Spring 5-4-2023

Safety and Operational Assessment of Rural Free Right-Turn Ramp Intersections

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SAFETY AND OPERATIONAL ASSESSMENT OF RURAL FREE RIGHT-TURN RAMP INTERSECTIONS

by

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A THESIS

Presented to the Faculty of

The Graduate College at the University of Nebraska

In Partial Fulfillment of Requirements

For the Degree of Master of Science

Major: Civil Engineering

Under the Supervision of Professor Aemal Khattak

Lincoln, Nebraska

May, 2023

SAFETY AND OPERATIONAL ASSESSMENT OF RURAL

FREE RIGHT-TURN RAMP INTERSECTIONS

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University of Nebraska, 2023

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Free right-turn (FRT) ramps are alternative right-turn lane designs for intersecting highways. As of 2023, 79 FRT ramps exist at 68 rural highway intersections in Nebraska. FRT ramps may be located on three-legged or four-legged intersections and may be on the minor, the major, or both minor and major approaches of the same intersection.

This research compared the 68 rural FRT intersections to 24 similar non-FRT rural intersections to identify differences in crash frequency and crash rate and tested for statistical significance using a two-sample t-test. Crash data were obtained for the ten-year period of 2010-2019, with a focus on crashes reported within a quarter mile of each intersection leg. Forty different comparisons were made between the FRT and non-FRT intersections, testing varying intersection legs, AADT, and location of the FRT ramp on the major, minor, or both approaches. The results of this analysis indicated a lack of any statistically significant difference in crash frequency or crash rate among the rural FRT ramp and rural non-FRT intersections.

In addition to the safety analysis, a conflict analysis was conducted to analyze the vehicle interactions between right-turning vehicles at the FRT ramp intersections and non-FRT intersections. Miovision Scout video recording equipment was used to record

the traffic conflicts over 72 hours at six FRT intersections of varying AADT and the number of intersection legs. Six non-FRT intersections were paired with the FRT intersections and the conflict experienced by right-turn movement on the same approach as its FRT counterpart was observed. The conflict analysis showed that non-FRT right-turns experienced higher conflicts per 1000 entering right-turning vehicles than the FRT ramp intersections.

It was concluded that the presence of FRT ramps at rural intersections does not affect the crash frequency or crash rate experienced. It was also concluded that conflict is reduced between right-turning vehicles and other traffic present at the intersection when an FRT ramp is present, especially compared to non-FRT intersections where no exclusive right-turn lane is present on the major approach. It is recommended that future research assess additional operational benefits of FRT ramps, such as delay and travel time.

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CHAPTER 1: INTRODUCTION

1.1 Background

Free right-turn (FRT) ramps are alternative right-turn lane designs for intersecting highways. In Nebraska, FRT ramps can be found in both rural and urban areas. In rural areas, they are typically located at two-way stop-controlled (TWSC) intersections, meaning traffic on the major road is free-flowing, while traffic on the minor road is controlled by a stop sign. Previous research, design standards, warrants, etc. are sparse, so there is no universal definition of an FRT ramp. For this research, a study conducted by McCoy et al. (1995) titled *Guidelines for Free Right-Turn Lanes at Unsignalized Intersections on Rural Two-Lane Highways*, was relied upon as a starting point when looking for definitions and common characteristics of FRT ramps. Therefore, for this research, an FRT ramp is being defined, as it was in McCoy's research, as "a turning roadway at an intersection to provide for free-flowing right-turn movements" (McCoy et al., 1995).

Figure 1-1 represents a typical FRT ramp in Nebraska, as depicted by McCoy. From the figure, the FRT ramp is located on the minor approach which is stop-controlled, with the major approach being uncontrolled. Leading to the ramp is a deceleration lane to separate the through traffic from the right-turning traffic. At the end of the ramp is an acceleration lane, which provides for a safe merge with through traffic on the major approach. At the exit of the FRT ramp, before the acceleration lane, is a yield sign which indicates to the right-turning vehicles to yield to the major through traffic, which has the right-of-way.

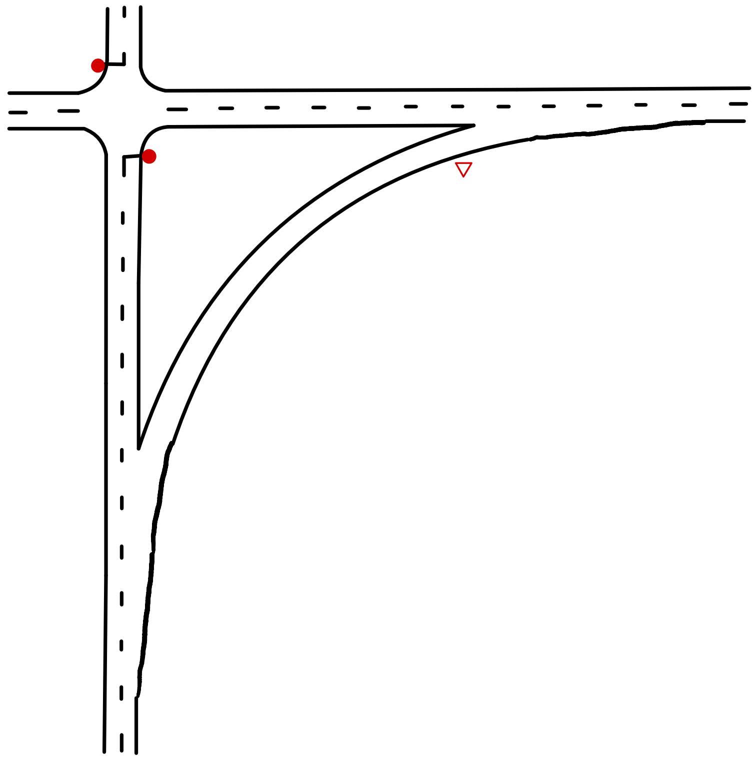

Figure 1-1 FRT Ramp Sketch (McCoy et al., 1995)

The layout of an FRT ramp is not exclusive to the figure presented above. For example, FRT ramps may also be located on the major approach, or even on both a major and minor approach of the same intersection. Additionally, rather than having an acceleration lane to merge with the crossing-through traffic, a designated lane may exist, so that right-turning drivers do not have to merge at all. In this case, the yield sign would not be present. While there are no strict guidelines for what dictates a free right-turn ramp, the focal concept is that a free right-turn ramp is a right-turn lane design found at rural two-way stop-controlled highway intersections, in which right-turning vehicles can make unimpeded right turns separated from through traffic, at free-flow speeds.

The idea in constructing free right-turn ramps at intersections is to reduce delay for right-turning vehicles, as well as make the turning maneuver safer by separating the right-turning traffic from the through traffic. The specific benefits experienced from the use of an FRT ramp by right-turning drivers differ slightly from when it is located on the minor approach versus when it is located on the major approach. As in Figure 1-1, when an FRT ramp is located on the minor approach, delay is reduced, because the driver does not have to slow to a stop, wait for an acceptable gap in traffic, then turn right. Instead, the driver can turn at a comfortable speed and merge with the crossing-through traffic. For the case of the ramp being located on the major approach, conflict is reduced in addition to the reduction in delay. Typically, rural highways are two lanes, therefore, at intersections, through traffic and right-turning traffic have to share the same lane. If a vehicle on the major road slows to make a right turn and there is no right-turn lane of any kind, a following-through vehicle traveling at a high rate of speed will have to slow down to avoid a possible rear-end collision. The FRT ramp, therefore, eliminates this problem by separating the traffic. These various scenarios will be explored in this research.

1.2 Problem Statement

Staff at the Nebraska Department of Transportation (NDOT) have expressed concern about traffic safety and operations at rural FRT ramps in Nebraska. Traffic safety at rural FRT ramps in Nebraska has not been investigated using sound statistical methods. Therefore, there is a need to statistically evaluate the safety of rural FRT intersections. Using common intersection safety metrics, such as crash frequency and crash rate, a comparison of FRT intersections and non-FRT intersections can be made. A t-test can then be used to test the statistical significance of these findings. The unit of analysis for safety evaluation will be 2010-2019 police-reported crashes at rural FRT intersections in Nebraska obtained from the Nebraska Department of Transportation.

1.3 Research Objectives

The main objective of the research is to statistically assess the safety of rural FRT intersections using the crash frequencies and crash rates, along with a two-sample t-test. Other objectives include:

- Identification of rural FRT intersections including geographic locations in Nebraska for analysis,
- Identification of rural non-FRT intersections that are similar to the FRT intersections based on considerations of intersection geometry and traffic characteristics,
- Collection of police-reported crashes for rural FRT intersections as well as for the non-FRT intersections for the period 2010-2019,
- Conduct safety analysis using the collected data, and
- Operational analysis of right-turning traffic at FRT intersections (conflict comparison of right-turning traffic at FRT and non-FRT intersections).
- Report analysis findings.

CHAPTER 2: LITERATURE REVIEW

Published literature on free right-turn ramps is somewhat scarce, as the concept is not widely utilized by many state transportation agencies. For those states that do use FRT ramps at rural intersections, guidelines, design standards, safety analyses, etc., are limited. This literature review first presents a discussion of the studies that are directly related to FRT ramps, followed by other topics that are related and relevant to traffic operations and safety of rural, unsignalized intersections containing an FRT ramp. These other topics include operations and safety at unsignalized, rural intersections, intersection sight distance, and acceleration and deceleration lanes.

