diagrams for multiple years at multiple sites resulted in a substantial number of diagrams, so the research team reduced this information to reflect crashes in before and after periods for the study sites. This report uses these graphics throughout. For example, in chapter 4, figure 2 and figure 3 show before and after data for Grant Road at First Avenue. In some cases, the crashes did not have latitude and longitude information, so the research team had to estimate the crash location based on location descriptions in the crash database. The source of the crash data varied and was not the same for any one agency. In all cases, the State departments of transportations provided the data, but generally the data were provided and not available online.

Following the assembly and analysis of the crash data, the research team conducted a simple safety analysis for the study sites (chapter 4).



Source: FHWA.

Figure 1. Illustration. Example collision diagram with legend for a portion of SH-16 at West Loop Road in Texas (May to December 2019).

CHAPTER 4. SAFETY ANALYSIS RESULTS

This chapter provides an overview of the safety analysis for the individual alternative intersections. Ideally, a robust safety assessment should include widely accepted performance measures that can be applied to each configuration as part of the overall safety evaluation. However, for this study, external factors influenced the research team's ability to conduct a comprehensive, data-driven safety analysis. Researchers can potentially conduct additional analysis at a future date.

The following two external factors influenced the limited safety performance evaluation:

- The COVID-19 pandemic in 2020 introduced irregular driving patterns for the 1-yr period. Those irregular driving patterns influenced crash frequency, occurrence, and type.

- The COVID-19 pandemic disrupted normal construction schedules, which adversely impacted the individual project completion dates for the alternative intersections and subsequent safety analysis. For example, the project originally included three RCUT sites in College Station, TX. Due to delays in construction, these three sites were not completed in time to accommodate the research project completion dates.

Ideally crash analysis should consider 3–5 yr before and at least 3 yr after construction. Because the pandemic extended over a 1-yr period, disrupted project schedules created another challenge. The research team was unable to acquire a sufficiently large crash data sample size after construction to fully address safety considerations during the study period. For this reason, the crash summaries are for descriptive statistical purposes and do not fully capture the comprehensive recommended safety analysis. At some future date when normalized, postpandemic operations resume, researchers may be able to conduct an extended safety analysis with sufficient additional crash data.

The study sites were introduced in volume I, chapter 3 of the companion operations report.(1) The construction dates are further summarized in table 2 for volume I, chapter 3 of that report. The research team developed this companion safety report for those study sites. This report summarizes the number of crashes, percentage of crash severity, and percentages of crash types. The research team also explored estimating conflicts using microsimulation tools and associated operational analysis tools available from FHWA and vendors. This analysis approach did not result in reliable calibration of travel time at most locations. This finding is likely related to the unique nature of the intersections evaluated in this study.

The following safety-related summary information begins with the crash data, by severity level and by distribution of crash type. Next, the crash patterns for each site are provided alphabetically by State. Within each State, the information is listed along the corridor wherever the analysis includes multiple sites from the same corridor.

CRASH COUNTS

After acquiring the crash data from State departments of transportation and from local transportation agencies, the research team examined the data to determine which crashes were related to the study intersections. Where feasible, the research team tried to identify crashes that occurred within 250 ft of the intersection influence area. An assessment of the location information included in each State's crash database clearly showed that Texas and Virginia crash data location information was based on coordinates (latitude and longitude). Arizona and Minnesota crashes were based on crash codes such as "intersection related." Instead of latitude and longitude coordinates for Arizona crashes, researchers used other variables, including name of the roads, direction of travel, and approximate distance, to assign the crashes. To determine the intersection and intersection-related crashes, the researchers used the associated crash code for Arizona sites since the locations were identified at approximate locations and their position relative to a 250-ft buffer could only be estimated.

For Minnesota, the crashes had coordinates, but their location accuracy was not reliable enough to confirm the crashes were located within a 250-ft buffer. Therefore, the crash code was also used to find the intersection and segment crashes for the Minnesota sites.

The Texas and Virginia data provided latitude and longitude coordinates for the crashes. Hence, the team used the crash codes and an influence area of 250 ft for signalized intersections to find intersection and segment crashes. Table 2 shows the beginning and ending dates for each crash period along with the number of months in the period for each study site. To develop an estimate of crashes per year that could be used for comparison, the researchers converted the observed crashes per observation period (units in crashes per month) to average crashes per year. For locations where the completion date was not known, the research team used Google® Earth™ historical data to estimate the completion of the alternative intersection construction.(26) Table 2 provides the crash data for three periods and COVID-19 combinations:

- Before period, not COVID-19.
- After period, not COVID-19.
- After period, COVID-19.

All before periods occurred prior to 2020. The after period, COVID-19 was typically 12 mo, except at one site where construction was still occurring in 2020 for which the after period, COVID-19 was only 9 mo.

Table 2. Number of crashes per site, the crash period, and whether the period included data from 2020 (COVID-19).

State	Intersection	Period	COVID-19	From	To	Months	Total Observed Crashes	Average Crashes per Year
AZ	Grant Road at First Avenue	Before	Not COVID-19	1/1/2014	7/31/2017	43	77	21.5
AZ	Grant Road at First Avenue	After	Not COVID-19	11/1/2018	4/30/2022	30	54	21.6

State	Intersection	Period	COVID-19	From	To	Months	Total Observed Crashes	Average Crashes per Year
AZ	Grant Road at First Avenue	After	COVID-19	1/1/ 2020	12/31/ 2020	12	33	33.0
AZ	Grant Road at Oracle Road North*	Compare -Before	Not COVID-19	1/1/ 2014	7/31/ 2017	43	43	12.0
AZ	Grant Road at Oracle Road North*	Compare -After	Not COVID-19	11/1/ 2018	4/30/ 2022	30	49	19.6
AZ	Grant Road at Oracle Road North*	Compare -After	COVID-19	1/1/ 2020	12/31/ 2020	12	17	17.0
AZ	Grant Road at Stone Avenue	Before	Not COVID-19	1/1/ 2012	7/31/ 2017	67	58	10.4
AZ	Grant Road at Stone Avenue	After	Not COVID-19	1/1/ 2019	4/30/ 2022	28	34	14.6
AZ	Grant Road at Stone Avenue	After	COVID-19	1/1/ 2020	12/31/ 2020	12	15	15.0
AZ	Valencia Road at Kolb Road	Before	Not COVID-19	1/1/ 2014	5/31/ 2018	53	4	0.9
AZ	Valencia Road at Kolb Road	After	Not COVID-19	10/1/ 2019	4/30/ 2022	19	54	34.1
AZ	Valencia Road at Kolb Road	After	COVID-19	1/1/ 2020	12/31/ 2020	12	25	25.0
MN	MN–65 at 157th Avenue Northeast	Before	Not COVID-19	1/1/ 2013	6/30/ 2018	66	18	3.3
MN	MN–65 at 157th Avenue Northeast	After	Not COVID-19	9/1/ 2019	12/31/ 2021	16	5	3.8
MN	MN–65 at 157th Avenue Northeast	After	COVID-19	1/1/ 2020	12/31/ 2020	12	3	3.0
MN	MN–65 at 181st Avenue Northeast	Before	Not COVID-19	1/1/ 2013	6/30/ 2018	66	12	2.2
MN	MN–65 at 181st Avenue Northeast	After	Not COVID-19	9/1/ 2019	12/31/ 2021	16	3	2.3
MN	MN–65 at 181st Avenue Northeast	After	COVID-19	1/1/ 2020	12/31/ 2020	12	3	3.0
MN	MN–65 at 187th Northeast	Before	Not COVID-19	1/1/ 2013	6/30/ 2018	66	12	2.2
MN	MN–65 at 187th Northeast	After	Not COVID-19	9/1/ 2019	12/31/ 2021	16	7	5.3
MN	MN–65 at 187th Northeast	After	COVID-19	1/1/ 2020	12/31/ 2020	12	0	0.0
MN	MN–65 at 209th Avenue Northeast*	Compare -Before	Not COVID-19	1/1/ 2013	6/30/ 2018	66	3	0.5

State	Intersection	Period	COVID-19	From	To	Months	Total Observed Crashes	Average Crashes per Year
MN	MN–65 at 209th Avenue Northeast*	Compare -After	Not COVID-19	9/1/ 2019	12/31/ 2021	16	3	2.3
MN	MN–65 at 209th Avenue Northeast*	Compare -After	COVID-19	1/1/ 2020	12/31/ 2020	12	1	1.0
MN	MN–65 at Viking Boulevard Northeast	Before	Not COVID-19	1/1/ 2013	6/30/ 2018	66	41	7.5
MN	MN–65 at Viking Boulevard Northeast	After	Not COVID-19	9/1/ 2019	12/31/ 2021	16	6	4.5
MN	MN–65 at Viking Boulevard Northeast	After	COVID-19	1/1/ 2020	12/31/ 2020	12	11	11.0
TX	SH–16 at West Loop 1604 Access Road	Before	Not COVID-19	1/1/ 2013	8/30/ 2017	56	881	188.8
TX	SH–16 at West Loop 1604 Access Road	After	Not COVID-19	5/1/ 2019	6/30/ 2022	26	280	129.2
TX	SH–16 at West Loop 1604 Access Road	After	COVID-19	1/1/ 2020	12/31/ 2020	12	127	127.0
VA	Indian River Road at Kempsville Road	Before	Not COVID-19	1/1/ 2011	2/28/ 2019	98	541	66.2
VA	Indian River Road at Kempsville Road	After	Not COVID-19	4/1/2 020	4/30/ 2022	16	93	69.8
VA	Indian River Road at Kempsville Road	After	COVID-19	4/1/ 2020	12/31/ 2020	9	51	68.0
VA	Military Highway at Northampton Boulevard	Before	Not COVID-19	1/1/ 2011	7/31/ 2016	48	102	25.5
VA	Military Highway at Northampton Boulevard	After	Not COVID-19	8/1/ 2018	3/31/ 2022	32	50	18.8
VA	Military Highway at Northampton Boulevard	After	COVID-19	1/1/ 2020	12/31/ 2020	12	12	12.0

*Replacement sites used for comparison purposes.

Table 3 provides the number of crashes by severity level for the before, after, compare-before, or compare-after periods along with whether the period included crashes that occurred within the COVID-19 timeframe.

Table 3. Number of crashes per study period by severity level.

State	Intersection	Period	COVID-19	K	A	B	C	O	Total Crashes	KABC Crashes
AZ	Grant Road at First Avenue	Before	Not COVID-19	1	6	19	20	31	77	46
AZ	Grant Road at First Avenue	After	Not COVID-19	0	0	10	6	38	54	16
AZ	Grant Road at First Avenue	After	COVID-19	0	0	3	5	25	33	8
AZ	Grant Road at Oracle Road North*	Compare-Before	Not COVID-19	0	3	7	15	18	43	25
AZ	Grant Road at Oracle Road North*	Compare-After	Not COVID-19	0	1	9	11	28	49	21
AZ	Grant Road at Oracle Road North*	Compare-After	COVID-19	0	1	2	5	9	17	8
AZ	Grant Road at Stone Avenue	Before	Not COVID-19	0	0	16	16	26	58	32
AZ	Grant Road at Stone Avenue	After	Not COVID-19	1	1	10	4	18	34	16
AZ	Grant Road at Stone Avenue	After	COVID-19	1	1	3	1	9	15	6
AZ	Valencia Road at Kolb Road	Before	Not COVID-19	0	0	2	0	2	4	2
AZ	Valencia Road at Kolb Road	After	Not COVID-19	1	3	15	4	31	54	23
AZ	Valencia Road at Kolb Road	After	COVID-19	0	0	4	6	15	25	10
MN	MN–65 at 157th Avenue Northeast	Before	Not COVID-19	1	1	2	6	8	18	10
MN	MN–65 at 157th Avenue Northeast	After	Not COVID-19	0	0	0	1	4	5	1
MN	MN–65 at 157th Avenue Northeast	After	COVID-19	0	1	1	0	1	3	2
MN	MN–65 at 181st Avenue Northeast	Before	Not COVID-19	2	0	4	0	6	12	6
MN	MN–65 at 181st Avenue Northeast	After	Not COVID-19	0	1	0	1	1	3	2
MN	MN–65 at 181st Avenue Northeast	After	COVID-19	0	0	0	0	3	3	0
MN	MN–65 at 187th Northeast	Before	Not COVID-19	1	0	3	1	7	12	5

State	Intersection	Period	COVID-19	K	A	B	C	O	Total Crashes	KABC Crashes
MN	MN–65 at 187th Northeast	After	Not COVID-19	0	1	0	1	5	7	2
MN	MN–65 at 187th Northeast	After	COVID-19	0	0	0	0	0	0	0
MN	MN–65 at 209th Avenue Northeast*	Compare-Before	Not COVID-19	0	0	1	0	2	3	1
MN	MN–65 at 209th Avenue Northeast*	Compare-After	Not COVID-19	0	1	0	0	2	3	1
MN	MN–65 at 209th Avenue Northeast*	Compare-After	COVID-19	0	0	0	0	1	1	0
MN	MN–65 at Viking Boulevard Northeast	Before	Not COVID-19	0	0	7	17	17	41	24
MN	MN–65 at Viking Boulevard Northeast	After	Not COVID-19	1	0	2	0	3	6	3
MN	MN–65 at Viking Boulevard Northeast	After	COVID-19	1	0	1	2	7	11	4
TX	SH–16 at West Loop 1604 Access Road	Before	Not COVID-19	1	10	59	195	616	881	265
TX	SH–16 at West Loop 1604 Access Road	After	Not COVID-19	0	4	26	54	196	280	84
TX	SH–16 at West Loop 1604 Access Road	After	COVID-19	0	1	8	33	85	127	42
VA	Indian River Road at Kempsville Road	Before	Not COVID-19	1	5	136	23	376	541	165
VA	Indian River Road at Kempsville Road	After	Not COVID-19	0	4	25	0	64	93	29
VA	Indian River Road at Kempsville Road	After	COVID-19	0	3	14	0	34	51	17
VA	Military Highway at Northampton Boulevard	Before	Not COVID-19	0	9	5	38	50	102	52
VA	Military Highway at Northampton Boulevard	After	Not COVID-19	0	1	10	2	37	50	13
VA	Military Highway at Northampton Boulevard	After	COVID-19	0	0	3	1	8	12	4

*Replacement sites used for comparison purposes.

Table 4 summarizes the KABCO and contrasts this information to the KABC conditions for each site. The values in the table do not include the crashes that occurred during 2020 (COVID-19 timeframe). In general, the total crashes increase following implementation of the new intersection configuration, but the injury crashes are consistently reduced (except for two Arizona and two Minnesota sites). Alternative intersection designs modify the path of left-turning vehicles. This conversion could aid in modifying the type of crashes, which could result in fewer severe injury crashes.

Table 4. Average number of total and injury crashes per year.

State	Intersection	Average Number of Total Crashes (KABCO) per Year			Average Number of Injury Crashes (KABC) per Year		
		Before	After	Change (percent)	Before	After	Change (percent)
AZ	Grant Road at First Avenue	21.5	21.6	0.5	12.8	6.4	−50.0
AZ	Grant Road at Stone Avenue	10.4	14.6	40.4	5.7	6.9	21.1
AZ	Valencia Road at Kolb Road	0.9	34.1	3688.9	0.5	14.5	2800.0
MN	MN–65 at 157th Avenue northeast	3.3	3.8	15.2	1.8	0.8	−55.6
MN	MN–65 at 181st Avenue Northeast	2.2	2.3	4.5	1.1	1.5	36.4
MN	MN–65 and 187th Northeast	2.2	5.3	140.9	0.9	1.5	66.7
MN	MN–65 at Viking Boulevard Northeast	7.5	4.5	−40.0	4.4	2.3	−47.7
TX	SH–16 at West Loop 1604 Access Road	188.8	129.2	−31.6	56.8	38.8	−31.7
VA	Indian River Road at Kempsville Road	66.2	69.8	5.4	20.2	21.8	7.9
VA	Military Highway at Northampton Boulevard	25.5	18.8	−26.3	13.0	4.9	−62.3

Table 5 provides the percent distribution of severity levels for the before and after periods. The values in the table do not include the crashes that occurred during 2020 (COVID-19 timeframe). In all cases but one, the after period was associated with an increase in observed PDO crashes. This finding is consistent with the observation for table 4 and suggests that the crash severity at these sites represents an increase in property damage-only crashes and an expected reduction in injury crashes. The one case when the distribution of PDOs increased was based on a limited number of crashes—only 12 crashes in the before period and 3 crashes in the after period.