2.1 Free Right-Turn Ramps

Free right-turn (FRT) ramps, also referred to as FRT lanes in prior research, are being defined in this study as "turning roadways for free-flowing right-turn movements at intersections, typically used to provide a high level of service at high-speed, high-volume intersections" (McCoy et al., 1995). The terms "FRT ramps" and "FRT lanes" will be used synonymously, as different reports use different verbiage, although they identify the same concept. A study conducted by McCoy et al. (1995) of the University of Nebraska-Lincoln, developed traffic volume warrants for when it was necessary to construct an FRT lane at two, two-lane rural, unsignalized intersections. Also included in the study was a discussion of the public's perspective regarding FRT lanes and a safety analysis comparing intersections with and without an FRT lane.

During the period in which McCoy's research was being conducted, an intersection in Genoa, Nebraska was going through the process of having an existing FRT lane removed. Citizens that frequented the intersection opposed this decision. From the perspective of the drivers, FRT lanes remedy concerns that non-FRT approaches present. Some of these concerns as stated by citizens, via a survey, were the inconvenience of having to slow down and stop to make a right turn, as well as needing to speed back up to merge with cross traffic, and difficulty in making right turns for large trucks, especially in icy conditions. Because of the speed changes and sudden stopping required to turn, citizens believed that the occurrence of rear-end crashes would be significantly lower with FRT lanes present at the intersection.

These concerns were tested through a safety analysis in which 32 approaches with an FRT lane on two, two-lane rural highways were selected. These approaches had stop-controlled or uncontrolled through traffic with yield-controlled or uncontrolled FRT lanes. Fifty-seven non-FRT approaches with similar traffic and geometric characteristics were chosen for comparison. The safety analysis concluded that the presence of an FRT lane does not affect the frequency, severity, or types of accidents that occur on approaches to unsignalized intersections of rural two-lane highways. Rear-end accidents were shown to decrease with the presence of an FRT lane, but these results were not statistically significant.

During field tests of intersections with FRT and non-FRT lanes, McCoy et al. (1995) concluded that FRT lanes reduce travel distances, speed changes, and delays of right-turning vehicles. After conducting a benefit-cost analysis, traffic volume warrants were created in which an intersection’s right-turning daily volume and percent trucks traffic determine whether an FRT lane was warranted or not. Percent trucks was included because FRT lanes were found to provide greater operational cost savings to trucks than to passenger cars. Because the crash analysis was not statistically significant, it was not included as a part of the FRT warrants.

In the recommendations of this research, it was stated: “FRT lanes should not be promoted to enhance safety, but to improve operational efficiency of right-turn movements” (McCoy et al., 1995).

Table 2-1 provides a summary of McCoy's research in terms of the public's concerns regarding the removal of an FRT lane at an intersection in Genoa, Nebraska compared to the findings from the study.

Table 2-1 Comparison of the Public's Concerns of FRT Removal and Findings of McCoy's Research

Public’s Concerns of FRT Lane Removal	Research Findings	Public’s Concerns Supported through Research?
An intersection with an FRT lane would be safer than an intersection without an FRT lane	A safety analysis concluded that the presence of an FRT lane does not affect the frequency, severity, or types of accidents that occur	No
FRT lanes remedy the inconvenience of having to slow down, stop, and speed back up when completing a right turn	Data from field tests revealed that FRT lanes reduce travel distances, speed changes, and delays of right-turning vehicles	Yes
FRT lanes make the right-turning process for trucks easier and safer, especially at night and during icy conditions	Data from field tests revealed that FRT lanes provide even greater operational cost savings to trucks than they do to passenger cars	Yes

A study by Yang (2008), established warrants for FRT lanes, as well. In this research, a statistical model was developed based on the concept of two-lane roadways where a decelerating right-turning vehicle forces the following through vehicle to decelerate to avoid a possible rear-end collision (Yang, 2008). Warrants were subsequently created where the total through traffic volume of the approach and the percentage of right-turning traffic determined whether an FRT lane was necessary. It was noted that traffic volume should not be the only factor in the decision of whether or not to construct an FRT lane. According to Yang (2008), in cases where other operational or safety factors have a significant impact, engineering judgment should be used.

The National Cooperative Highway Research Program (NCHRP) Report 208 titled *Design Guidance for Channelized Right-Turn Lanes* (2014), provides a good understanding of FRT ramps, when they may be warranted, and their advantages and disadvantages. The primary reasons for adding an FRT ramp are to increase vehicular capacity at intersections, reduce delay to drivers by allowing them to turn at higher speeds, reduce unnecessary stops, clearly define the appropriate path for right-turn maneuvers at skewed intersections or at intersections with high right-turning traffic volumes, improve safety by separating the points at which crossing conflicts and right-turning traffic merge conflicts occur, and to permit the use of large curb radii to accommodate large turning vehicles (Potts et al., 2014). A significant advantage of FRT ramps is that delay to right-turning drivers is reduced. Yield-controlled FRT ramps can reduce right-turn delay by 25 to 75 percent compared to conventional right-turn lane designs (Potts et al., 2014). The use of acceleration and deceleration lanes can also reduce delay by allowing vehicles to separate from through traffic and have easier merge capabilities. An issue with FRT ramps is the conflict of turning vehicles with pedestrians. However, because the focus of this research is on rural intersections where there is little-to-no pedestrian traffic, that concern should not be of much influence, which is also stated in the NCHRP report.

The *NDOT Roadway Design Manual* (2012) does not contain much information on FRT ramps. They are identified in the text as “free-flow right-turn lanes.” These lanes are defined as channelized right-turn lanes at intersections, providing free-flow turn movements. The design of these turn lanes consists of “a deceleration lane leading to a horizontal curve, providing a gradual speed reduction with a more natural turning path for the driver” (Nebraska Department of Transportation, 2012). The document then references “Widths for Turning Roadways at Intersections” in *A Policy on Geometric Design of Highways and Streets (2011)* for further information.

Similar to the FRT ramp as defined in this research, a free right-turn channel is a free-flowing right-turn lane that is separated from through traffic, with a designated lane after the right-turn movement (Macfarlane et al., 2011). This design differs from an FRT ramp in that it requires no merging once the right-turn movement has been made. Free right-turn channels reduce delay, fuel emissions, and right-turn conflicts with crossing through traffic. A problem found with this design is that drivers tend to yield to cross traffic upon completing the turn even though it was not necessary, due to the added lane designated for right-turning traffic. This conflict thus increases delay at the intersection. A remedy suggested by the researchers was to add signage instructing drivers that they do not need to yield.

In another study regarding free right-turn channels, an email survey asked approximately 1,000 responding participants to indicate how they would behave at several right-turn lane designs at signalized intersections (i.e., STOP, YIELD, PROCEED, WAIT) (Macfarlane et al., 2011). These designs included free right-turn channels, yield right-turn channels, and standard right-turn lanes. The results showed that a statistically significant proportion of drivers behaved similarly at all intersection treatments, regardless of signage or channelization. This results in unnecessary added delay, as a free right-turn channel's purpose is to eliminate delay for right-turning vehicles.

Table 2-2 provides a summary of the related research on FRT ramps and the main findings and/or conclusions drawn from them.

Table 2-2 Summary of FRT-Related Research

Research Topic	Author(s)	Main Findings
Free Right-Turn Lanes	McCoy et al., 1995	The presence of an FRT lane does not affect the frequency, severity, or types of accidents that occur
		The public often prefers FRT lanes, compared to non-FRT lanes, noting perceived safety and operational benefits.
Free Right-Turn Lanes	Yang, 2008	Warrants were created for free right-turn lanes, based on total through volume and percentage of right turns
		It is recommended that volume should not be the only consideration when deciding to construct a free right-turn lane or not
Channelized Right-Turn Lanes	Potts et al., 2014	Yield-controlled FRT ramps can reduce right-turn delay by 25 to 75 percent, compared to conventional right-turn lane designs
Free-Flow Right-Turn Lanes	Nebraska Department of Transportation, 2012	These lanes consist of a deceleration lane leading to a horizontal curve, providing a gradual speed reduction with a more natural turning path for the driver
Free Right-Turn Channels	Macfarlane et al., 2011	FRT channels reduce delay, fuel emissions, and right-turn conflicts with crossing through traffic
		FRT channels provide a designated lane after the right-turn maneuver, rather than just an acceleration lane
		Drivers tend to yield to cross traffic after completing the turn, creating unnecessary added delay
Free Right-Turn Channels	Macfarlane et al., 2011	It was found that a statistically significant portion of drivers behave similarly at all intersection treatments, regardless of signage or channelization

2.2 Rural, Unsignalized Intersections

Intersections, compared to roadway segments, have greater potential for traffic crashes due to the complexity of traffic movements and potential conflicts between vehicles on the major and minor approaches (Kim et al., 2006). A typical rural, unsignalized intersection is a two-way, stop-controlled (TWSC) intersection. At these intersections, the major roadway traffic is free-flowing (uncontrolled), while the minor roadway traffic is stop-controlled. Drivers on the minor approach must decide on an acceptable gap in traffic to proceed through the intersection or make a turn. These intersections typically experience a higher crash frequency and severity than other rural intersections because of the difficulty in selecting gaps and poor decision-making by drivers on the minor approach (Leckrone et al., 2011). Comparing unsignalized and signalized, rural intersections, it has been noted that 90 percent of fatalities occur at the former, while 10 percent of fatalities occur at the latter (Pawar & Patil, 2017). The area of the major roadway segment where minor approach drivers must analyze conflicts is often called the "dilemma zone." The dilemma zone is the zone of a major roadway segment over which, if a vehicle is present with a certain speed, a dilemma is created for minor road vehicles regarding maneuvering (Pawar & Patil, 2017). If drivers on the minor approach are aggressive or misjudge the vehicles in the dilemma zone, potential conflict arises. Figure 2-1, taken from Pawar and Patil’s (2017) research, illustrates situations in which a driver can easily reject a gap, easily accept a gap, and one in which a dilemma arises where the decision is not clear.

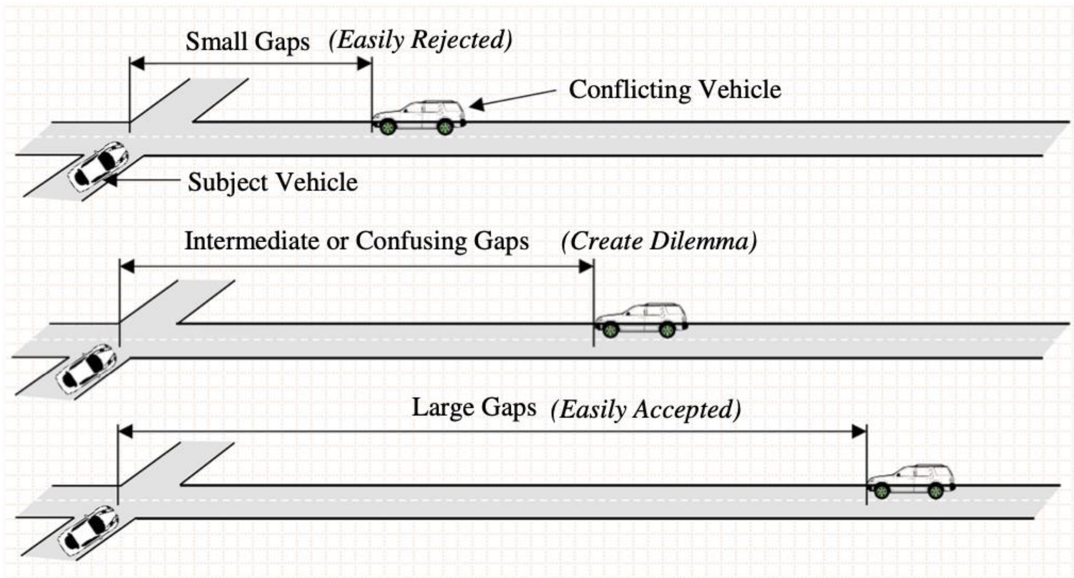

Figure 2-1 Dilemma Zone Faced by Drivers on the Minor Approach (Pawar & Patil, 2017)

An Indiana study analyzed 600 TWSC intersections and determined potential solutions to reducing the frequency and severity of crashes at these intersections. The authors recommended adding acceleration lanes, increasing the intersection angle, widening medians to more than 80 feet, and improving recognizability of intersections to improve safety (Leckrone et al., 2011). In an Iowa study, changes to signage on the minor roads and median were investigated by adding a double-yellow center line in the median and yield/stop bars, adding advance in-lane rumble strips for minor roadway traffic, and right- and left-turn lanes were recommended for safety improvement (Maze et al., 2004). There is no "fix-all" solution to solving the safety issues at rural, unsignalized intersections and many state agencies take measures that best suits their economic and operational needs.

On the topic of the minor approach of TWSC intersections, operations are also significantly influenced by the drivers' behavior. Drivers' decision on gap acceptance when judging vehicles in the “dilemma zone” affects delay at the intersection (Khattak & Jovanis, 1990). Some drivers are more conservative and experience anxiety in these situations, and they may not accept gaps that would be considered acceptable, thus increasing the delay experienced by the following vehicles. The type of signage present on the minor approach also has effects on traffic operations. Comparing stop control and yield control, yield control shows a decrease in travel time, gasoline consumption, and exhaust emissions. (Hall et al., 1978).

2.3 Sight Distance

Sight distance at rural, unsignalized intersections can be a potential safety hazard for vehicles on the minor approach. If an exclusive right-turn lane is present on the major road, drivers on the minor road will have restricted sight distance. This can be dangerous because vehicles traveling on the major roadway are traveling at high speeds, so if a minor approach driver’s view is obstructed by a right-turning vehicle, a potential conflict could arise if the driver on the minor approach enters the intersection and does not see a vehicle traveling through on the major road (Zeidan & McCoy, 2000). A study of right-turn-on-red situations at signalized intersections revealed that with the obstructed sight distance, right-turning vehicles on the minor approach often accepted smaller gaps, which could increase conflicts as a result (Yan & Richards, 2009). A solution to the sight distance obstruction, presented by an Auburn University research team, is to offset the right-turn lane on the major approach, thus giving vehicles on the minor approach a clearer view of traffic on the main road (Zhou et al., 2017). This idea was studied at the University of Nebraska, as well, providing design guidelines on how to maximize the sight distance at TWSC intersections by using offset right-turn lanes (Schurr & Foss Jr, 2010). Research on offset right-turn lanes in Nebraska was done further in 2018, providing their economic and safety benefits compared to intersections with non-offset right-turn lanes or no right-turn lanes at all (Khattak & Kang, 2018).

2.4 Acceleration and Deceleration Lanes

Acceleration and deceleration lanes provide both operational and safety benefits when accompanied by an FRT ramp. Deceleration lanes provide a means of safe deceleration outside the through-lane traffic and a means of separating right-turning vehicles from other traffic at stop-controlled intersection approaches (Potts et al., 2007). In low-traffic scenarios, drivers can decelerate at higher speeds than in high-traffic scenarios and can decelerate earlier, thus creating a safe decelerating environment, which could be expected at rural FRT ramp locations (Calvi et al., 2012). Potential conflicts increase as the deceleration lane length decreases; therefore, careful consideration should be taken when designing deceleration lanes (Bared et al., 1999).

Acceleration lanes provide an opportunity for vehicles to complete the right-turn maneuver unimpeded and then accelerate parallel to the cross-street traffic before merging. Depending on the type of traffic control, traffic volume, and other characteristics, acceleration lanes can reduce right-turn delay by 65 to 85 percent (Potts et al., 2014). Traffic volumes on the major roadway affect whether or not a driver accepts a gap or not when merging and merging length increases as traffic volume increases. Unlike deceleration lanes, the length of the acceleration lane does not significantly influence drivers' speed, decision-making, or conflicts (Calvi & De Blasiis, 2011). From McCoy’s research, a survey was sent out to which 37 states’ transportation agencies responded, and the majority of the concerns regarding FRT ramps was safety while merging from the FRT lane to the through traffic; therefore, an acceleration lane was highly suggested when designing FRT ramps (McCoy et al., 1995).

CHAPTER 3: INVENTORY OF FRT RAMP INTERSECTIONS

At the beginning of this research, there was no complete inventory of the FRT ramps in Nebraska. The first objective of this research, therefore, was to develop one.

3.1 Identifying FRT Ramps and their Intersections

The process began using the latest edition of the *Nebraska Highway Reference Logbook*, which identifies structures, grade changes, and other important characteristics of the highways, spurs, and connecting links in Nebraska by their numbered highway markings. Using a simple keyword search of the pdf file of the logbook, “RAMP” was searched, in which interchanges, weigh station entrances and exits, and a multitude of right-turn lane designs, including free right-turn ramps, were selected. Of the approximately 1,200 results, the interchanges and weigh stations were eliminated through a simple search on Google Earth, using the highway markings provided in the logbook as reference. With roughly 200 “ramps” remaining, criteria were developed so that only suitable FRT ramps would be selected for this study. These criteria included: the ramps being located in rural areas, with uncontrolled or yield-controlled traffic operations at the merge point, and the major road being free-flowing (uncontrolled), with the minor road through traffic being stop-controlled. In the end, 79 FRT ramps were identified at 68 intersections, with 11 intersections having two FRT ramps. Figure 3-1 presents all 68 rural FRT ramp intersections on the Nebraska highway system.

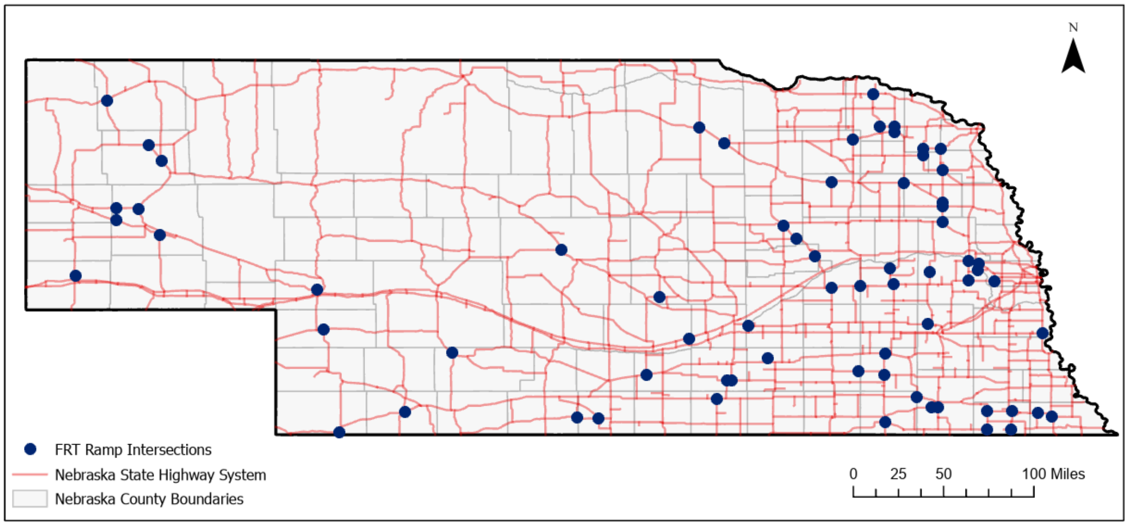

Figure 3-1 Map of all FRT Ramp Intersections in Nebraska

Table 3-1 shows the number of intersections containing an FRT ramp, broken down into three-legged and four-legged intersections, as well as showing whether these intersections contain one or two FRT ramps. It is clear from the table that four-legged intersections are home to the majority of the two-ramp fixtures, with only one three-legged intersection having two FRT ramps. Additionally, it is fairly even split between three-legged and four-legged intersections in relation to the presence of at least one FRT ramp.