Table 5. Percent distribution of crashes by severity level, intersection, and period.

State	Intersection	Period	K (%)	A (%)	B (%)	C (%)	O (%)	Change in KABC Crashes (%)
AZ	Grant Road at First Avenue	Before	1	8	25	26	40	NA
AZ	Grant Road at First Avenue	After	0	0	19	11	70	−30

State	Intersection	Period	K (%)	A (%)	B (%)	C (%)	O (%)	Change in KABC Crashes (%)
AZ	Grant Road at Oracle Road North	Compare-Before	0	7	16	35	42	NA
AZ	Grant Road at Oracle Road North	Compare-After	0	2	18	22	57	−15
AZ	Grant Road at Stone Avenue	Before	0	0	28	28	45	NA
AZ	Grant Road at Stone Avenue	After	3	3	29	12	53	−8
AZ	Valencia Road at Kolb Road	Before	0	0	50	0	50	NA
AZ	Valencia Road at Kolb Road	After	2	6	28	7	57	−7
MN	MN–65 at 157th Avenue Northeast	Before	6	6	11	33	44	NA
MN	MN–65 at 157th Avenue Northeast	After	0	0	0	20	80	−36
MN	MN–65 at 181st Avenue Northeast	Before	17	0	33	0	50	NA
MN	MN–65 at 181st Avenue Northeast	After	0	33	0	33	33	17
MN	MN–65 at 187th Northeast	Before	8	0	25	8	58	NA
MN	MN–65 at 187th Northeast	After	0	14	0	14	71	−13
MN	MN–65 at 209th Avenue Northeast	Compare-Before	0	0	33	0	67	NA
MN	MN–65 at 209th Avenue Northeast	Compare-After	0	33	0	0	67	0
MN	MN–65 at Viking Boulevard Northeast	Before	0	0	17	41	41	NA
MN	MN–65 at Viking Boulevard Northeast	After	17	0	33	0	50	−9
TX	SH–16 at West Loop 1604 Access Road	Before	0	1	7	22	70	NA
TX	SH–16 at West Loop 1604 Access Road	After	0	1	9	19	70	0
VA	Indian River Road at Kempsville Road	Before	0	1	25	4	70	NA
VA	Indian River Road at Kempsville Road	After	0	4	27	0	69	1
VA	Military Highway at Northampton Boulevard	Before	0	9	5	37	49	NA
VA	Military Highway at Northampton Boulevard	After	0	2	20	4	74	−25

NA = the comparison is only applicable for the after period.

CRASH TYPES

The research team next subdivided the data by crash types. Table 6 provides the distribution of crash type for the before period and the after period (not including the COVID-19 year of 2020) for intersections in Arizona, Minnesota, Texas, and Virginia.

Table 6. Distribution of crash type by intersection for before and after periods.

State	Intersection	Period	RE (%)	Angle (%)	LT (%)	SS (%)	HO (%)	Veh PorB (%)	ROR SV (%)	Other (%)
AZ	Grant Road at First Avenue	Before	30	13	34	3	3	13	4	1
AZ	Grant Road at First Avenue	After	24	19	50	2	0	2	2	2
AZ	Grant Road at Oracle Road North	Compare -Before	28	9	23	16	2	9	12	0
AZ	Grant Road at Oracle Road North	Compare -After	22	14	35	8	0	16	4	0
AZ	Grant Road at Stone Avenue	Before	22	14	38	3	2	16	3	2
AZ	Grant Road at Stone Avenue	After	26	12	29	9	3	12	9	0
AZ	Valencia Road at Kolb Road	Before	75	0	25	0	0	0	0	0
AZ	Valencia Road at Kolb Road	After	28	30	11	7	0	0	22	2
MN	MN–65 at 157th Avenue Northeast	Before	11	61	6	6	6	6	0	6
MN	MN–65 at 157th Avenue Northeast	After	40	0	0	60	0	0	0	0
MN	MN–65 at 181st Avenue Northeast	Before	8	25	8	0	25	0	0	33
MN	MN–65 at 181st Avenue Northeast	After	33	0	0	33	0	0	0	33
MN	MN–65 at 187th Northeast	Before	17	50	0	17	0	0	0	17
MN	MN–65 at 187th Northeast	After	57	14	0	14	0	0	0	14
MN	MN–65 at 209th Avenue Northeast	Compare -Before	0	0	0	0	0	0	33	67
MN	MN–65 at 209th Avenue Northeast	Compare -After	33	33	0	0	0	0	0	33

State	Intersection	Period	RE (%)	Angle (%)	LT (%)	SS (%)	HO (%)	Veh PorB (%)	ROR SV (%)	Other (%)
MN	MN–65 at Viking Boulevard Northeast	Before	78	10	0	0	0	0	5	7
MN	MN–65 at Viking Boulevard Northeast	After	50	17	0	0	0	0	0	33
TX	SH–16 at West Loop 1604 Access Road	Before	14	26	NA	19	0	1	1	39
TX	SH–16 at West Loop 1604 Access Road	After	17	30	NA	20	0	1	0	32
VA	Indian River Road at Kempsville Road	Before	48	39	NA	7	1	1	1	3
VA	Indian River Road at Kempsville Road	After	32	52	NA	8	2	1	1	4
VA	Military Highway at Northampton Boulevard	Before	62	26	NA	6	2	1	1	2
VA	Military Highway at Northampton Boulevard	After	34	40	NA	16	4	0	4	2

RE = rear-end; SS = sideswipe; HO = head on; Veh PorB = vehicle and pedestrian or vehicle and bicyclist; ROR = ran off road; SV = single vehicle; NA = Texas and Virginia crash data did not include codes that would identify a left-turn crash.

As designated by the two bullets at the beginning of chapter 4, due to two critical issues (delays created by COVID-19 restrictions and potential changes in travel patterns), the research team was unable to capture after data for a period of 3–5 yr as commonly targeted. For that reason, the research team could not conduct a comprehensive and robust safety evaluation. Instead, this report provides before and after information based on a simple comparison. To avoid discarding partial-year crash data, the research team considered crashes in monthly periods.

ARIZONA INTERSECTIONS

The research team studied four Arizona sites (table 1). Three of the sites located along Grant Road are MUT configurations (i.e., RLTCI). The fourth site is located at the intersection of Valencia Road and Kolb Road and is a hybrid version of this intersection. A before-after aerial view and a schematic of each final configuration were included in volume I, chapter 3 of the companion operations report for this project.[(1)]

Arizona Newly Constructed Signalized Intersection with Reduced Left-Turn Conflicts

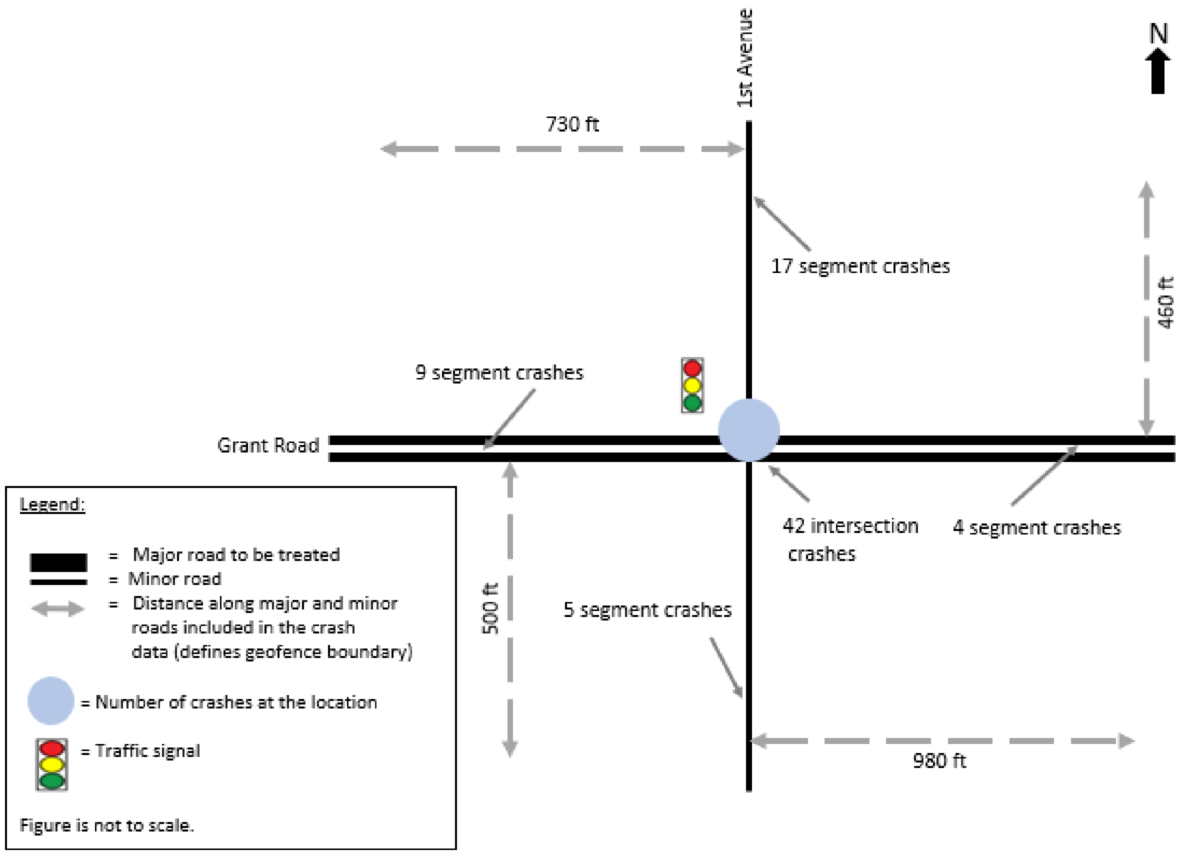
The three intersections located along the Grant Road corridor are in fully developed urban regions where left-turn maneuvers at the conventional signalized intersections on the major road previously introduced significant delay, and this delay created safety concerns at the primary intersection. The North Oracle Road intersection was converted from a conventional signalized intersection to an MUT during an earlier phase of construction that preceded the data collection efforts for this project and was included in this study as a comparison intersection.

These MUTs are a subset of RLTCIs as summarized in the chapter 2 literature review. For the RLTCIs, the main roadway retains through and right-turn movements, while the left turn is prohibited at the primary intersection and is instead relocated to a downstream median opening. The minor road typically retains all movements. The restricted left turn on the major road is generally enforced using regulatory signing instead of a raised island.

The main approach legs for the Grant Road corridor are in the eastbound and westbound direction. These intersections are in Tucson, AZ, and are positioned a few blocks to the east of a major freeway commuting corridor. All three intersections are signalized, and this Grant Road corridor is undergoing a phased reconstruction effort. The U-turn locations associated with these three intersections are located upstream and downstream of the Grant Road study intersections. Construction started on the intersection of Grant Road and North Oracle Road before the data-collection efforts for this study, but after data for this intersection have been included for comparison purposes where appropriate. The U-turn locations also contain loons (an expanded paved apron opposite a median crossover), which is common when the median separating direction of travel is relatively narrow. The loon is additional pavement that is outside of the normal travel lanes and specifically designed to help accommodate U-turn maneuvers for large vehicles.

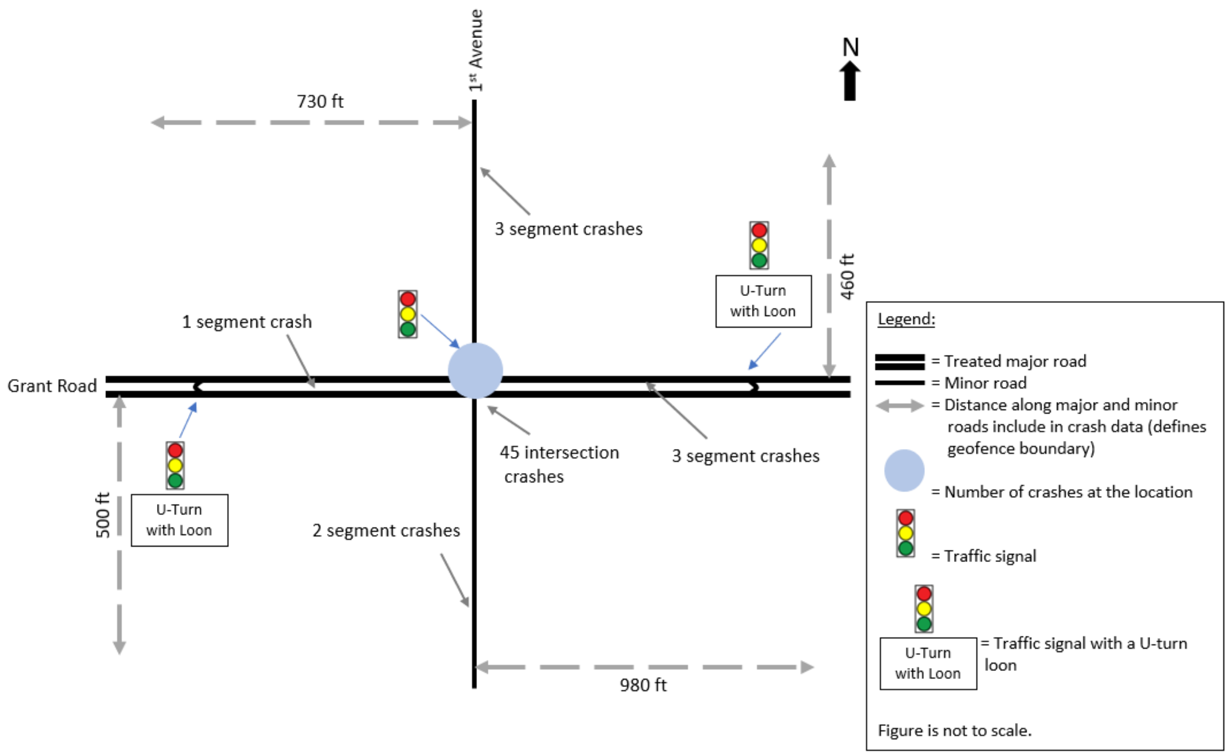
Grant Road at First Avenue

For Grant Road at First Avenue, the research team acquired crash data for 43 mo before construction and 42 mo after construction. The 42 mo after construction period included 12 mo during COVID-19 and 30 mo not during COVID-19. Table 2 provides the crash period dates along with the number of crashes observed during the period and a converted value of crashes per year. Figure 2 provides an overview of the number of crashes for the before period by location. Figure 3 provides that information for the after period.



Source: FHWA.

Figure 2. Illustration. Number of crashes by location for the before period (43 mo) for Grant Road at First Avenue.



Source: FHWA.

Figure 3. Illustration. Number of crashes by location for the after period (30 mo) for Grant Road at First Avenue.

Before construction, the intersection of Grant Road at First Avenue experienced an average of 21.5 crashes per year. In 2016, one fatal crash and one serious injury crash occurred at the intersection. In 2015 and 2017, two and three serious injury crashes occurred, respectively. Construction of the MUT configuration occurred from August 2017 through October 2018.