Table 3-1 Breakdown of the Intersections Containing FRT Ramps

	3-Leg Intersections	4-Leg Intersections	All Intersections
Intersections with:			
1 FRT Ramp	30	27	57
2 FRT Ramps	1	10	11
Total	**31**	**37**	**68**

Regarding the FRT ramps themselves, rather than their intersections, Table 3-2 shows the number of FRT ramps at each intersection configuration, and if their location is on the major (uncontrolled) or minor (stop-controlled) approach. Although the number of intersections containing an FRT ramp are fairly even between three-legged and four-legged, four-legged intersections have more FRT ramps in total, due to the significant number of intersections containing two ramps. Also, from the table, the majority of the FRT ramps are located on the major approach rather than the minor approach, especially for three-legged intersections.

Table 3-2 Breakdown of FRT Ramp Approaches

	3-Leg Intersections	4-Leg Intersections	All Intersections
FRT Ramps	**32**	**47**	**79**
On Minor Approach	5	18	23
On Major Approach	27	29	56

3.2 FRT Ramp Intersection Characteristics

With the FRT ramps identified, their characteristics and the characteristics of their intersections were of interest. Using Google Earth and NDOT's Pathweb online database, information describing the intersection, such as the number of legs, presence of lighting, and county, were recorded. Regarding the major and minor roads of the intersections, information such as the number of lanes, presence of shoulders, surface material, etc., were recorded. Additionally, for the FRT ramp itself, signage present, type of channelizing island, FRT radius, FRT length, and presence of acceleration and deceleration lanes were recorded. These data were stored in an Excel spreadsheet for easy access. Appendix A provides a complete list of the variables that were logged as a part of the FRT ramp intersection inventory process, some basic FRT intersection characteristics, and a breakdown of the FRT intersections and ramps by the county they're located in.

3.3 Traffic Volume

In addition to the characteristics in Appendix A, the traffic volume of the FRT ramp intersections from 2010 to 2019 was obtained to match the years of crash data used for this study. Because the intersections of interest are in rural areas, traffic volume is not always easily attainable. NDOT produced state highway AADT maps for 2010, 2012, 2014, 2016, and 2018, however, there were no reliable data found for the odd years. To substitute the missing data, a simple average between the even years was done. For example, the 2011 AADT was taken as an average of the 2010 and 2012 values. To find the AADT of each intersection, each highway leg's AADT was summed, to give the total entering traffic volume. In a few cases for four-legged intersections, the fourth leg was unpaved or a non-highway local road. A value of 50 was used for the AADT of that leg, as NDOT stated that as typical practice. The traffic volume data for each FRT intersection, for each year from 2010-2019 is tabulated in Appendix A.

For identifying non-FRT comparison intersections, the year 2018 was chosen as the best option to represent the AADT of the intersections. This is because it is the most recent data available, while not being affected by potentially skewed values as a result of the COVID-19 pandemic.

Table 3-3 shows the average 2018 AADT values of three-legged, four-legged, and all intersections with an FRT ramp.

Table 3-3 2018 AADT by FRT Intersection Type

Intersection Type	3- Legged Intersections	4-Legged Intersections	All Intersections
Number of Intersections	31	37	68
Average 2018 AADT	8518	8478	8496

CHAPTER 4: INVENTORY OF COMPARISON INTERSECTIONS

Non-FRT ramp intersections were identified to serve as comparison locations to the FRT ramp intersections. Efforts were made to identify non-FRT ramp intersections that were similar to the FRT ramp intersections based on the number of legs, total through lanes of the major approach, and range of AADT. The first criterion was finding two-way stopped-controlled (TWSC) intersections located in rural areas. The majority of the FRT ramp intersections were two, two-lane highways, so that was the secondary deciding factor. Using the 2018 AADT of the FRT intersections, summary statistics were calculated, giving the average, range, and quartiles accounting for all of the FRT ramp intersections in Nebraska, as well as divided into FRT ramps located at both three-legged and four-legged intersections. The year 2018 was selected for the AADT because the following years are potentially influenced by the COVID-19 pandemic and may not be representative of “normal” values. For three- and four-legged intersections, the quartile values were used as limits for three ranges of AADT – "Low," "Medium," and "High." With these AADT ranges, now exist six categories: Low, Medium, and High AADT for three-legged intersections and Low, Medium, and High AADT for four-legged intersections. For each of these categories, four sites were identified, complying with the other criteria, totaling 24 non-FRT ramp comparison intersections. The AADT ranges, as well as the 2018 AADT averages for the selected comparison sites, are given in Table 4-1.

Table 4-1 Non-FRT Ramp Intersection AADT Averages

Three-Legged Intersections				
AADT Range	Lower Limit	Upper Limit	Number of Non-FRT Ramp Intersections	Average 2018 AADT
LOW	4,657	6,720	4	5,203
MEDIUM	6,721	10,098	4	7,808
HIGH	10,099	27,050	4	15,323
Four-Legged Intersections				
LOW	4,714	9,068	4	7,120
MEDIUM	9,069	13,888	4	11,349
HIGH	13,889	23,338	4	15,983

The locations of the non-FRT ramp comparison intersections are identified in Figure 4-1. The majority of the intersections selected for this study were in Eastern Nebraska, for the needs of the conflict analysis, which will be presented later. Field visits had to be made to many of these sites, therefore they were chosen for shorter travel times. Appendix B has some basic non-FRT intersection characteristics, location by county, and the ten-year AADT values for each site.

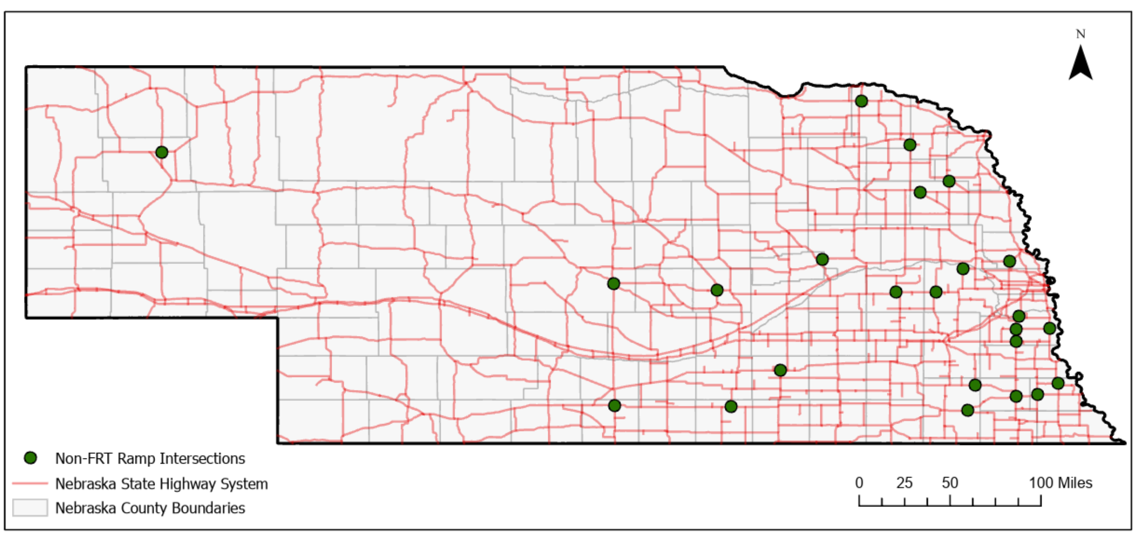

Figure 4-1 Map of Non-FRT Intersections for Comparison

CHAPTER 5: SAFETY ANALYSIS

5.1 Methodology

There were two methods considered for the safety analysis of the FRT ramp intersections. The first is the Empirical Bayes method, and the second is a comparison of crash frequencies and crash rates with a t-test measuring significance.

5.1.1 Empirical Bayes Method

Before-after studies are often used in transportation safety analyses. To determine the effect of some treatment, safety before and after the treatment can be measured, and if nothing else changes, any change in safety can be attributed to the treatment. This is referred to as a naïve before-after study because the assumption that no other variables affect changes in safety is not realistic. A comparison group is often used to account for this shortcoming. The idea is that any other variables (i.e., weather, geometric characteristics, etc.) that may affect safety, will do so similarly to the sites with and without the treatment in the before and after periods, thus eliminating the flaw of the naïve before-after study. However, issues still arise with this procedure.

The Empirical Bayes method is thought to be the best version of the before-after study using a comparison group, as it accounts for the regression-to-mean problem and offers more precise estimations (Hauer, 1997). What is needed for the Empirical Bayes method is information about the safety of other similar entities, referred to as the reference population, and the crash history of the entity.

5.1.2 Crash Frequency and Crash Rate with Test of Significance

Crash frequency and crash rate are two representations of safety for roadway segments and intersections. Crash frequency (F) is a simple calculation of the total number of crashes (C) divided by the years (N), as shown by Equation 5-1, giving crashes per year as an output.

Equation 5-1 Crash Frequency

$$F = \frac{C}{N}$$

Crash frequency has a flaw in that it does not take into account traffic volume. Therefore, when comparing a low-AADT intersection to a high-AADT intersection, the high-AADT intersection will inherently have a higher crash frequency due to the increased exposure. Crash rate, on the other hand, accounts for exposure, setting all locations, from those with low AADT to high AADT on an even playing field. Crash rate (R) is calculated by using Equation 5-2, with the total number of crashes in the study period (C), the number of years of data (N), and the daily entering traffic volume (V). Crash rate is given as crashes per million entering vehicles.

Equation 5-2 Crash Rate

$$R = \frac{C * 1{,}000{,}000}{N * V * 365}$$

When comparing the crash frequency or crash rate of a group of intersections, it is good practice to use a test of significance to identify whether any changes in safety are statistically significant or not. Because in this case, the crash rates of FRT ramp intersections and non-FRT ramp intersections would be compared, a two-sample t-test would need to be used to measure the statistical significance of the two means. The null hypothesis of the two-sample t-test is $H_0: \mu_1 = \mu_2$, or $H_0: \mu_1 - \mu_2 = 0$, meaning that there is no observed difference between the two tested means. The alternative hypothesis is $H_A: \mu_1 \neq \mu_2$, or $H_A: \mu_1 - \mu_2 \neq 0$, meaning there is an observed difference between the two tested means. A two-sample t-statistic is calculated from the data in question and compared to a critical t-value that is determined from the t-table, given the degrees of freedom and a chosen alpha value. If the two-sample t-statistic is greater than the critical t-value, it can be said that sufficient evidence is provided to reject the null hypothesis and conclude that the two means are different. If the two-sample t-statistic is less than the critical t-value, it would be concluded that there is not sufficient evidence to reject the null hypothesis.

The two-sample t-statistic is calculated using Equation 5-3, with $\bar{x}_1 - \bar{x}_2$ being the difference in means, $(\mu_1 - \mu_2)_0 = 0$, n_1 being the sample size of the first population, n_2 being the sample size of the second population, and s_p^2 being the pooled sample variance, calculated using Equation 5-4, with s_1^2 and s_2^2 being the sample variances of the two respective populations.

Equation 5-3 Two-sample t-statistic

$$t = \frac{(\bar{x}_1 - \bar{x}_2) - (\mu_1 - \mu_2)_0}{\sqrt{\frac{s_p^2}{n_1} + \frac{s_p^2}{n_2}}}$$

Equation 5-4 Pooled sample variance

$$s_p^2 = \frac{(n_1 - 1)s_1^2 + (n_2 - 1)s_2^2}{n_1 + n_2 - 2}$$

5.1.3 Method Selection

While the Empirical Bayes method is the ideal option for measuring changes in safety due to an entity (in this case - the FRT ramp), this research lacks a clear “before” and “after” period. The before period for each site would be the duration before the FRT ramp was constructed, and the after period would be the duration from when it was constructed up until the present day. Because this information was not available, it would be impossible to conduct a before-after analysis using the Empirical Bayes method. Therefore, the best option would be to compare the crash frequencies and crash rates of FRT ramp and non-FRT ramp intersections and test for significance thereafter.

5.2 Data Collection

Police reported crashes in Nebraska from 2010 to 2019 were provided by NDOT, along with their latitude and longitude. These crashes were uploaded to ArcGIS and plotted using their coordinates. Also using ArcGIS, shapefiles for the FRT ramp and non-FRT ramp intersections were created and plotted along with the crashes. It was decided to use crashes occurring within a quarter-mile of the center point of the intersection, for each intersection leg, for each site, as this best represents crashes that would occur at the intersection, or as a result of the FRT ramp. This was also done to ensure the entirety of the FRT ramps’ geometry would be included in the crash data collection range, especially for those with larger radii. For non-FRT ramps, the same parameters for crash data collection were used for consistency purposes. For each FRT ramp and non-FRT ramp intersection, polygon buffers were created in ArcGIS with a radius of 0.25 miles. Crashes occurring in these created buffers were then exported into separate shapefiles corresponding to each intersection. Figure 5-1 illustrates this process for the four-legged State Highway 16/State Highway 35 FRT intersection located in Wayne County.

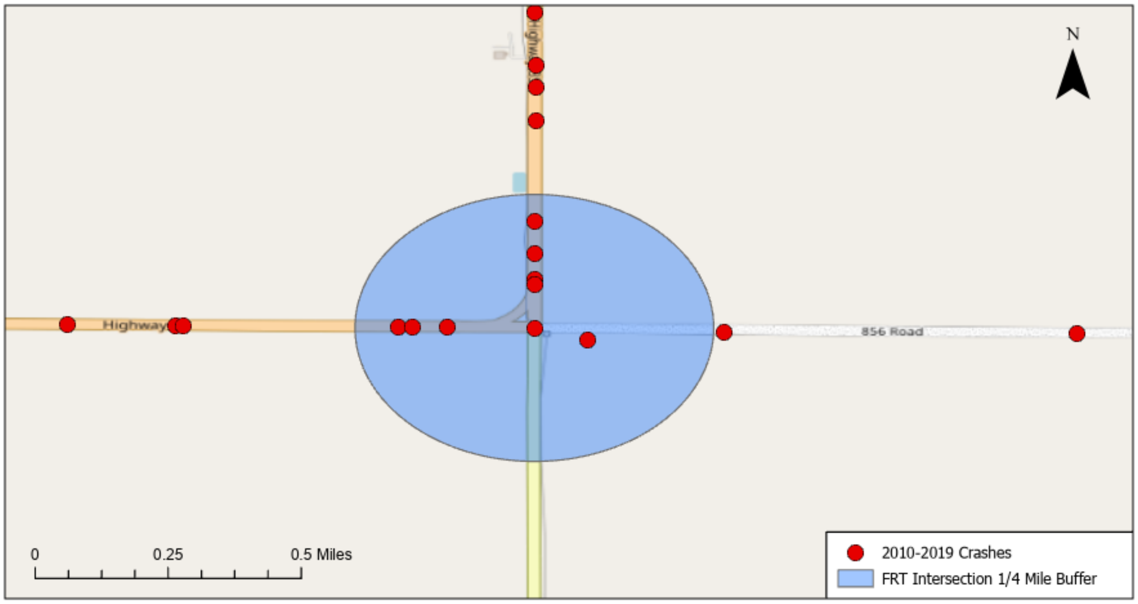

Figure 5-1 Crashes from 2010-2019 at N-16/N-35 FRT Intersection

With shapefiles created for each FRT and non-FRT intersection containing the crashes occurring a quarter-mile from the center point of the intersection, the attribute tables were exported as an Excel file, so the data could be analyzed. Examples of data found in these attribute tables include crash severity, crash type, number of involved vehicles, road conditions, weather conditions, and presence of alcohol impairment, to name a few. Appendix C details the crashes occurring at each intersection, for each year, for both FRT and non-FRT intersections. It should be noted that all vehicle types were included in this data.

Figure 5-2 compares the crash severity experienced at all FRT ramp and non-FRT ramp intersections. These categories are presented on the x-axis per NDOT's KABC crash reporting procedure: fatal (K), disabling injury (A), visible injury (B), and possible injury (C). Following these, the non-injury categories of property damage only (PDO) and non-reportable are plotted. Overall, little differences are realized in this comparison. The most notable finding is that the FRT intersections (1.41%) experienced 0.40% more fatal crashes from 2010-2019 than the non-FRT intersections (1.01%).