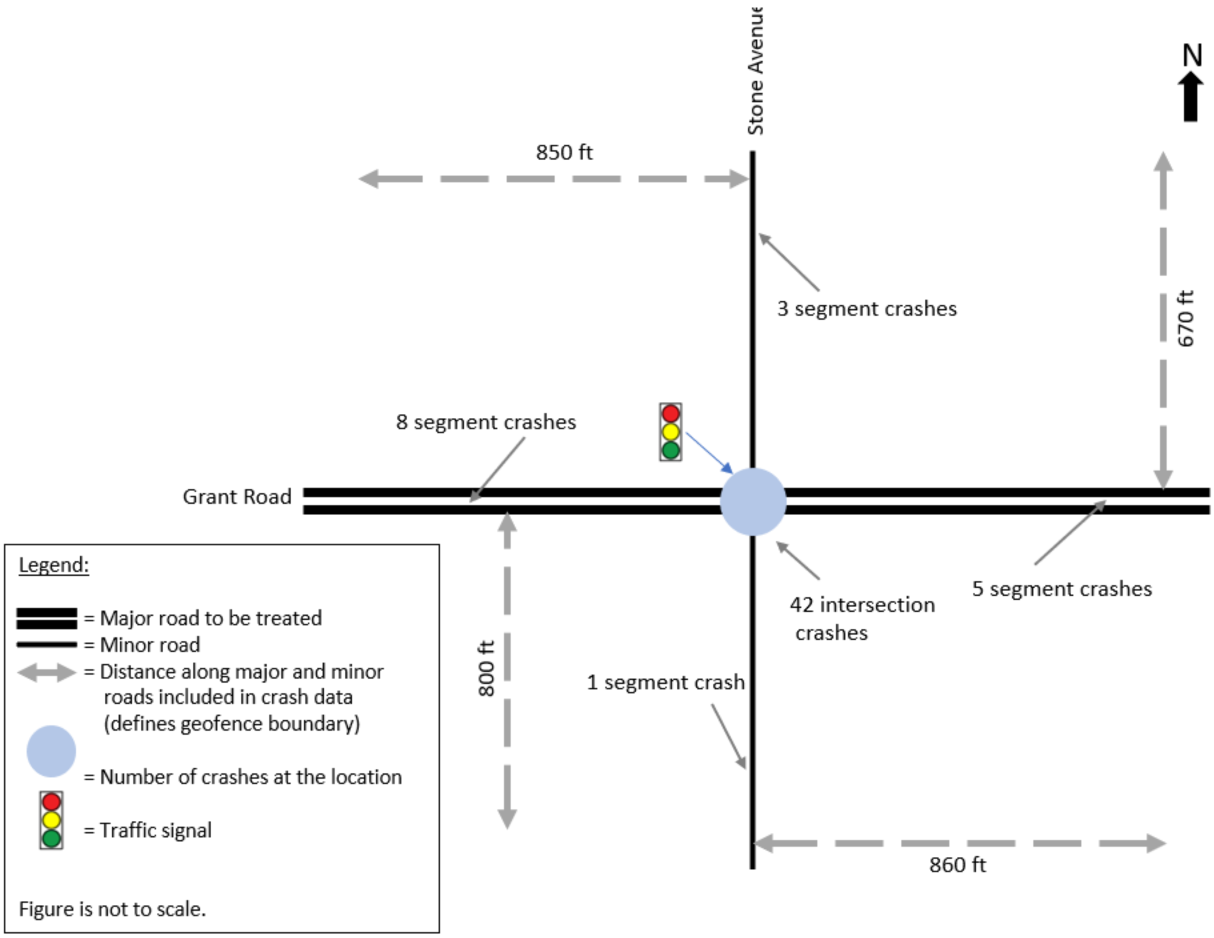
Following construction, an average of 21.6 crashes per year occurred at the site, with 33.0 crashes per year occurring during the pandemic years of 2020. As noted, the value during the pandemic was much higher than the other after years. No observed severe or fatal crashes occurred following construction at this intersection.

Before construction of the MUT intersection configuration, the most common crash types at the intersection were left-turn, rear-end, angle, and vehicle and pedestrian or vehicle and bicyclist crashes (table 6). After construction of the MUT intersection configuration, the most common crash types at the intersection were left-turn, rear-end, and angle crashes. Though these findings are primarily descriptive, the findings do indicate that the revised intersection configuration can be expected to have predominantly left-turn, angle, and rear-end crashes. The crash severity, based on this limited sample, also appears to improve with the modification. Table 5 shows that the proportion of property damage-only crashes increased in the after period, indicating that fewer fatal- and injury-related crashes occurred.

The crash type distribution includes pedestrian and bicycle crashes (table 6). In the before period, 13 percent of the crashes were pedestrian or bicycle related. However, this value decreased to 2 percent in the after period. The site did experience one fatal pedestrian-related crash in 2016.

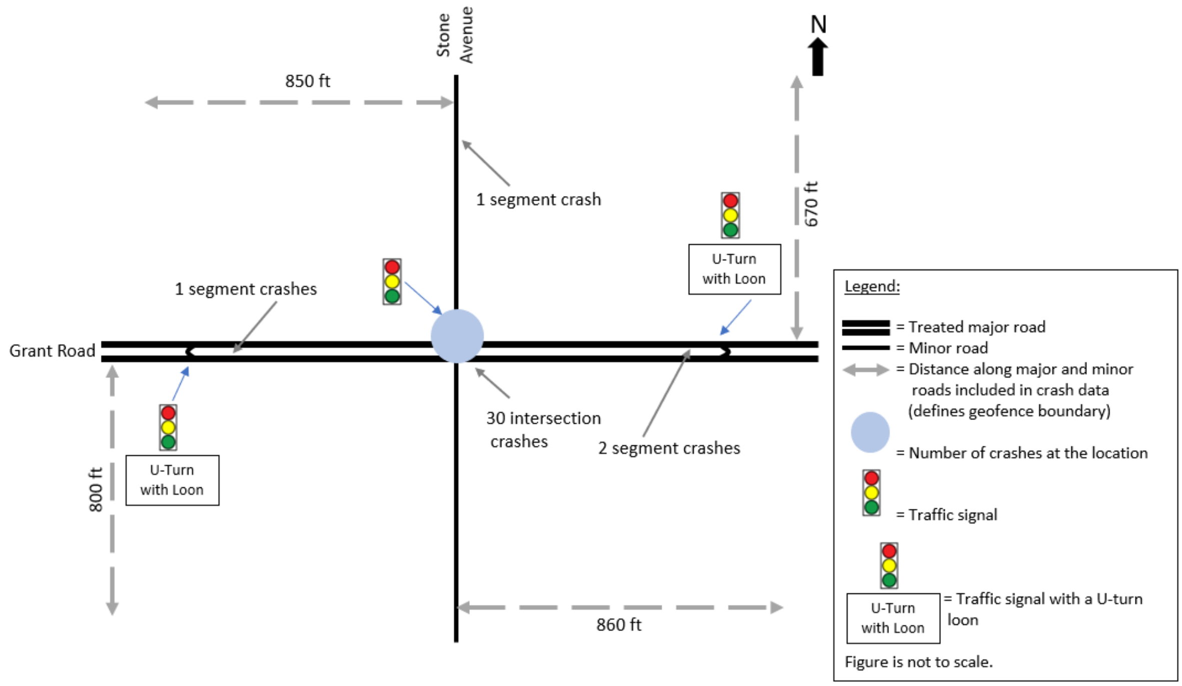
Grant Road at Stone Avenue

For Grant Road at Stone Avenue, the crash data included crashes that occurred 67 mo before construction and 28 mo (non-COVID-19) after construction. Table 2 provides the crash period dates along with the number of crashes observed during the period and a representative number of crashes per year. Figure 4 provides an overview of the number of crashes for the before period by location with the corridor. Figure 5 provides that information for the after period.



Source: FHWA.

Figure 4. Illustration. Number of crashes by location for the before period (67 mo) for Grant Road at Stone Avenue.



Source: FHWA.

Figure 5. Illustration. Number of crashes by location for the after period (28 mo) for Grant Road at Stone Avenue.

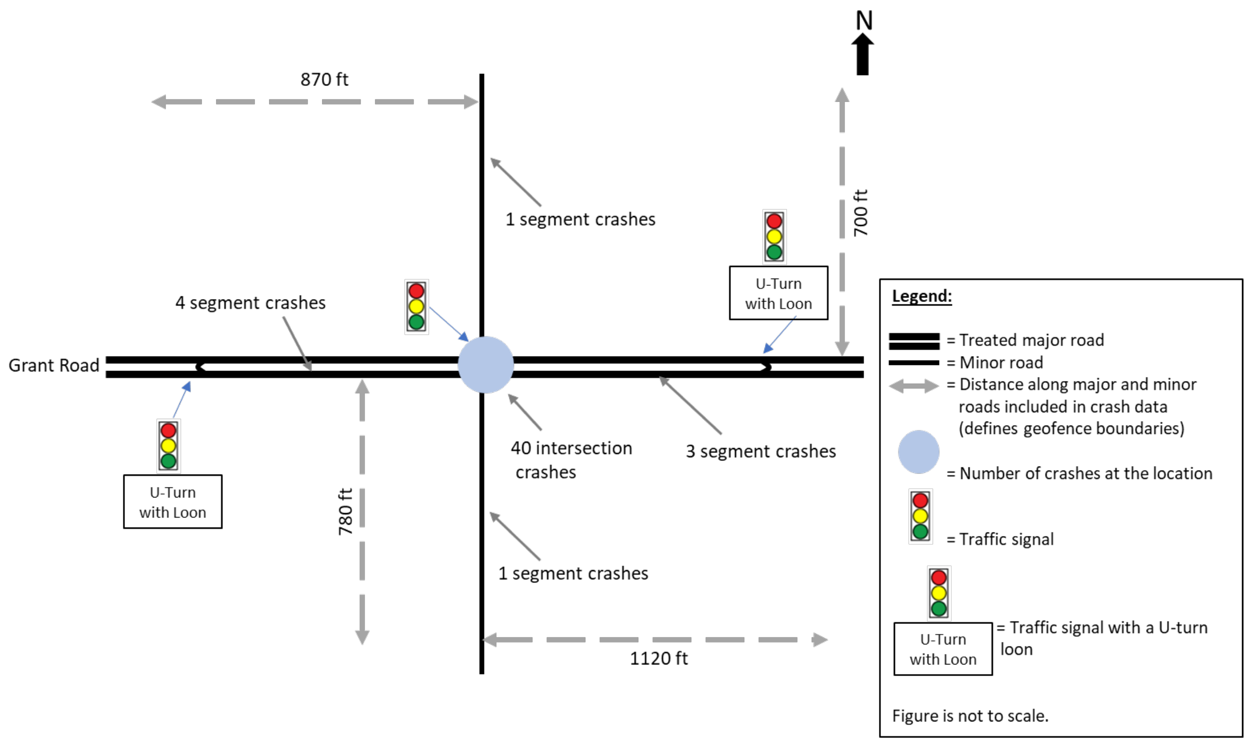
Before construction, the intersection of Grant Road at Stone Avenue typically experienced an average of 10.4 crashes per year. During the most recent years preceding the intersection reconfiguration, no fatal or serious injury crashes occurred at the intersection. In 2020, one fatal crash occurred; another fatal crash occurred in 2022. In addition, two serious injury crashes occurred in 2019 and 2020. Construction of the MUT occurred from August 2017 through October 2018. Following construction, an average of 14.6 crashes per year occurred (crashes during 2020 were removed from this average).

Before construction of the MUT configuration, the most commonly observed crash types were the left-turn and rear-end collisions. Following construction, these two crash types were again the most frequently observed (table 6). Grant Road at Stone Avenue experienced one fatal pedestrian crash in 2020 and another in 2022 after the intersection reconfiguration.

Grant Road at Oracle Road North

The intersection of Grant Road and Oracle Road North is the existing MUT intersection constructed before this study. The research team included this information as a comparison to help determine if one of the other two sites with similar intersection configurations experienced any unexpected trends in crash or severity information. The Grant Road and Oracle Road North intersection had an average of 19.6 crashes per year for the 30 mo after period similar to the neighboring intersection and an average of 12.0 crashes per year from 2014 to 2017, before period (table 2). Table 6 shows that the most common crash types at this site were the left-turn and rear-end crashes, a finding that is similar to the other intersections within this region

(Grant Road at First Avenue and Grant Road at Stone Avenue). Figure 6 shows the location of the crashes for this site for the 30 mo that match the period used at the neighboring treated sites.



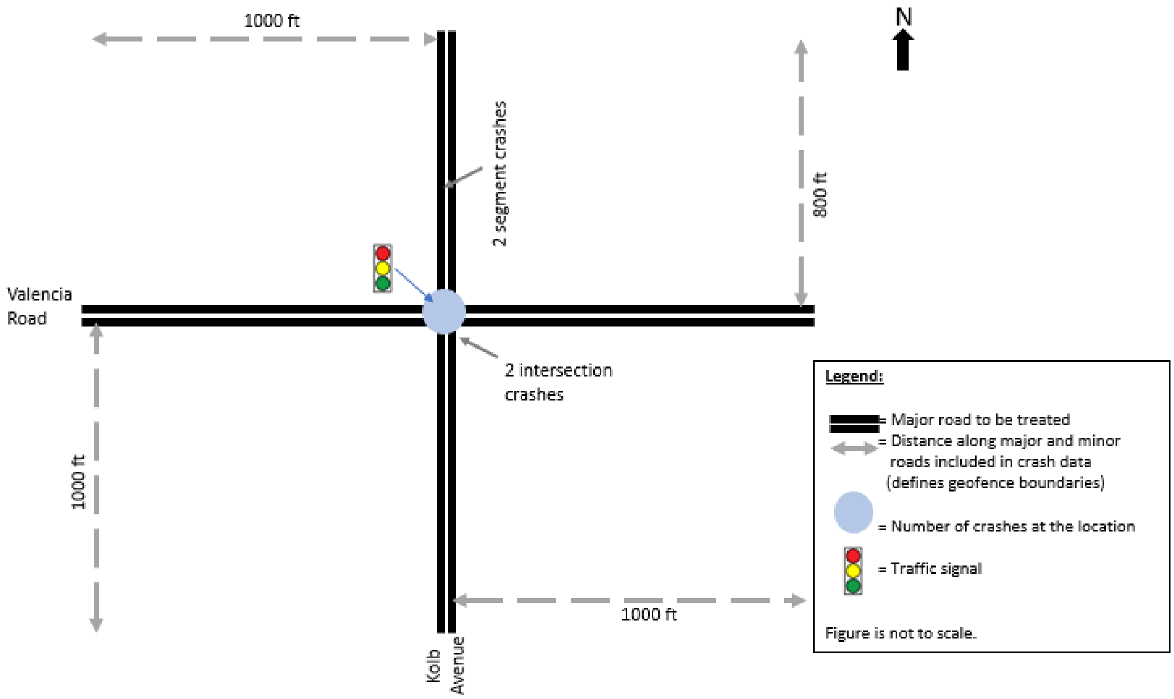
Source: FHWA.

Figure 6. Illustration. Number of crashes by location for the comparison after period (30 mo) that matches the after period for neighboring intersections for Grant Road at Oracle Road North.

Valencia Road at Kolb Road

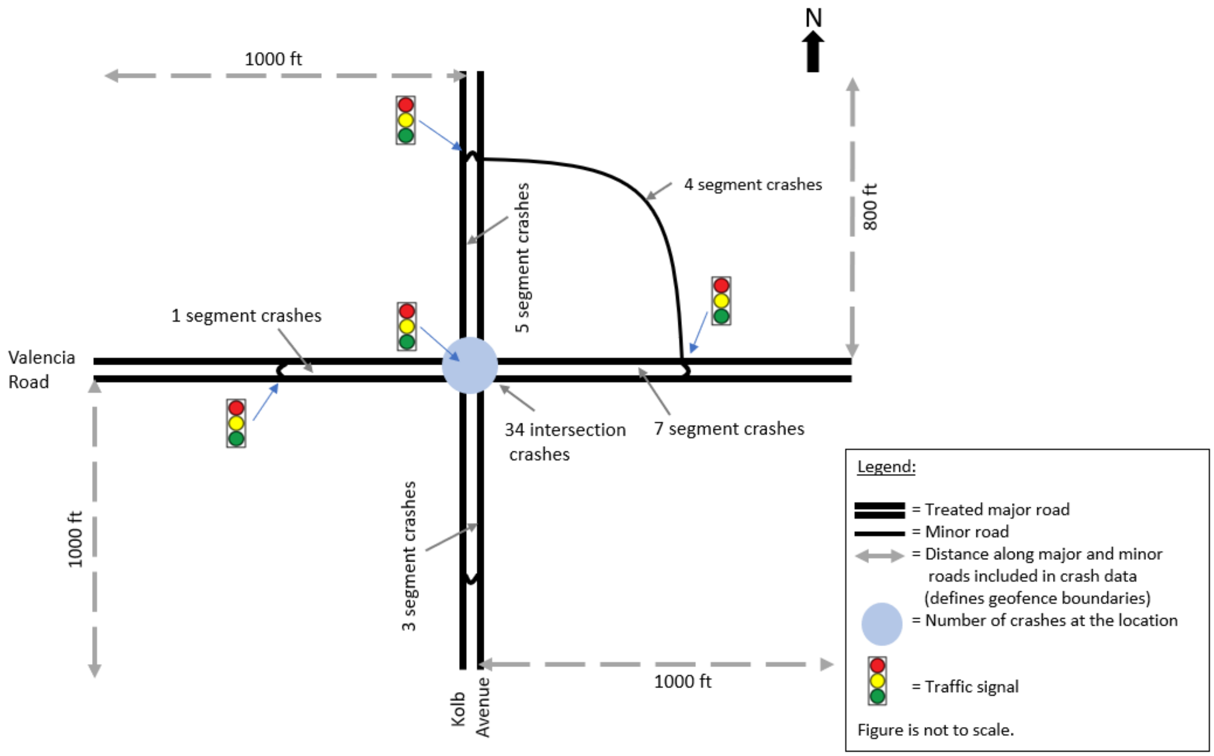
The remaining Arizona intersection of Valencia Road at Kolb Road is a unique innovative intersection with an indirect left-turn configuration and a quadrant-type connector. Before construction, the intersection of Valencia Road at Kolb Road experienced an average of 0.9 crashes per year. Following construction, the site experienced an average of 34.1 crashes per year. The construction included a quadrant-like feature that facilitated access to adjacent commuter routes. Consequently, the traffic volume increased substantially at this site due to the additional road. This increase in traffic volume can be expected to increase crashes.