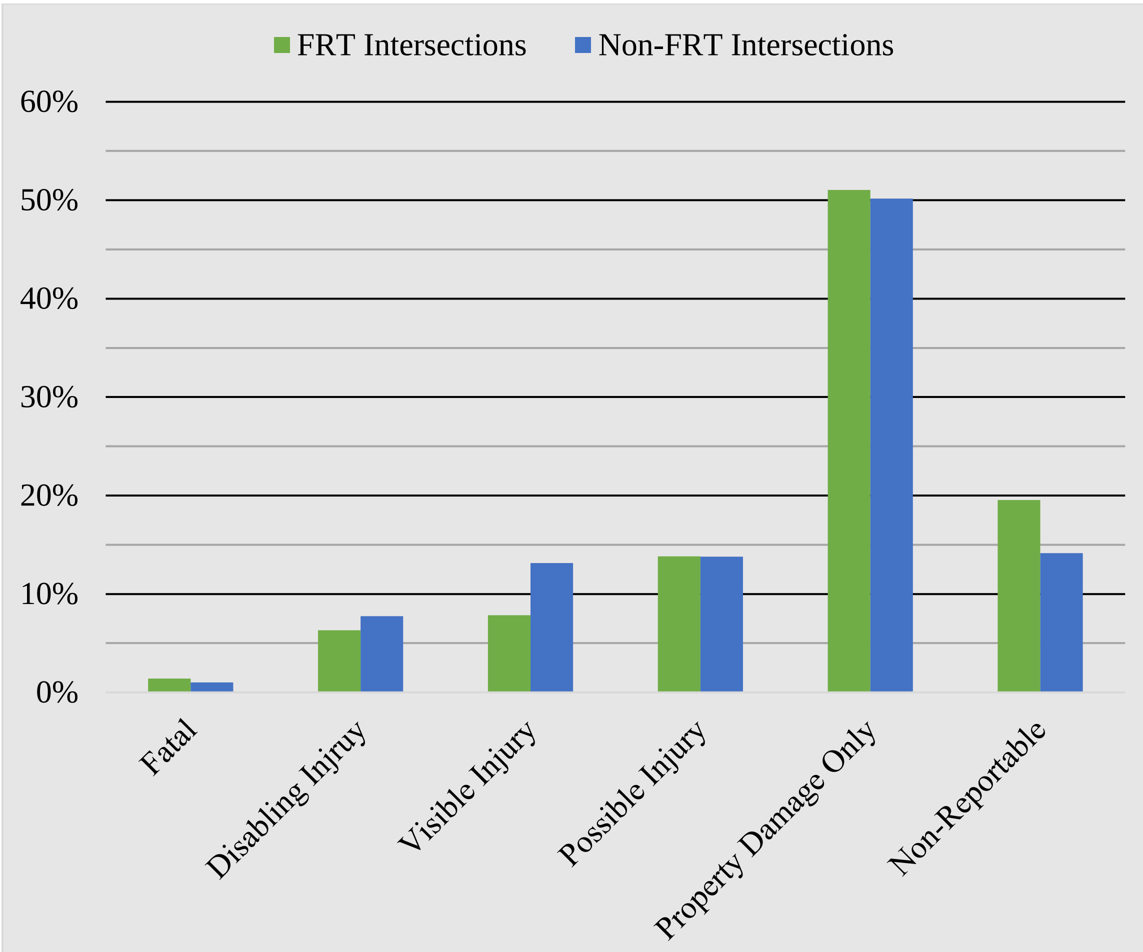

Figure 5-2 Crash Severity Comparison

Data that was also of interest was the crash type. When comparing the crash type of FRT intersections and non-FRT intersections, in Figure 5-3, two findings are notable. The first is the FRT intersections having 7.53% fewer rear-end crashes than the non-FRT intersections. This supports the theory discussed in the Literature Review that by separating through and right-turning traffic, rear-end crashes would be less prevalent. The second finding is that FRT intersections have 9.35% more sideswipe crashes than non-FRT intersections. This intuitively makes sense, because the FRT ramp forces a merging maneuver where sideswipe crashes would likely result with turning and crossing traffic conflicting more frequently than in the case if an FRT ramp were not present.

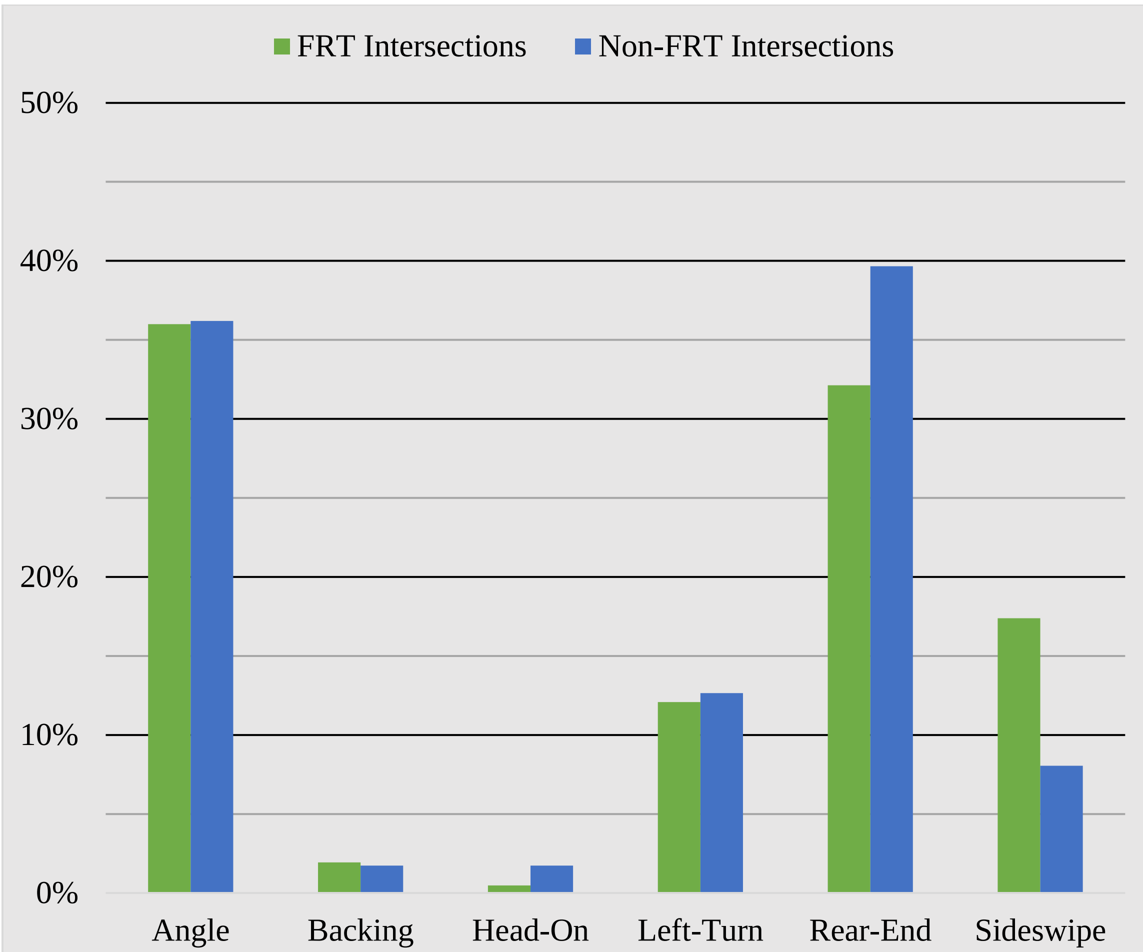

Figure 5-3 Crash Type Comparison

5.3 Analysis and Results

From the raw data, the crash frequencies and crash rates for each intersection were calculated using Equation 5-1 and Equation 5-2, respectively. For crash rate, calculations were made for each year from 2010 to 2019, as well as collectively over the ten years, which is tabulated in Appendix C. With these values, many comparisons were made to search for any trends or significant differences. These comparisons include FRT versus non-FRT intersections with varying AADT and intersection legs, using the AADT ranges of low, medium, and high that were developed in Table 4-1. Additionally, comparisons of FRT intersections by the approach on which the FRT ramp is located were made to the non-FRT intersections. Table 5-1 presents the 20 scenarios where different comparisons were made. The items in the crash frequency columns that are bolded indicate that they are higher than their counterpart, for viewing ease. Of the 20 scenarios, the FRT intersections had a higher crash frequency in 14 of them.

Table 5-2 presents the same comparisons, but instead of crash frequency, the crash rate was analyzed. From these comparisons, of the 20 scenarios, the FRT intersections had higher crash rates in all but one.

Table 5-1 Crash Frequency Comparison

Scenario	Comparison1		Comparison2	
	Sample Intersections	Crash Frequency (crashes/year)	Sample Intersections	Crash Frequency (crashes/year)
1	Low AADT, 3-Leg FRT	**0.856**	Low AADT, 3-Leg Non-FRT	0.525
2	Low AADT, 4-Leg FRT	0.664	Low AADT, 4-Leg Non-FRT	**0.925**
3	Low AADT, All Legs FRT	**0.760**	Low AADT, All Legs Non-FRT	0.725
4	Medium AADT, 3-Leg FRT	0.763	Medium AADT, 3-Leg Non-FRT	**1.025**
5	Medium AADT, 4-Leg FRT	**1.413**	Medium AADT, 4-Leg Non-FRT	0.975
6	Medium AADT, All Legs FRT	**1.088**	Medium AADT, All Legs Non-FRT	1.000
7	High AADT, 3-Leg FRT	**3.014**	High AADT, 3-Leg Non-FRT	1.925
8	High AADT, 4-Leg FRT	**2.486**	High AADT, 4-Leg Non-FRT	2.050
9	High AADT, All Legs FRT	**2.750**	High AADT, All Legs Non-FRT	1.988
10	All 3-Leg FRT	**1.319**	All 3-Leg Non-FRT	1.158
11	All 4-Leg FRT	1.170	All 4-Leg Non-FRT	**1.317**
12	All FRT	**1.245**	All Non-FRT	1.238
13	FRT on Major Road, 3-Leg	1.112	All 3-Leg Non-FRT	**1.158**
14	FRT on Minor Road, 3-Leg	**2.625**	All 3-Leg Non-FRT	1.158
15	FRT on Major Road, 4-Leg	1.095	All 4-Leg Non-FRT	**1.317**
16	FRT on Minor Road, 4-Leg	0.738	All 4-Leg Non-FRT	**1.317**
17	FRT on Both Major and Minor Road , 4-Leg	**1.660**	All 4-Leg Non-FRT	1.317
18	FRT on Major Road, All Legs	**1.104**	All Non-FRT	1.238
19	FRT on Minor Road, All Legs	**1.367**	All Non-FRT	1.238
20	FRT on Both Major and Minor Road, All Legs	**1.755**	All Non-FRT	1.238