In 2021, a fatal crash occurred at this intersection. In addition, severe crashes occurred in 2015 and again in 2021 and 2022. Construction of the indirect left-turn configuration occurred from June 2018 through September 2019. Before construction of the indirect left-turn configuration, the most commonly observed crash type was the rear-end collision (table 6). After construction, the two most common crash types were angle and rear-end crashes. Figure 7 and figure 8 show the number of crashes by location for the before and after periods, respectively.



Source: FHWA.

Figure 7. Illustration. Number of crashes by location for the before period (53 mo) for Valencia Road at Kolb Road.



Source: FHWA.

Figure 8. Illustration. Number of crashes by location for the after period (19 mo) for Valencia Road at Kolb Road.

MINNESOTA INTERSECTIONS

The following sections review the safety performance for the Minnesota unsignalized RCUTs, a signalized RCUT, and two comparison sites (one with an unsignalized RCUT previously constructed and one with a conventional two-way intersection located along the same corridor). Table 1 identifies the before and after configurations for these intersections.

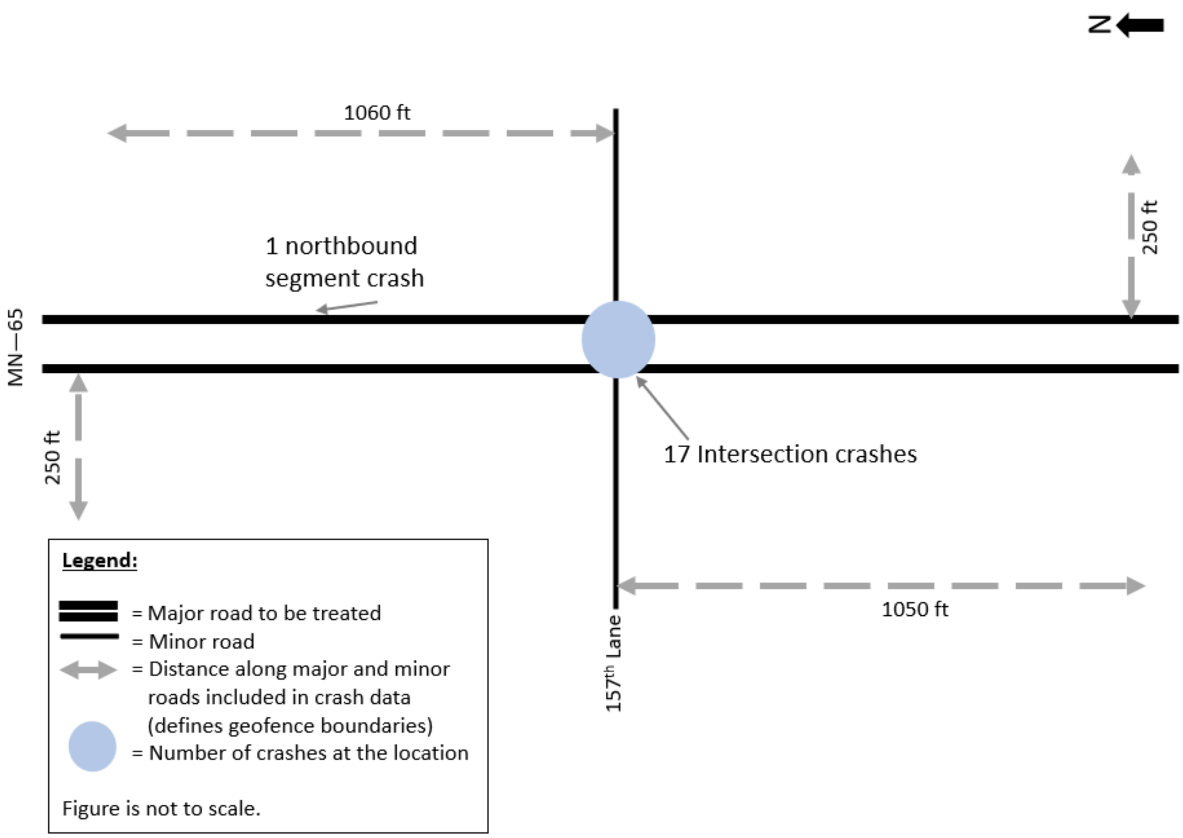
Minnesota Unsignalized RCUTs

The main approach legs for each intersection along the Minnesota study corridor are in the northbound and southbound direction. The MN–65 study sites are located north of Minneapolis and accommodate high traffic volumes traveling south toward the city during morning peak hours and similarly high traffic volumes travelling away from the city during afternoon peak periods. As noted in table 1, the intersection at 181st Avenue Northeast preceded construction of the RCUTs constructed at 157th Avenue Northeast and 187th Lane Northeast. The intersection of MN–65 and 157th Avenue Northeast and the intersection at MN–65 and 187th Lane Northeast are available as comparison sites.

As designated by the two bullet items at the beginning of Chapter 4, due to two critical issues (delays created by COVID-19 restrictions and potential changes in travel patterns), the research team was unable to capture sufficient after data for the 3–5 yr that is commonly targeted. For that reason, the research team could not conduct a comprehensive and robust safety evaluation. For each site, the team was able to conduct some simple before and after comparisons.

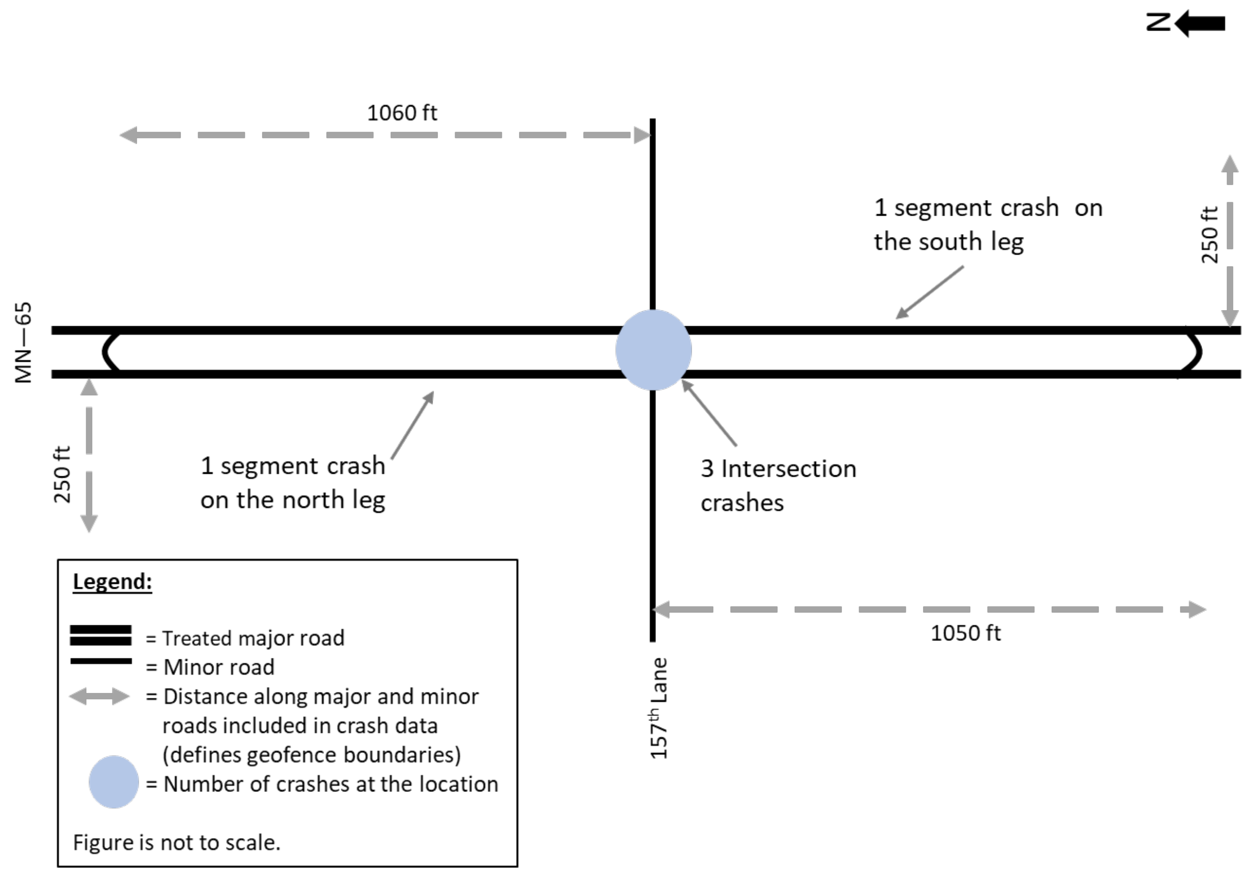
MN–65 at 157th Avenue NE

Before construction, the intersection of MN–65 at 157th Avenue Northeast experienced an average of 3.3 crashes per year (see table 2). A serious injury crash occurred in 2017 and a fatal crash occurred in 2018 at the intersection. Construction of the RCUT occurred from July 2018 through August 2019 (the construction date has been estimated from the Google Earth aerial view).[26] A severe crash occurred at the new RCUT site in 2020. For the available 16 mo of after data (data from 2020 were removed) there was an average of 3.8 crashes per year (a value that is similar to the average value for the before period). In general, the overall number of crashes slightly increased for the after period compared to the before period. However, a 36-percent reduction in fatal and injury crashes was observed (or an increase in property damage-only crashes) (table 5). Figure 9 provides an overview of the number of crashes for the before period by location within the corridor. Figure 10 provides that information for the after period.



Source: FHWA.

Figure 9. Illustration. Number of crashes by location for the before period (66 mo) for MN–65 at 157th Avenue Northeast.



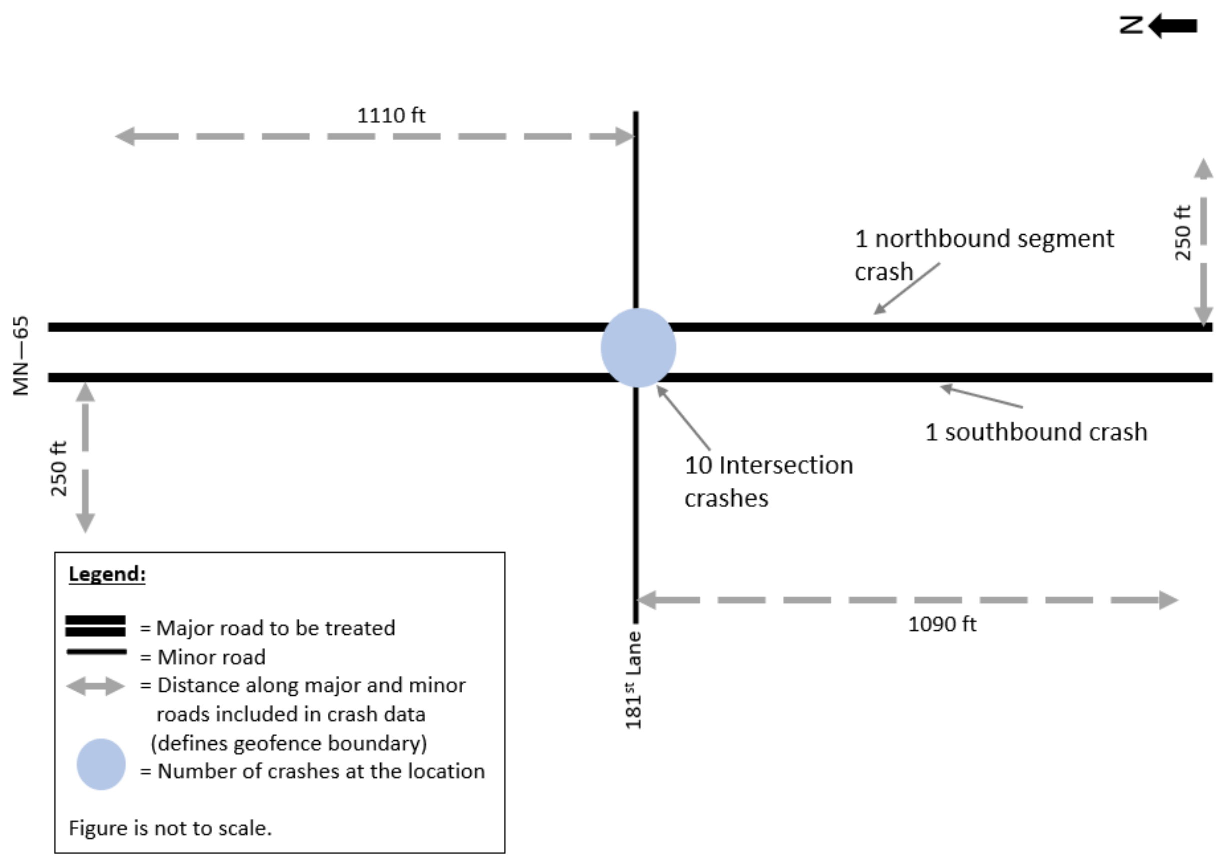
Source: FHWA.

Figure 10. Illustration. Number of crashes by location for the after period (16 mo) for MN–65 at 157th Avenue Northeast.

Before the construction of the RCUT, the most common crash type at the intersection was the angle crash (table 6). Following construction, the most common crash type was the rear-end crash.

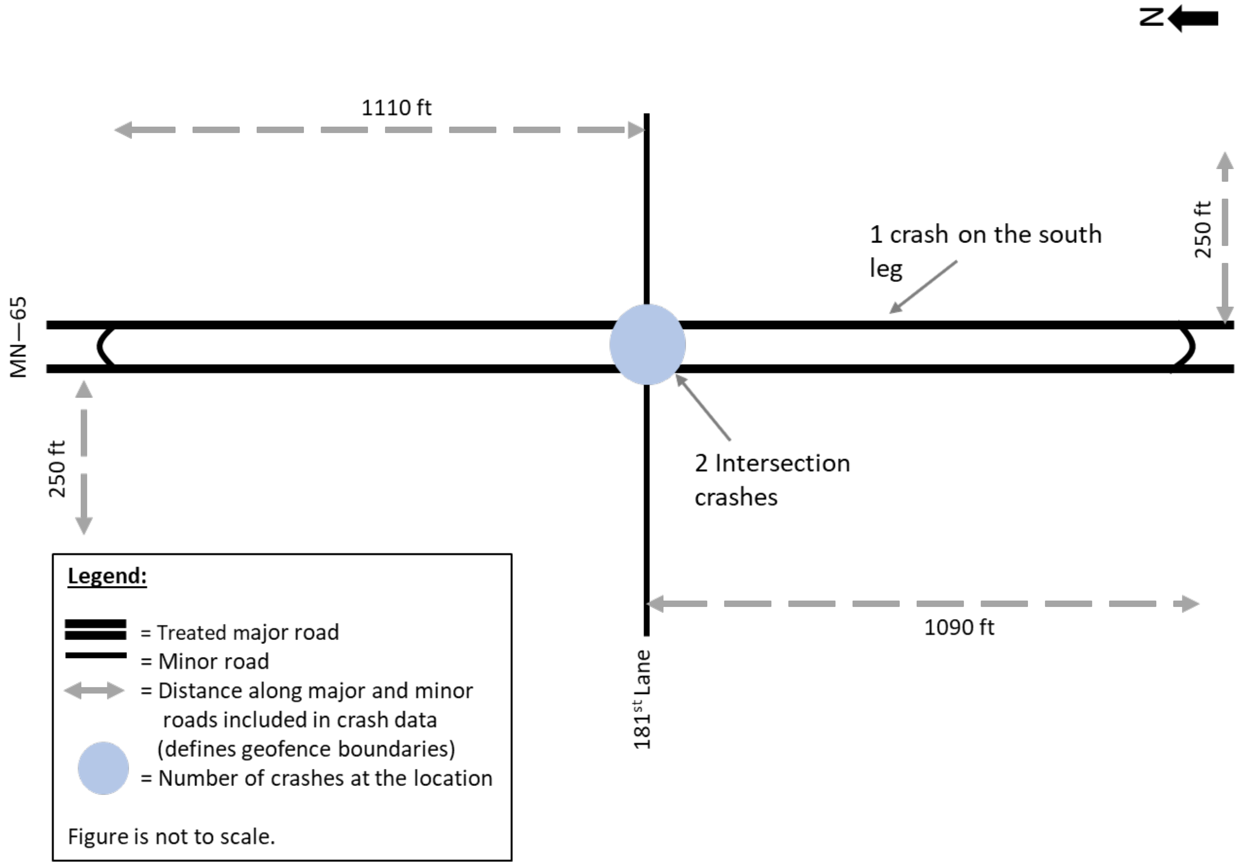
MN–65 at 181st Avenue Northeast

The Minnesota Department of Transportation (MnDOT) converted the conventional unsignalized intersection at MN–65 and 181st Avenue Northeast to an unsignalized RCUT. Before construction of the signalized RCUT at 181st Avenue NE, the intersection experienced an average of 2.2 crashes per year (table 2). The number of crashes during the after period was similar to the before period (2.3 crashes per year). This observation suggests that the number of crashes remained almost constant throughout the total study period. This site experienced one fatal angle crash in 2013 and another fatal angle crash in 2016 (both occurred during the before period). The number of crashes per location is shown in figure 11 for the before period and in figure 12 for the after period.