Table 5-2 Crash Rate Comparison

Scenario	Comparison1		Comparison2	
	Sample Intersections	Crash Rate (crashes/million vehicles)	Sample Intersections	Crash Rate (crashes/million vehicles)
1	Low AADT, 3-Leg FRT	**0.546**	Low AADT, 3-Leg Non-FRT	0.294
2	Low AADT, 4-Leg FRT	**0.428**	Low AADT, 4-Leg Non-FRT	0.389
3	Low AADT, All Legs FRT	**0.478**	Low AADT, All Legs Non-FRT	0.349
4	Medium AADT, 3-Leg FRT	0.263	Medium AADT, 3-Leg Non-FRT	**0.382**
5	Medium AADT, 4-Leg FRT	**0.352**	Medium AADT, 4-Leg Non-FRT	0.253
6	Medium AADT, All Legs FRT	**0.315**	Medium AADT, All Legs Non-FRT	0.306
7	High AADT, 3-Leg FRT	**0.517**	High AADT, 3-Leg Non-FRT	0.353
8	High AADT, 4-Leg FRT	**0.441**	High AADT, 4-Leg Non-FRT	0.408
9	High AADT, All Legs FRT	**0.480**	High AADT, All Legs Non-FRT	0.379
10	All 3-Leg FRT	**0.459**	All 3-Leg Non-FRT	0.350
11	All 4-Leg FRT	**0.410**	All 4-Leg Non-FRT	0.351
12	All FRT	**0.432**	All Non-FRT	0.351
13	FRT on Major Road, 3-Leg	**0.417**	All 3-Leg Non-FRT	0.350
14	FRT on Minor Road, 3-Leg	**0.547**	All 3-Leg Non-FRT	0.350
15	FRT on Major Road, 4-Leg	**0.448**	All 4-Leg Non-FRT	0.351
16	FRT on Minor Road, 4-Leg	**0.360**	All 4-Leg Non-FRT	0.351
17	FRT on Both Major and Minor Road , 4-Leg	**0.388**	All 4-Leg Non-FRT	0.351
18	FRT on Major Road, All Legs	**0.429**	All Non-FRT	0.351
19	FRT on Minor Road, All Legs	**0.448**	All Non-FRT	0.351
20	FRT on Both Major and Minor Road, All Legs	**0.395**	All Non-FRT	0.351

5.4 Significance Testing

To further investigate these findings a two-sample t-test was performed to identify the statistical significance of the differences in the crash frequencies and crash rates between FRT and non-FRT intersections. Using the collected data, a t-statistic was calculated for each comparison in Table 5-1 and Table 5-2 and was compared to a critical t-value found using the t-table in Appendix D. Due to the large data set and multiple comparisons, the SAS programming language was used to calculate the t-statistics, in the hope to reduce errors that could be made manually. Appendix D contains the detailed results of the t-tests for crash frequency and the crash rate at both a 0.05 and 0.10 alpha level. For the results discussed here, the alpha value of 0.05 will be chosen, as it gives the highest confidence level of the two at 95%.

For the comparisons of crash frequency between FRT and non-FRT intersections, there were no statistically significant findings.

For the comparisons of crash rates between FRT and non-FRT intersections, there was one statistically significant finding:

1. For FRT intersections that have an FRT ramp on the major approach, either at three-legged or four-legged intersections, a statistically significant higher crash rate is observed when compared to non-FRT intersections of all-leg types

CHAPTER 6: TRAFFIC CONFLICT ANALYSIS

6.1 Background

Crash data, in the form of crash rate or crash frequency, is a typical metric used to measure safety at intersections. Although a common practice, it has its flaws. For example, crash data one sees in research is *reported* crashes, meaning there is no way to know how many crashes *actually* occurred. Each state has its own reporting criteria in the form of a dollar amount, so if a crash occurs, but there is minimal-to-no repair cost, it potentially will not be reported. Additionally, in single-vehicle crashes, crashes occurring at night, or situations where one or more drivers are under the influence of alcohol or drugs, drivers may opt not to report the crash, even if it is considered reportable. In lower traffic, rural areas, such as where this research is being conducted, it would be safe to assume that not all of the actual crashes are reported, because of the above factors and lack of witnesses or recording equipment in these types of areas, to identify a crash.

Safety analyses using traffic conflicts as a measure are a widely used and standardized method. A traffic conflict is defined as a traffic event involving two or more vehicles, where one or both drivers take evasive action such as braking or swerving to avoid a collision (Parker Jr & Zegeer, 1989). To have a reliable set of conflict data, adequate time for observation and a good understanding of what type of conflict is of interest, is important.

6.2 Methodology

For this research, 12 sites were selected for the conflict analysis using the AADT ranges of three-legged and four-legged intersections, identified in Table 6-1.

Table 6-1 Intersections for Conflict Analysis

	AADT Range	FRT Intersection [2018 AADT]		Non-FRT Intersection [2018 AADT]	
3-Legged Intersections	Low	N-4/N-103	[5,460]	N-31/N-50	[5,349]
	Medium	N-15/N-65	[9,975]	N-22/L-63A	[8,510]
	High	US-77/N-109	[20,390]	N-15/N-92	[13,891]
4-Legged Intersections	Low	N-74/US-281	[6,815]	N-9/N-16	[6,994]
	Medium	N-15/N-92	[12,366]	N-1/N-50	[13,595]
	High	US-77/N-92	[21,614]	N-1/US-34	[14,570]

During field visits to these locations, Miovision Scout cameras (Figure 6-1) were affixed to utility poles or sturdy signage posts at the intersections where a good view of the right-turning vehicles could be observed. The cameras were then left for a minimum of 72 hours to ensure adequate data to perform an analysis. There were a few instances where the 72-hour mark was not reached due to the camera's battery dying or the memory card becoming full, but in the end, it was determined sufficient data were obtained to run the analysis confidently.

At the FRT intersections, the camera was positioned to view the right-turning vehicle's interaction with the crossing-through traffic. At the non-FRT intersections, the camera was positioned at the right turn on the same approach as its FRT counterpart. For example, if an FRT ramp was located on the major approach of an intersection, the right-turn movement observed at the non-FRT intersection of similar AADT was also on the major approach. These scenarios will be discussed in detail in a later section.

Figure 6-1 Miovision Scout Camera (https://miovision.com/scout/scout-hardware)

6.2.1 Conflict Definitions

To get accurate data, sound definitions needed to be created to ensure uniformity across all sites when reviewing the videos. In general, a traffic conflict was defined as a traffic event involving two or more vehicles, where one or both drivers take evasive action such as braking or swerving to avoid a collision. When reviewing videos for FRT intersections and non-FRT intersections, different traffic conflicts were observed, depending on the presence of an FRT ramp and the other movements at the intersection.

For FRT intersections, there was one conflict that was of interest. This was defined as a merging conflict.

1. **A Merging conflict** is present when a vehicle with yield control impedes a right-of-way vehicle's path, causing the right-of-way vehicle to slow, swerve or brake to avoid a collision (Fazio et al., 1993).

For non-FRT intersections, there were several conflict types, depending on the number of intersection legs, turning movements, and the presence of exclusive right-turn lanes on the major approach. These conflicts are:

2. **Right-turn, same-direction conflict** - also referred to as a rear-end conflict. This is present when a vehicle on the major approach slows to make a right turn, where no exclusive right-turn lane is present, causing a following-through vehicle to brake or cross the painted centerline to avoid a rear-end collision (Parker Jr & Zegeer, 1989).
3. **Opposing left-turn conflict** – occurs when a vehicle turning right with the right-of-way, must brake to avoid an opposing left-turn vehicle that makes its turn in front of the right-turning vehicle’s path (Parker Jr & Zegeer, 1989).
4. **Through, cross traffic from left conflict -** occurs when a right-turning vehicle on the major approach slows to make a right turn and a vehicle from the minor approach to the left enters the intersection and impedes on the right-of-way of the right-turning vehicle (Parker Jr & Zegeer, 1989).
5. **Right-turn-on-red (RTOR) conflict -** a conflict observed at signalized intersections but is also useful for identifying conflict for right-turning vehicles on the minor approach of a two-way stop-controlled intersection. This conflict is present when a right-turning vehicle stopped on the minor approach misjudges the gap in the crossing, through traffic and proceeds to make its right turn, causing the crossing vehicle to slow or stop to avoid a collision (Parker Jr & Zegeer, 1989).

These conflicts will be illustrated in the following section, to show which conflicts were experienced at each intersection and where.

It should be noted that although traffic conflicts are believed to be a sound method of evaluating safety at intersections, there are both liberal and more strict definitions, depending on the research study conducted. For example, in some studies, conflict is only recorded if near-miss crashes occur, being the most extreme scenario. In other studies, conflict may be recorded if vehicles slow down or brake, with the assumption that a crash would occur if they didn't. Additionally, some studies record conflict as single-vehicle traffic violations, such as a vehicle not stopping at a stop sign, making a wide turn, or turning on the shoulder (Parker Jr & Zegeer, 1989). Because this research is conducted at rural intersections where traffic volume is lower and fewer conflicts may inherently result, a more liberal approach was taken in identifying conflicts. However, because this research is focused on conflicts with right-turning vehicles and other vehicles at the intersection, traffic violations and other single-vehicle conflicts were not included.