Source: FHWA.

Figure 11. Illustration. Number of crashes by location for the before period (66 mo) for MN–65 at 181st Avenue Northeast.



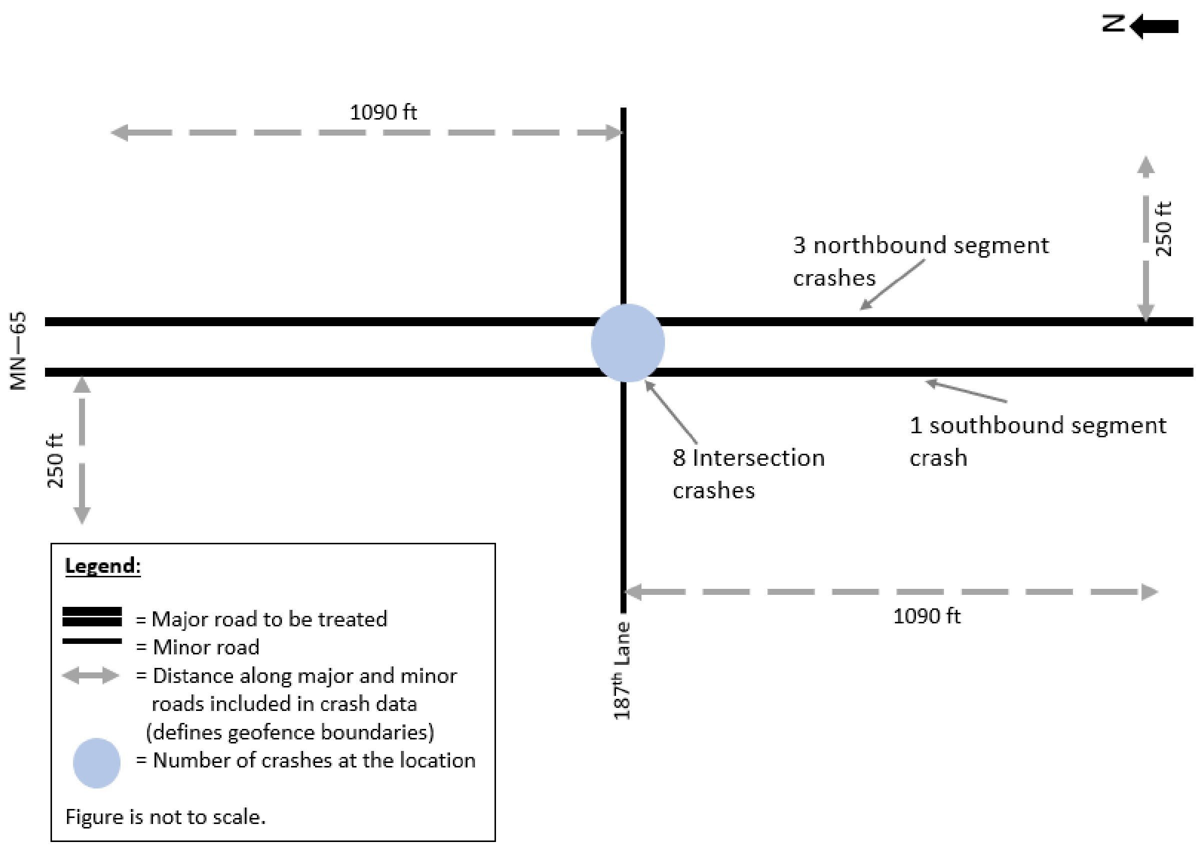
Source: FHWA.

Figure 12. Illustration. Number of crashes by location for the after period (16 mo) for MN–65 at 181st Avenue Northeast.

The most common crash types during the before period at the intersection were other, angle, and head-on crashes (table 6). In the after period, there was one rear-end, one sideswipe, and one other crash.

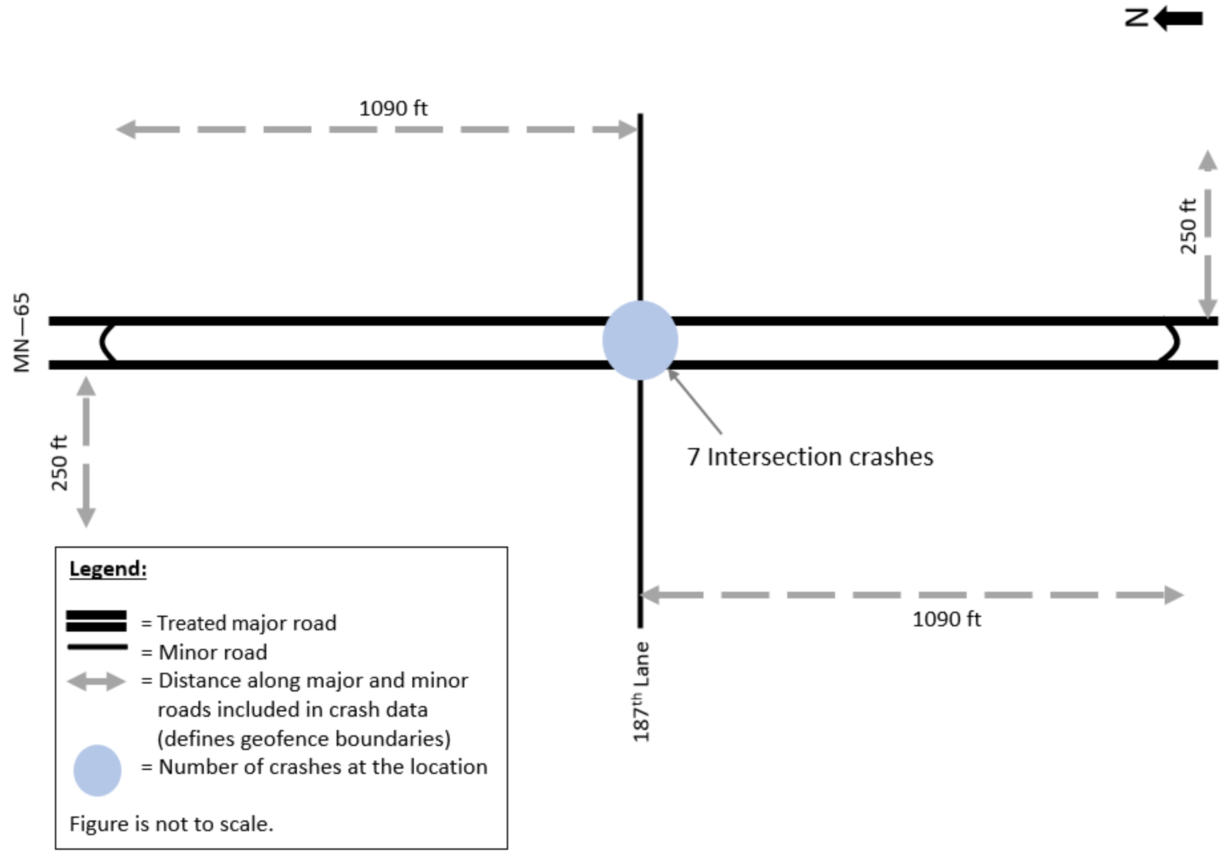
MN–65 at 187th Lane Northeast

Before construction of the RCUT at 187th Lane Northeast, the intersection experienced an average of 2.2 crashes per year (table 2). Following construction, this number of crashes increased to 5.3 crashes per year. However, as previously noted, the sample size is small, so this observation cannot be statistically verified. Table 5 shows that the proportion of KABC crashes decreased in the after period, indicating that fewer fatal and injury-related crashes occurred. Figure 13 provides an overview of the number of crashes for the before period by location. Figure 14 provides that information for the after period. In both periods, the crashes occurred at the main intersection, with most being in the center of the intersection rather than on the minor road approaches.



Source: FHWA.

Figure 13. Illustration. Number of crashes by location for the before period (66 mo) for MN–65 at 187th Lane Northeast.



Source: FHWA.

Figure 14. Illustration. Number of crashes by location for the after period (16 mo) for MN–65 at 187th Lane Northeast.

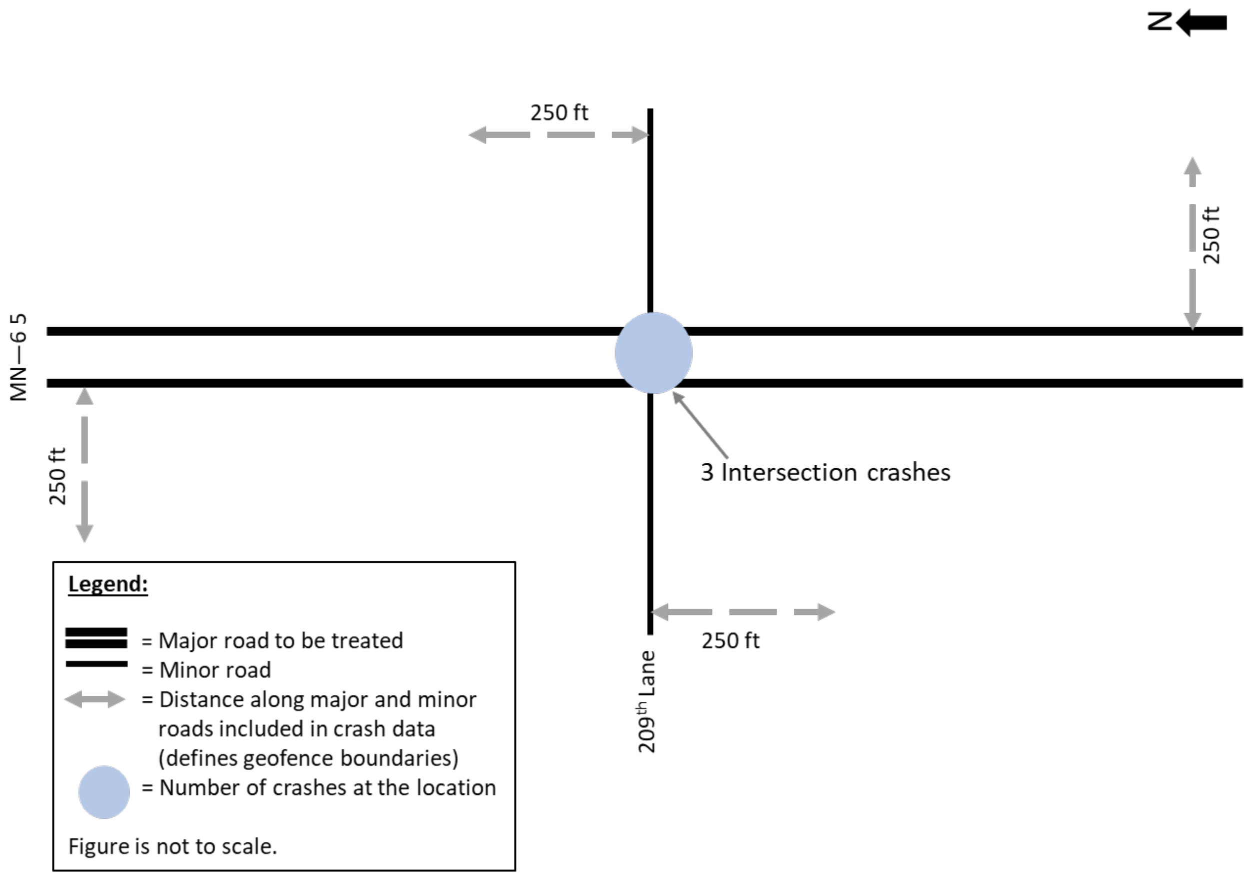
A fatal crash occurred at the intersection in 2017 during the before period. Construction of the RCUT occurred from July 2018 through August 2019. Following construction, two crashes occurred during the last 4 mo of 2019, which is the average annual number of crashes for the before period.

Before the construction of the RCUT, the most common crash types at the intersection were angle crashes. Following construction, the most common crash type was a rear-end collision.

Minnesota TWSC Comparison Site, MN–65 and 209th Avenue Northeast

The intersection of MN–65 at 209th Avenue Northeast is a conventional TWSC intersection with a median. This cross section is consistent with the before configuration for the MN–65 at 157th Avenue NE, 181st Avenue NE, and 187th Lane Northeast The intersection is located at the northern limits of the MN–65 corridor (just beyond Viking Boulevard Northeast). This site has been included for comparison purposes.

The site has an average of 0.5 crashes per year for the years that match the before period for the treated sites and an average of 2.3 crashes per year for the non-COVID-19 period that matches the after period for the near-by treated sites (table 2). The locations of the three crashes that occurred in the 16 mo of evaluation are shown in figure 15, with all the crashes occurring at the intersection than on the legs. Overall, having less than 1 crash per year suggests that the number of crashes remained constant throughout the total study period, and the site is not subjected to any significant safety concerns. The crash data indicate that there was at least 1 crash per year during the study period except for 2013, 2015, and 2018. A serious injury crash occurred at the site in 2019.

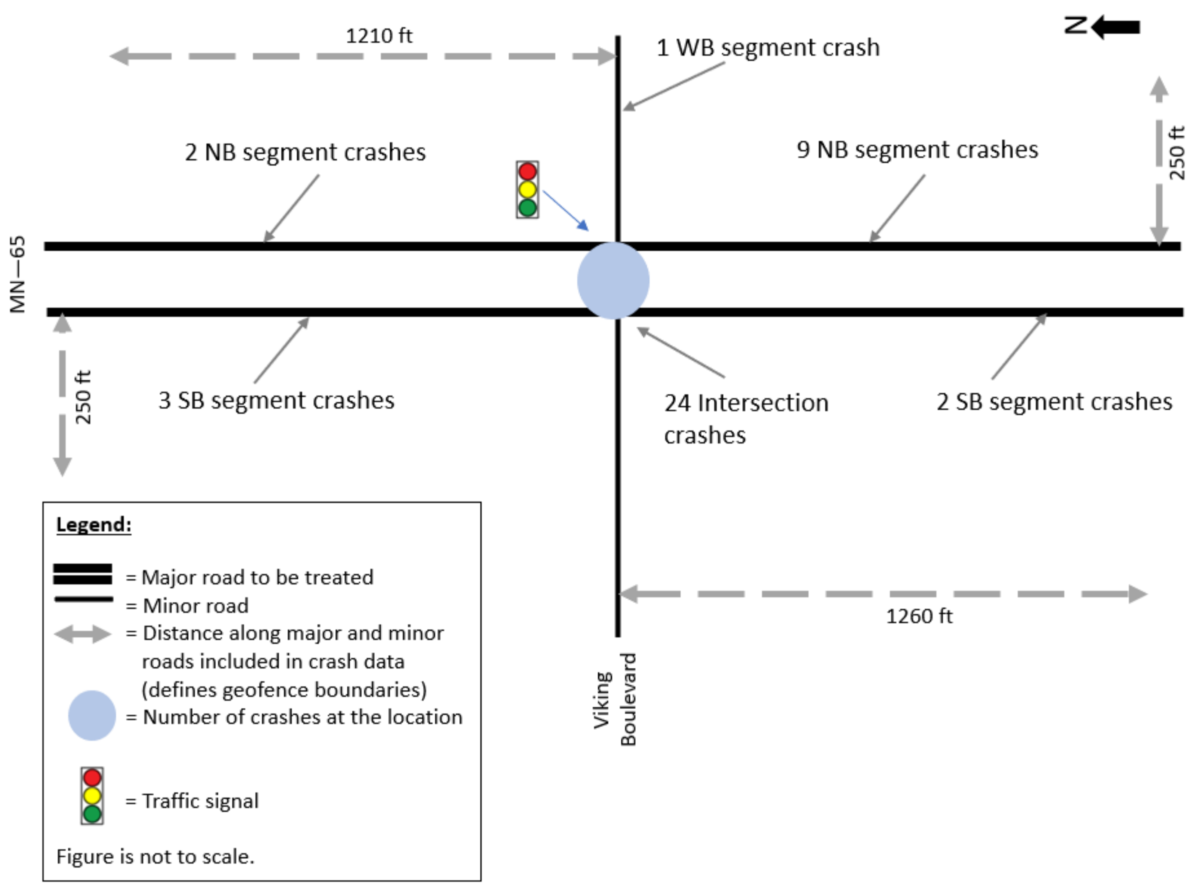


Source: FHWA.

Figure 15. Illustration. Number of crashes for the comparison after period (16 mo) that matches the after period for neighboring intersections for MN–65 at 209th Avenue Northeast.

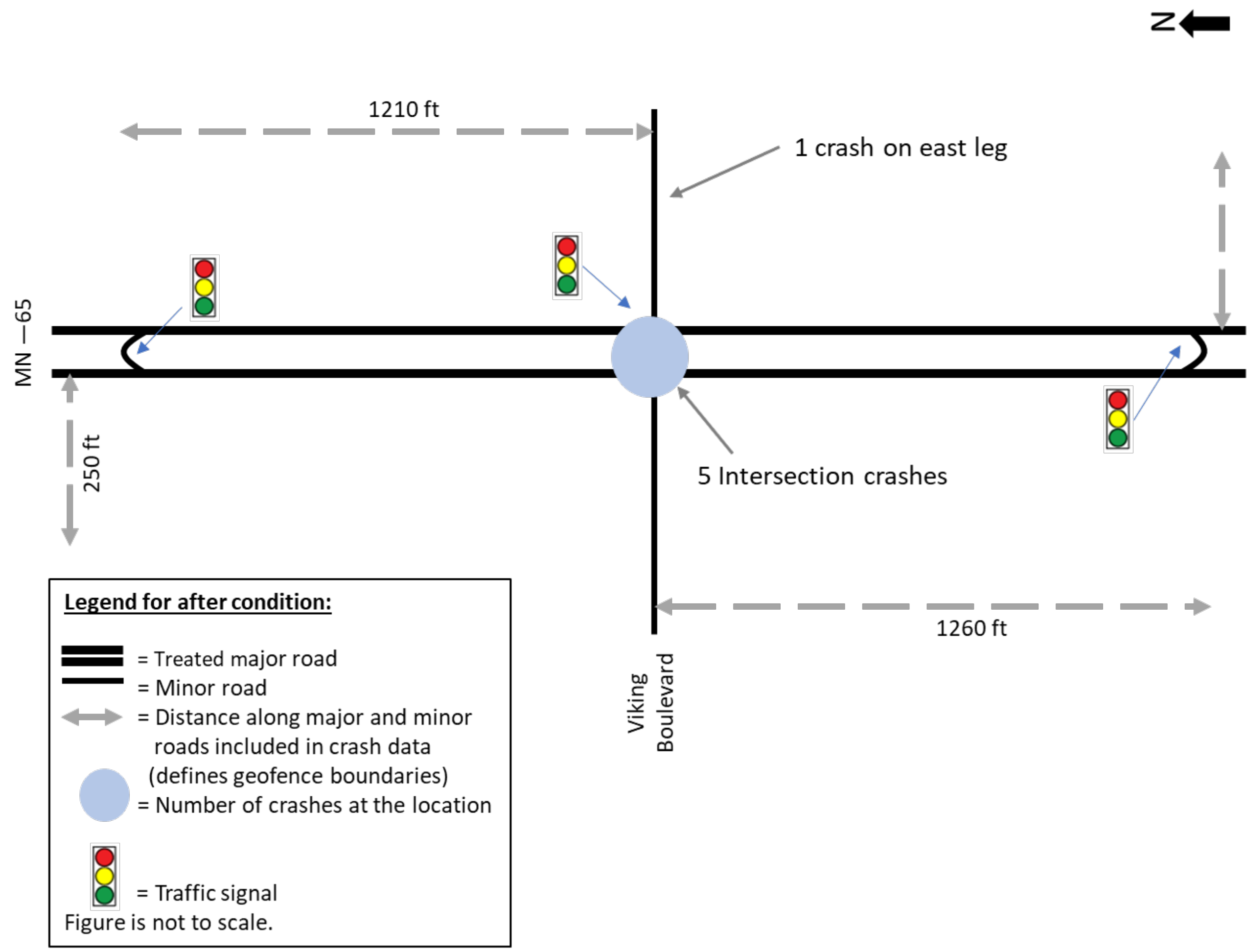
Minnesota Signalized RCUT, MN–65 at Viking Boulevard NE

As indicated in the short bullet list at the beginning of chapter 4, the research team could only capture limited crash data and so conducted a simple before and after analysis comparison. The team assembled before and after data for the number of crashes and the severity of crashes at the Viking Boulevard Northeast signalized RCUT location. Figure 16 shows the number of crashes by location for the before period. Figure 17 shows that information for the after period. Most of the crashes occurred at the intersection for both the before and after periods.



Source: FHWA.

Figure 16. Illustration. Number of crashes by location for the before period (66 mo) for MN–65 at Viking Boulevard Northeast.



Source: FHWA.

Figure 17. Illustration. Number of crashes by location for the after period (16 mo) for MN–65 at Viking Boulevard Northeast.

A traffic signal is located at the central intersection and at each U-turn location. Dual right-turn lanes facilitate the eastbound and westbound approaches, and the U-turns have two turning lanes. A right turn on red is not permitted at the central intersection.

Before construction of the signalized RCUT at Viking Boulevard NE, the intersection experienced an average of 7.5 crashes per year (table 2). Construction of the RCUT occurred from July 2018 through August 2019. Following construction, the number of crashes decreased to 4.5 crashes per year after excluding the crash data for 2020 because of COVID-19 (table 2). However, as previously noted, the sample size is small, so this observation cannot be statistically verified. A fatal crash occurred at the intersection in 2019 and another occurred in 2020. The 2020 fatal crash was an angle crash in the central intersection. The 2019 fatal crash was a single vehicle roadway departure. The total number of KABC crashes decreased by 9 percent from the before period to the after period (table 5).

Before the construction of the RCUT, the most common crash type at the intersection was the rear-end collision (table 6). Following construction, the most commonly observed crash types were rear-end and other crash types, as shown in table 6.

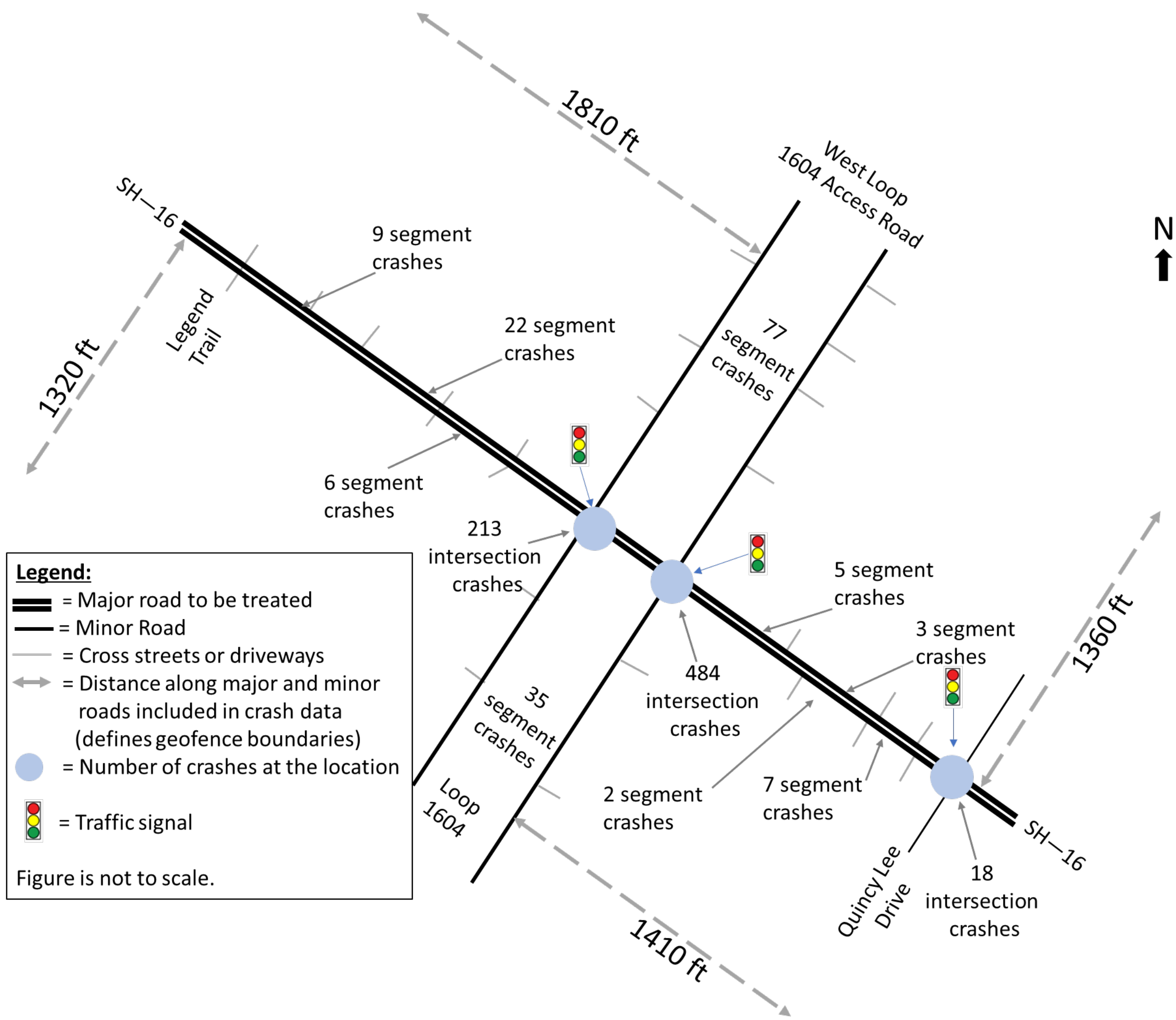
TEXAS INTERSECTION

Stakeholders considering constructing interchanges like the diverging diamond or intersections with a displaced left turn configuration often express concern that vehicle positions are switched, so that vehicles drive in the lane that is commonly the opposing through lane. This concern also creates expectation that one direction of travel is bounded by cars going in the other direction, and that the situation might be confusing, particularly at intersection locations along the corridor. To address this concern, the new displaced left diamond alternative interchange configuration keeps the through traffic in its typical lanes and adds a DLT to the intersection at the left turn located upstream of the signalized intersection.

Texas has a mature frontage road system, and often a Texas turnaround (sometimes called the Texas U-turn) is positioned under the bridge to help facilitate U-turns for the frontage road and provide an alternative that allows a U-turn from the frontage road in one direction to the frontage road in the opposing direction. The displaced left diamond interchange uses this U-turn space as a path for the separate displaced left-turn lane. Though this research project was focused on intersections and not interchanges, FHWA agreed with the research team's request to include the displaced left diamond interchange in the project. The initial intersection configuration was a conventional diamond interchange with Texas turnarounds at each end of the bridge. The Texas Department of Transportation modified the terminal intersection between the frontage road (off ramp) and the cross street to enable the displaced left-turn movement.

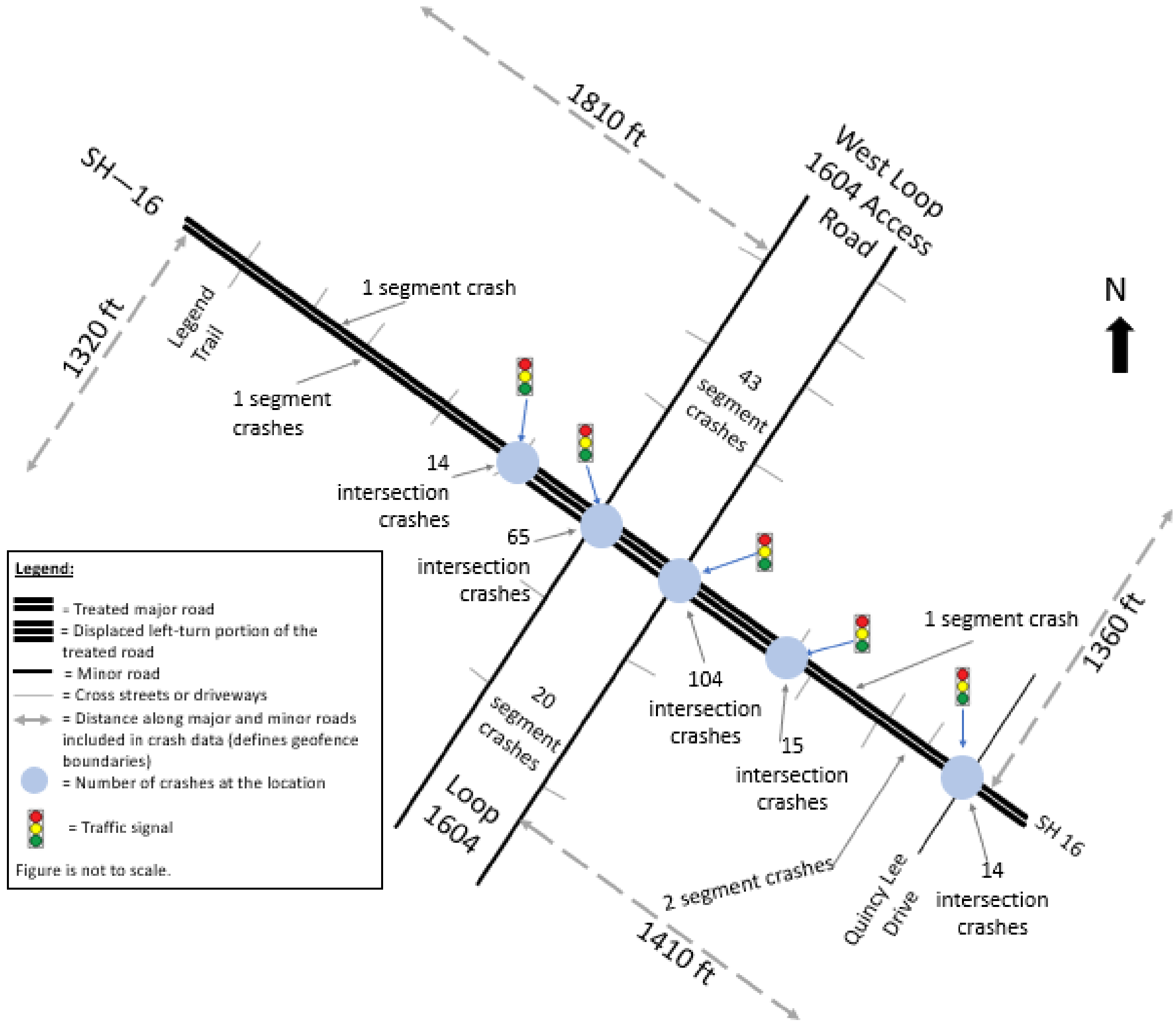
As previously indicated, the research team could only capture limited after crash data and so conducted a simple before-after analysis comparison. Like the unsignalized RCUT analysis, the team assembled before and after data for the number of crashes, the severity of crashes, and the crash type at the Texas displaced left diamond location and for several hundred feet along each approach to the interchange. A traffic signal is located at the central intersection and upstream where the left-turn traffic crosses over to the outside lane (previously the Texas U-turn location).

Figure 18 provides an overview of the number of crashes by location within the corridor for the before period. Figure 19 provides that information for the after period, which does not include the data for the COVID-19 period, year 2020. These figures also provide the limits of the crash data. Because the influence area for an alternative intersection can reach beyond the center of the intersection, the research team used a geofence for data boundaries. Figure 18 and figure 19 provide the limits used for this site. Texas crash data include the latitude and longitude of the crash, and these values were used to group the crashes to the nearest intersection or driveway. The latitude and longitude for crashes within a Texas freeway and frontage road corridor are coded to the centerline of the freeway, hence the presence of the crash counts along the center the freeway in figure 18 and figure 19. The research team removed any clearly identified freeway crashes from the analysis for this study.



Source: FHWA.

Figure 18. Illustration. Number of crashes by location for the before period (56 mo) for SH–16 at West Loop 1604 Access Road in San Antonio.



Source: FHWA.

Figure 19. Illustration. Number of crashes by location for the after period (26 mo) for SH–16 at West Loop 1604 Access Road in San Antonio.

Before construction of the displaced left diamond interchange in Texas, the region typically experienced approximately 188.8 crashes per year (table 2). Construction occurred from September 2018 through April 2019. Following construction, the number of crashes per year decreased to 129.2 (table 2). A fatal crash occurred at the site in 2017 (before construction of the alternative intersection). Most of the crashes were angle or other crashes for both the before and after period (table 6). In addition, crashes between pedestrians and motor vehicles represented 1 percent of the number of crashes at the site.

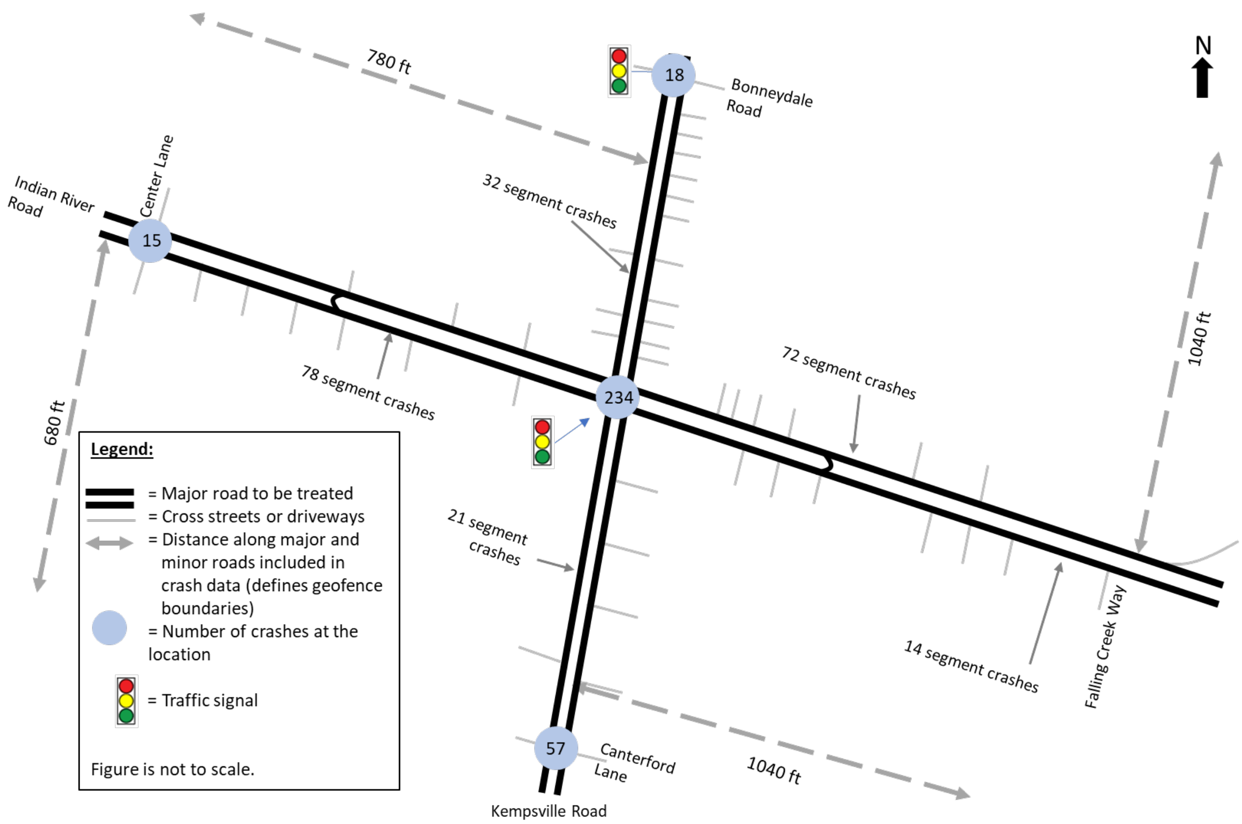
VIRGINIA INTERSECTIONS

The research team studied two hybrid innovative intersections in Virginia. The first site is in Virginia Beach at the intersection of Indian River Road at Kempsville Road. The second site is in Norfolk at the intersection of Military Highway at Northampton Boulevard (U.S. 13 at VA SR–165).

Indian River Road and Kempsville Road, Virginia Beach

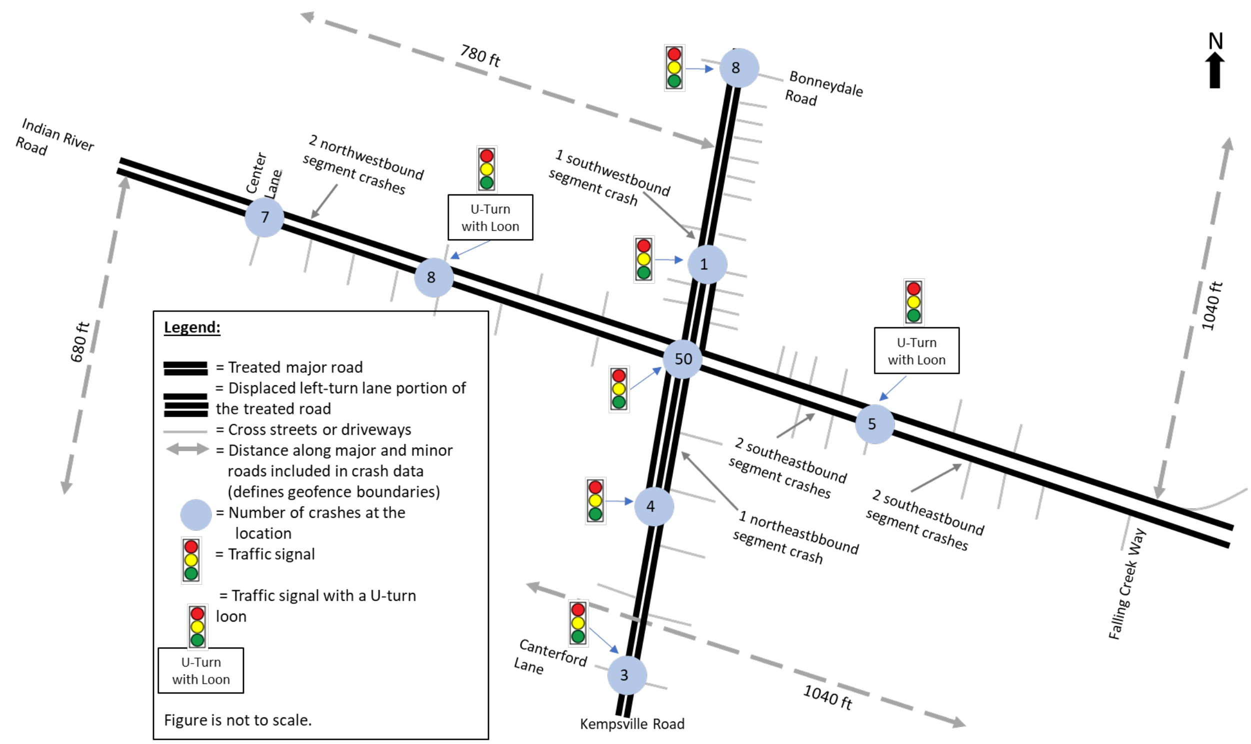
Virginia Beach converted a conventional intersection with high traffic volume northbound to westbound during peak hours. The afternoon peak hour experienced high traffic volumes for the eastbound and southbound movements. The team assembled before and after data for the number of crashes, the severity of crashes, and the crash type at the intersection of Indian River Road at Kempsville Road. Traffic signals were located at the central intersection and upstream for each approach leg.

Figure 20 provides an overview of the number of crashes by location within the corridor for the before period. Figure 21 provides that information for the after period. Before reconstruction of the intersection, an average of 66.2 crashes per year occurred (table 2), based on data for 98 mo. This site experienced an extended delay before the start of construction because the local jurisdictions conducted an additional series of public hearings based on feedback from the community. Construction was completed in March 2020. Following construction, the average number of crashes increased to 69.8 per year (does not include data for 2020, the COVID-19 period).



Source: FHWA.

Figure 20. Illustration. Number of crashes by location for the before period (96 mo) for Indian River Road at Kempsville Road.



Source: FHWA.

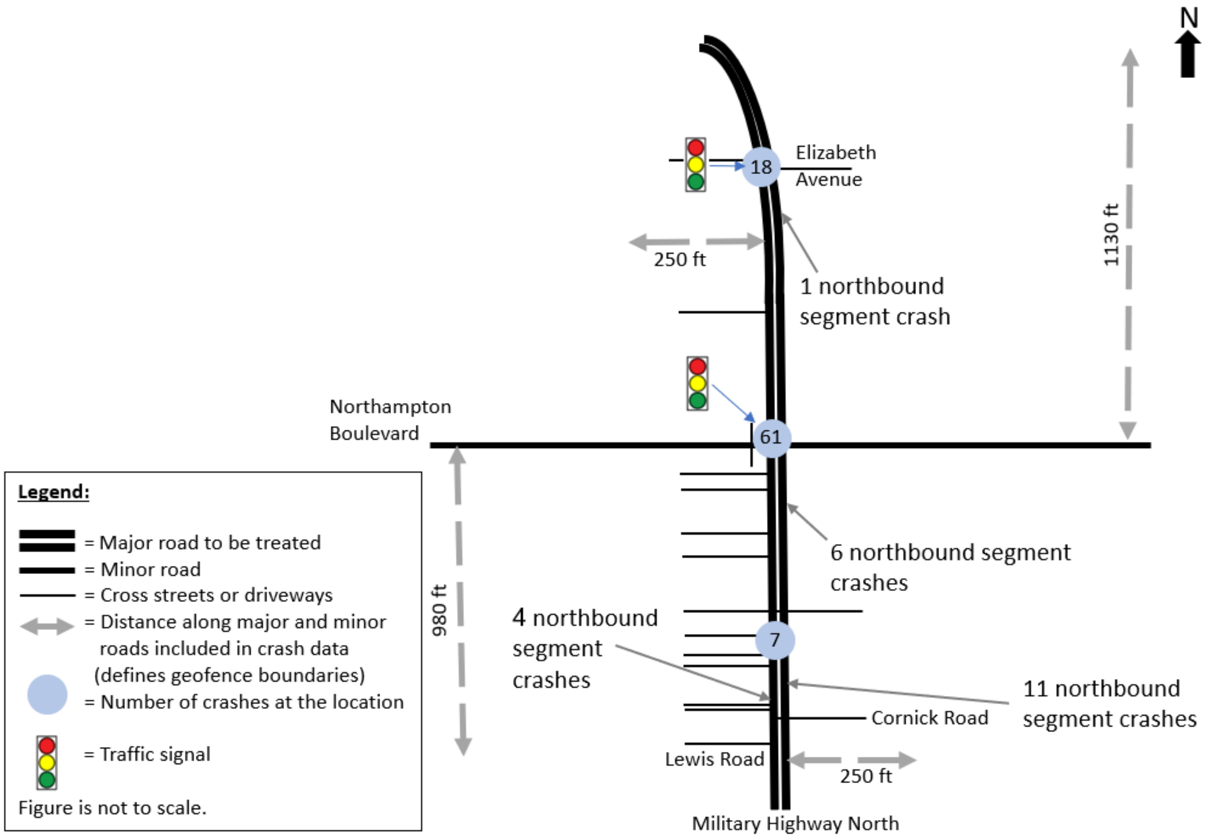
Figure 21. Illustration. Number of crashes by location for the after period (16 mo) for Indian River Road at Kempsville Road.

One fatal crash (in 2013) and five severe crashes occurred during the before period. In the after period, no fatal crashes occurred up to the time of this analysis. The more frequent observed crash types included angle and rear-end crashes (table 6). Crashes between pedestrians and motor vehicles remained constant at 1 percent of the number of crashes at the site.

Military Highway at Northampton Boulevard, Norfolk

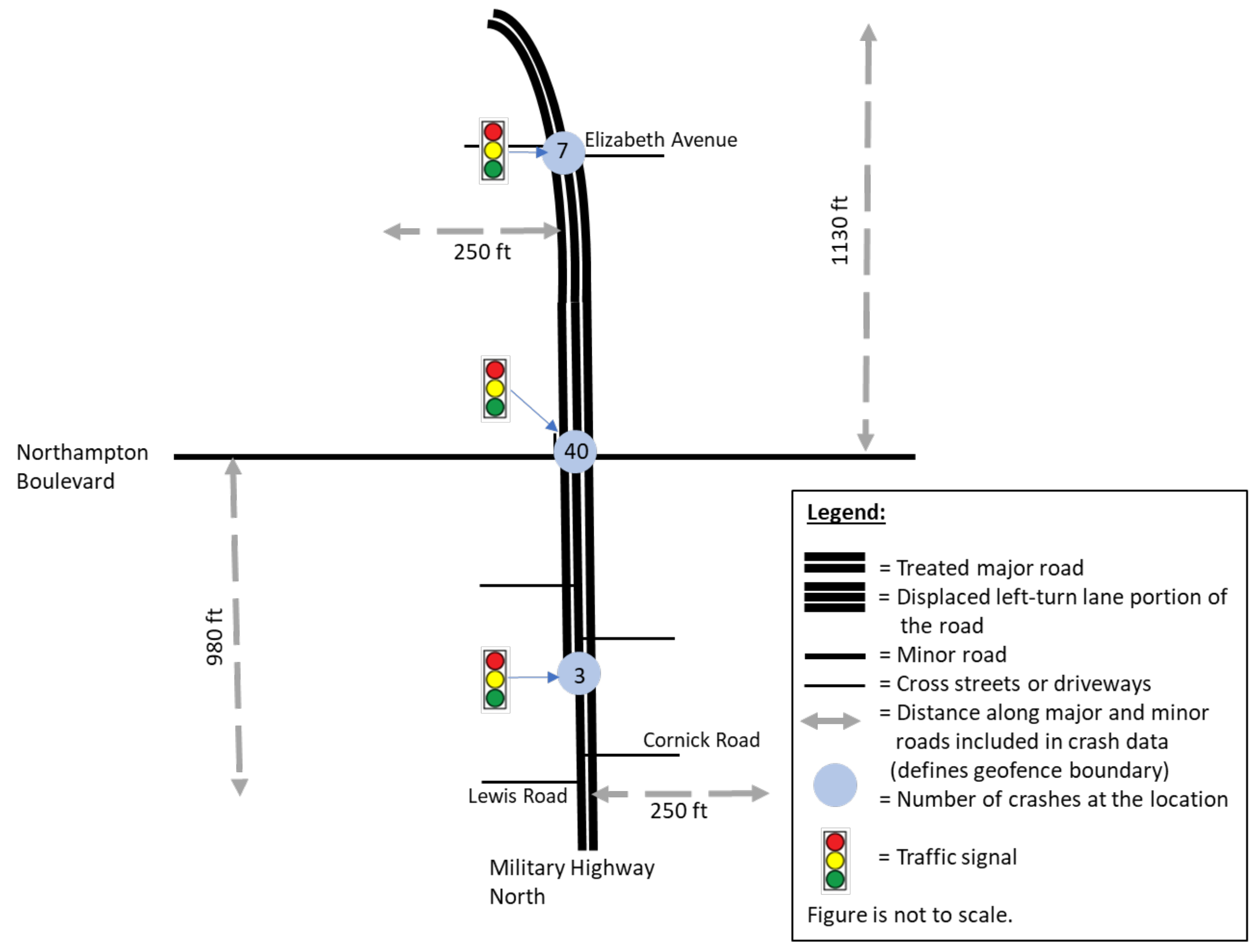
The intersection of Military Highway and Northampton Boulevard uses DLTs with crossovers similar to the design of diverging diamond interchanges. The treatment was only applied along one road (two approaches), so three traffic signals were included in the design for the after period—one at the central intersection and two at the upstream intersection where the left turns are displaced. The signal on the northern end replaced an existing signal at Elizabeth Avenue. The signal on the southern end was new. Several driveways were closed as part of the project.

Figure 22 shows the number of crashes per location for the before period. Figure 23 shows that information for the after period. These figures also show the distances the research team used for the crash request to ensure inclusion of crashes that occurred near the start of the DLTs (e.g., at Elizabeth Avenue on the north end).



Source: FHWA.

Figure 22. Illustration. Number of crashes by location for the before period (48 mo) for Military Highway at Northampton Boulevard.



Source: FHWA.

Figure 23. Illustration. Number of crashes by location for the after period (32 mo) for Military Highway at Northampton Boulevard.

Before reconstruction of the intersection, approximately 25.5 crashes per year occurred (table 2). Construction was completed in July 2018. Following construction, an average of 18.8 crashes per year occurred at the site during the after period that did not include the COVID-19 year. In addition to the average number of crashes per year decreasing from the before period to the after period, the percentage of fatal and injury crashes decreased by 25 percent (table 5). The increase in property damage-only crashes is offset by a decrease in KABC crashes for before and after conditions. Table 6 shows that the most common crash types observed at the intersection of Military Highway and Northampton Boulevard were angle and rear-end crashes.

CONSIDERATION OF PEDESTRIANS AND BICYCLISTS

The number of crashes observed at the sites were based primarily on motor vehicle crashes. However, considering impacts for all users is important. Currently, most States do not report pedestrian and bicycle crashes unless a motor vehicle is also involved. For this reason, traffic professionals generally assume that the reported crashes for these two user groups underestimate the actual problem.

An alternative strategy to estimate the likelihood of pedestrian and bicycle crashes is measuring the exposure of the vulnerable user (primarily the pedestrian) to other road users (primarily motor vehicles). For the developed urban locations in this project, the research team measured the driveway widths as the driveways intersect with the adjacent road. The team then determined if exposure at driveways increased or decreased. For the Minnesota sites, the team did not use this pedestrian assessment because currently little pedestrian traffic exists along the study corridor. For the Arizona sites, the team evaluated the Grant Road intersections and deemed exposure levels comparable for the before versus the after condition. The team also evaluated the one Texas site and the two Virginia sites.

For the Texas site, the interchange configuration created a challenge for pedestrians. The configuration change lengthened the relatively short (before reconfiguration) pedestrian paths considerably. Though this change may appear to be an operational issue, the change also becomes a safety issue when pedestrians grow impatient because extra time is required to complete trips. In many cases, the research team observed pedestrians crossing at locations other than those with a marked crosswalk. For Virginia, direct access to driveways was somewhat minimized using raised, narrow islands to channel traffic.

Additional information about integrating pedestrian and bicycle facilities into intersection designs, including both conventional and alternative types, can be found in the FHWA publication *Improving Intersections for Pedestrians and Bicyclists*.[27]

CHAPTER 5. CONCLUDING FINDINGS AND RECOMMENDATIONS

In recent years, transportation agencies have implemented alternative intersection configurations using innovative treatments that may alleviate critical congestion pinch points along roadway networks. For this study, the research team conducted a before-and-after field study of several newly constructed innovative intersections. This report reviewed the selected sites, identified the data used for the analysis, and conducted a qualitative analysis of crash conditions at the 12 study sites. The report also notes that due to the small after sample size of only a few years (and the COVID-19 pandemic traffic disruption that occurred in 2020), the safety assessment is only descriptive because the data are not yet sufficient to conduct a robust statistical analysis.

TYPE OF DATA AND ASSOCIATED PERFORMANCE MEASURES

Each innovative intersection can include some common, conventional elements as well as alternative treatments. One common operational issue is an intersection that initially experiences saturation at left-turn locations. For this challenge, agencies modifying intersections with medians can alter the left turn by physically restricting the left turn from the major to the minor road through the use of deceleration lanes, acceleration lanes, and a U-turn. For the RCUT configuration, the Minnesota corridor uses this U-turn treatment at unsignalized and signalized intersections. For the Arizona sites, the Grant Road enhancements included construction of MUTs that restricted left-turn maneuvers and redirected them to downstream U-turns. This treatment functions like the RCUT by requiring left-turning vehicles to proceed straight through the intersection and then execute a U-turn and then a right turn to complete the maneuver. The MUT differs from the RCUT because the MUT permits direct through and left turns from the minor road, a movement not provided by the RCUT. For this reason, the MUT's indirect left intersection enforces U-turn restrictions based primarily on companion regulatory signs.

Another common treatment included in the study is the DLT. The DLT physically shifts the left-turn movement into a new location (generally upstream of the central intersection). The Norfolk and Texas sites included DLTs as a primary treatment. The intersection of Indian River Road and Kempsville Road, however, developed a true hybrid and included indirect and DLT movements.

As noted in the two bullets at the beginning of chapter 4, to fully evaluate the safety at these intersections, researchers need 3–5 yr of available crash data before construction and a similar quantity after construction. Due to COVID-19 delays coupled with the need to conclude this research project within a specific time frame, the research team acquired crash data and site data for use in assessing relative safety performance. This qualitative approach to the safety performance analysis helps to identify trends in the crash conditions but stops short of a comprehensive safety assessment. Normally crash data are parsed into annual data sets, but due to the smaller sample sizes for after conditions, the research team assembled monthly data and then converted this information to crashes per year.

SUMMARY OF FINDINGS AND RECOMMENDATIONS

Based on this safety assessment, traffic professionals can reasonably expect that converting a conventional intersection to one of the innovative intersection types included in this study will generally maintain or improve safety performance. However, the types of crashes tend to change, depending on the treatment configuration. Table 7 provides a summary of the 12 study sites included in the final analysis and the safety metrics available for each site.

Table 7. Summary of safety performance at 12 study sites.

State	Site	Number of KABC Crashes After Construction	Crash Severity After Construction	Crash Type Before Construction (Greater than 10 Percent in the Period)	Crash Type After Construction (Greater than 10 Percent in the Period)
AZ	Tucson, Grant Road and First Avenue	Reduced	Improved	RE, ANG, LT, Veh PorB	RE, ANG, LT
AZ	Tucson, Grant Road and Stone Avenue	Increased†	Improved	RE, ANG, HO, Veh PorB	RE, ANG, HO, Veh PorB
AZ	Tucson, Grant Road and North Oracle Road	NA	NA	NA	RE, ANG, SS, LT, Veh PorB
AZ	Tucson, Valencia Road at Kolb Road	Increased†§	Mix†	RE, LT	RE, ANG, SS, ROR SV
MN	Ham Lake, MN–65 and 157th Avenue NE	Equivalent	Improved	RE, ANG	RE, SS
MN	East Bethel, MN–65 and 181st Avenue NE	Equivalent	Improved	ANG, HO, Other	RE, SS, Other
MN	East Bethel, MN–65 and 187th Lane NE	Equivalent	Improved	RE, ANG, SS, Other	RE, ANG, SS, Other
MN	East Bethel, MN–65 and 209th Avenue NE	NA	NA	NA	RE, ANG, Other
MN	East Bethel, MN–65 and Viking Boulevard NE	Equivalent	Improved	RE	RE, ANG, Other
TX	San Antonio, SH–16 and West Loop 1604 Access Road	Reduced	Improved	RE, ANG, SS, Other	RE, ANG, SS, Other
VA	Virginia Beach, Indian River Road and Kempsville Road	Equivalent	Equivalent	RE, ANG	RE, ANG
VA	Norfolk, Military Highway and Northampton Boulevard (U.S. 13 and VA SR–165)	Reduced	Improved	RE, ANG	RE, ANG, SS

†Volume increased in the after period, which may have contributed to the increase in average crashes per year.
§Addition of new road dramatically increased volume and associated crashes.
ANG = angle; RE = rear-end; LT = left-turn; SS = sideswipe; HO = head on; Veh PorB = vehicle and pedestrian or vehicle and bicyclist; ROR = ran off road; SV = single vehicle; NA = not applicable.

For each of the 12 study sites, the research team also conducted an operational assessment that is documented in a companion report.[1] Overall, constructing alternative intersections does appear to have significant safety benefits based on a reduction in crash severity. More evaluation is needed for accommodating pedestrians and bicycles at alternative intersection sites. In particular, the intersection configurations that favor motor vehicle travel times over bicycle and pedestrian travel times would benefit from detailed safety assessments.

The after-crash data for these sites included data from the pandemic period and included altered travel patterns that extended for 12 mo. In addition, ideally a before-and-after safety assessment should include 3 yr of data for the periods before and after implementation. The research team was unable to consider the crash data for a reliable duration. Though this issue does make the value of the safety analysis less beneficial, researchers can use the crash data in conjunction with other crash-data traits such as maneuver type or commonly observed driver errors at the site.

REFERENCES

1. Dixon, K., K. Fitzpatrick, and S. M. Mousavi. 2024. *Field Evaluation of At-Grade Alternative Intersection Designs, Volume I—Operations Report*. Report No. FHWA-HRT-24-126. Washington, DC: Federal Highway Administration.

2. FHWA. 2022. “About Intersection Safety” (web page). https://safety.fhwa.dot.gov/intersection/about/index.cfm, last accessed October 22, 2022.

3. FHWA. 2020. *Proven Countermeasures: Reduced Left-Turn Conflict Intersections*. Report No. FHWA-SA-18-048. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/rltci/fhwasa18048.pdf, last accessed August 5, 2024.

4. FHWA. 2020. *Median U-Turn Intersection: An Innovative, Proven Solution for Improving Safety and Mobility at Intersections*. Fact Sheet No. FHWA-SA-14-042. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/rltci/fhwasa14042.pdf, last accessed February 15, 2023.

5. Taylor, W. C., I. Lim, and D. R. Lighthizer. 2001. “Effect on Crashes After Construction of Directional Median Crossovers.” *Transportation Research Record* 1758, no. 1: 30–35.

6. FHWA. 2020. *Michigan Avenue and South Harrison Road, East Lansing, MI: Median U-Turn Intersection*. Fact Sheet No. FHWA-SA-14-050. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/rltci/fhwasa14050.pdf, last accessed February 15, 2023.

7. FHWA. 2020. *Woodward Avenue and East Maple Road, Birmingham, MI: Median U-Turn Intersection*. Fact Sheet No. FHWA-SA-14-052. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/rltci/fhwasa14052.pdf, last accessed February 15, 2023.

8. Al-Omari, M., M. Abdel-Aty, J. Lee, L. Yue, and A. Abdelrahman. 2020. “Safety Evaluation of Median U-Turn Crossover-Based Intersections.” *Transportation Research Record* 2674, no. 7: 206–218.

9. Kay, J., T. J. Gates, P. T. Savolainen, and M. Mahmud. 2022. “Safety Performance of Unsignalized Median U-Turn Intersections.” *Transportation Research Record* 2676, no. 9: 451–466.

10. Inman V. W., and R. P. Haas. 2012. *Field Evaluation of Restricted Crossing U-Turn Intersection*. Report No. FHWA-HRT-11-067. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/safety/hsis/11067/11067.pdf, last accessed February 15, 2023.

11. Inman, V. W., R. P. Haas, and C. Y. D. Yang. 2013. "Evaluation of Restricted Crossing U-Turn Intersection as a Safety Treatment on Four-Lane Divided Highways." *ITE Journal* 83, no. 9: 29–35.

12. Edara, P., C. Sun, and S. Breslow. 2013. *Evaluation of J-turn Intersection Design Performance in Missouri*. Report No. cmr14-005. Jefferson City, MO: Missouri Department of Transportation.

13. Edara, P., S. Breslow, C. Sun, and B. R. Claros. 2015. "Empirical Evaluation of J-Turn Intersection Performance: Analysis of Conflict Measures and Crashes." *Transportation Research Record Board* 2486, no. 1: 11–18.

14. Mishra, R., and S. S. Pulugurtha. 2021. "Evaluating the Safety Effectiveness of Restricted Crossing U-turn (RCUT) Intersections." Paper No. TRBAM-21-03723. Presented at the *100th Annual Meeting of the Transportation Research Board*. Washington, DC: Transportation Research Board.

15. Inman, V. W., and R. P. Haas. 2012. *Field Evaluation of a Restricted Crossing U-Turn Intersection*. Report No. FHWA-HRT-11-067. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/safety/hsis/11067/11067.pdf, last accessed February 15, 2023.

16. Hummer, J. E., and S. Rao. 2017. *Safety Evaluation of Signalized Restricted Crossing U-Turn Intersections*. Report No. FHWA-HRT-17-082. Washington, DC: Federal Highway Administration. https://www.fhwa.dot.gov/publications/research/safety/17082/17082.pdf, last accessed February 15, 2023.

17. Sun, X., and M. A. Rahman. 2019. *Investigating Safety Impact of Center Line Rumble Strips, Lane Conversion, Roundabouts, and J-Turn Features on Louisiana Highways*. Report No. FHWA/LA.18/597. Baton Rouge, LA: Louisiana Department of Transportation and Development.

18. Al-Omari, M. M. A., M. Abdel-Aty, J. Lee, L. Yue, and A. Abdelrahman. 2020. "Safety Evaluation of Median U-Turn Crossover-Based Intersections." *Transportation Research Record* 2674, no. 7: 206–218.

19. Ulak, M. B., E. E. Ozguven, H. H. Karabag, M. Ghorbanzadeh, R. Moses, and M. Dulebenets. 2020. "Development of Safety Performance Functions for Restricted Crossing U-Turn Intersections." *Journal of Transportation Engineering, Part A: Systems* 146, no. 6.

20. Abramson, P., C. Bergren, and R. Goldblatt. 1995. "Human Factors Study of the Continuous Flow Intersection at the Dowling College NAT Center." Presented at the *4th Annual Symposium on Intermodal Transportation*, Oakdale, NY. Sponsored by the Transportation Research Board, Washington, DC and Dowling College, NY.

21. Steyn, H., Z. Bugg, B. Ray, A. Daleiden, P. Jenior, and J. Knudson. 2014. *Displaced Left Turn Intersection Informational Guide.* Report No. FHWA-SA-14-068. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/crossover/fhwasa14068.pdf, last accessed February 15, 2023.

22. FHWA. 2014. *Displaced Left Turn Intersection: An Innovative, Proven Solution for Improving Safety and Mobility at Signalized Intersections*. Fact Sheet No. FHWA-SA-14-041. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/crossover/fhwasa14041.pdf, last accessed February 15, 2023.

23. FHWA. 2014. *Missouri Route 30 and Summit Drive, Fenton, MO: Displaced Left Turn Intersection*. Fact Sheet No. FHWA-SA-14-056. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/crossover/fhwasa14056.pdf, last accessed February 15, 2023.

24. FHWA. 2014. *Bangerter Corridor, Salt Lake County, UT: Displaced Left Turn Intersection*. Fact Sheet No. FHWA-SA-14-060. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/crossover/fhwasa14060.pdf, last accessed February 15, 2024.

25. Abdelrahman, A., M. Abdel-Aty, J. Lee, L. Yue, and M. M. A. Al-Omari. 2020. "Evaluation of Displaced Left-Turn Intersections." *Transportation Engineering* 1, no. 100006.

26. Google®. 2022. "Google® Earth™" (website). https://earth.google.com/web/, last accessed December 21, 2022.

27. Blackburn, L., M. Dunn, R. Martinson, P. Robie, and K. O'Reilly. 2022. *Improving Intersections for Pedestrians and Bicyclists Informational Guide*. Report No. FHWA-SA-22-017. Washington, DC: Federal Highway Administration. https://safety.fhwa.dot.gov/intersection/about/fhwasa22017.pdf, last accessed February 15, 2023.

Recycled
Recyclable

Recommended citation: Federal Highway Administration,
Field Evaluation of At-Grade Alternative Intersection Designs, VolumeII—Safety Report
(Washington, DC: 2024) https://doi.org/10.21949/1521599

HRSO-10/10-24(WEB)E