6.3 Conflicts Observed at Each Site

In this section, sketches of the FRT and non-FRT intersections are presented, with the types of conflicts observed for the right-turning vehicles. The conflicts defined above are indicated by the number corresponding to the conflict. To restate those conflicts, they are identified as follows:

1. Merging Conflict
2. Right-Turn, Same Direction Conflict
3. Opposing Left-Turn Conflict
4. Through, Cross Traffic from Left Conflict

5. RTOR Conflict

6.3.1 Category 1: Low AADT, 3-Leg

The intersection to the left of Figure 6-2, is the FRT ramp located at N-4/N-103 in Gage County. For this case, the only conflict observed is the merging conflict of the right-turning vehicles using the FRT ramp and the crossing-through traffic. The intersection to the right of Figure 6-2 is a non-FRT intersection located at N-31/N-50 in Sarpy County. Because the FRT ramp is located on the major approach of the intersection, the right turn located on the non-FRT intersection that was observed was also on the major approach. The right-turning vehicles share a lane with the through traffic, therefore, the conflicts present at this intersection are the right-turn, same-direction conflict, as well as opposing left-turn conflict.

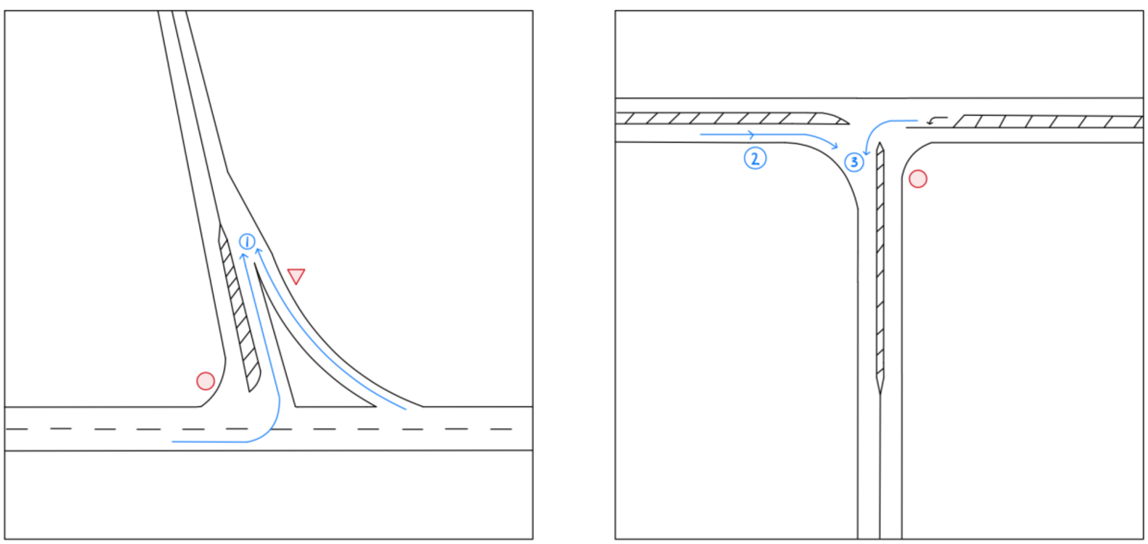

Figure 6-2 Low AADT, 3-Leg Intersections for Conflict Analysis

6.3.2 Category 2: Low AADT, 4-leg

The intersection to the left of Figure 6-3, is the FRT ramp located at N-74/US-281 in Adams County. For this case, the only conflict observed is the merging conflict of the right-turning vehicles using the FRT ramp and the crossing-through traffic. The intersection to the right of Figure 6-3 is a non-FRT intersection located at N-9/N-16 in Thurston County. Because the FRT ramp is located on the major approach of the intersection, the right turn located on the non-FRT intersection that was observed was also on the major approach. The right-turning vehicles share a lane with the through traffic, therefore, the conflicts present at this intersection are the right-turn, same direction conflict, opposing left-turn conflict, and through, cross traffic from left conflict.

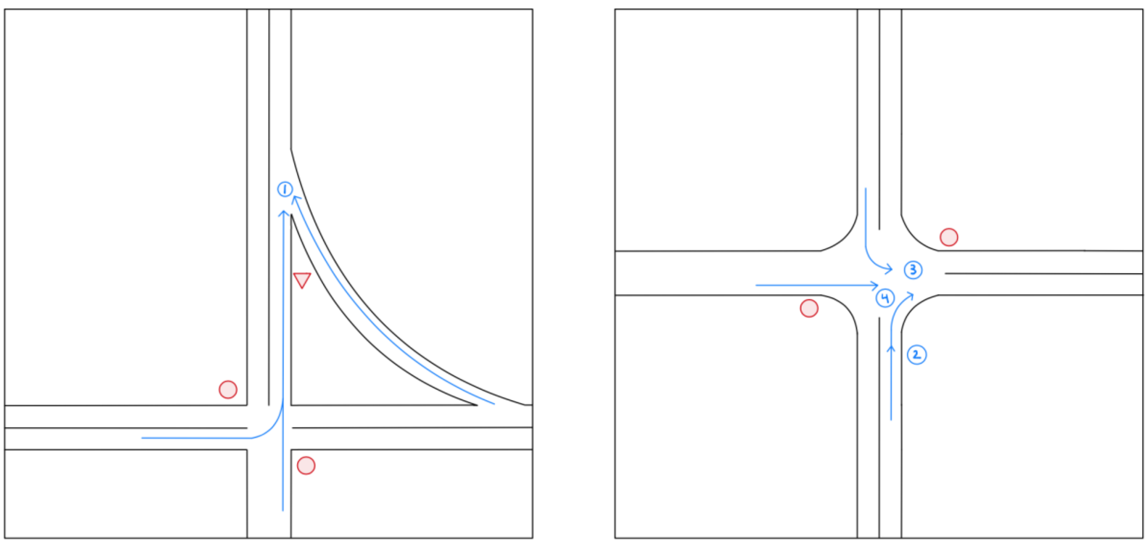

Figure 6-3 Low AADT, 4-Leg Intersections for Conflict Analysis

6.3.3 Category 3: Medium AADT, 3-Leg

The intersection to the left of Figure 6-4, is the FRT ramp located at N-15/N-65 in Butler County. For this case, the only conflict observed is the merging conflict of the right-turning vehicles using the FRT ramp and the crossing-through traffic. The intersection to the right of Figure 6-4 is a non-FRT intersection located at N-22/L-63A in Nance County. Because the FRT ramp is located on the minor approach of the intersection, the right turn located on the non-FRT intersection that was observed was also on the minor approach. Due to this, the only conflict of interest is the RTOR conflict involving the right-turning vehicles at the minor approach and the major through traffic.

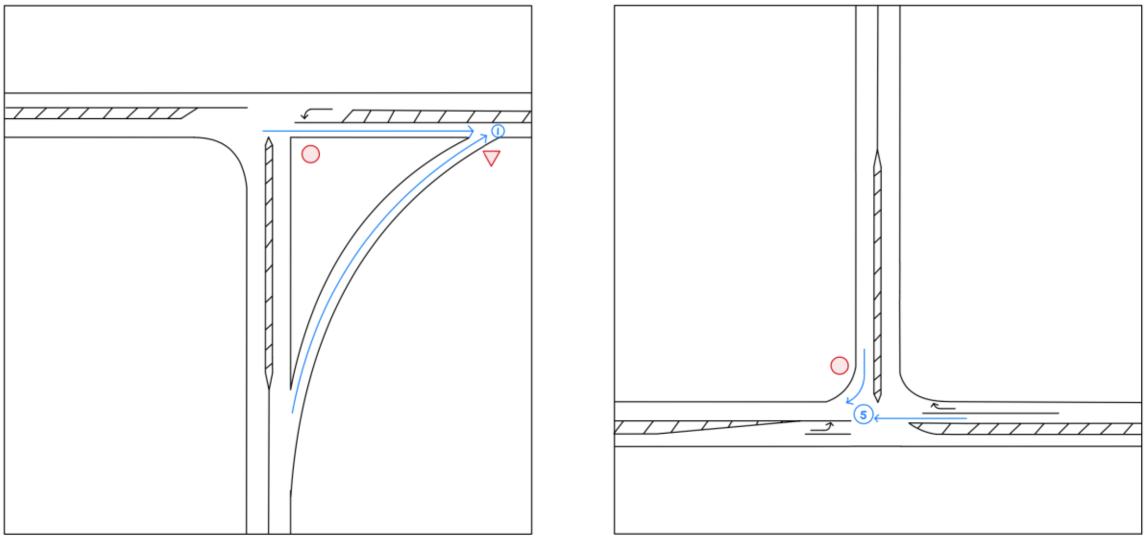

Figure 6-4 Medium AADT, 3-Leg Intersections for Conflict Analysis

6.3.4 Category 4: Medium AADT, 4-Leg

The intersection to the left of Figure 6-5, is the FRT ramp located at N-15/N-92 in Butler County. For this case, the only conflict observed is the merging conflict of the right-turning vehicles using the FRT ramp and the crossing-through traffic. The intersection to the right of Figure 6-5 is a non-FRT intersection located at N-1/N-50 in Cass County. Because the FRT ramp is located on the major approach of the intersection, the right turn located on the non-FRT intersection that was observed was also on the major approach. The right-turning vehicles share a lane with the through traffic, therefore, the conflicts present at this intersection are the right-turn, same direction conflict, opposing left-turn conflict, and through, cross traffic from left conflict.

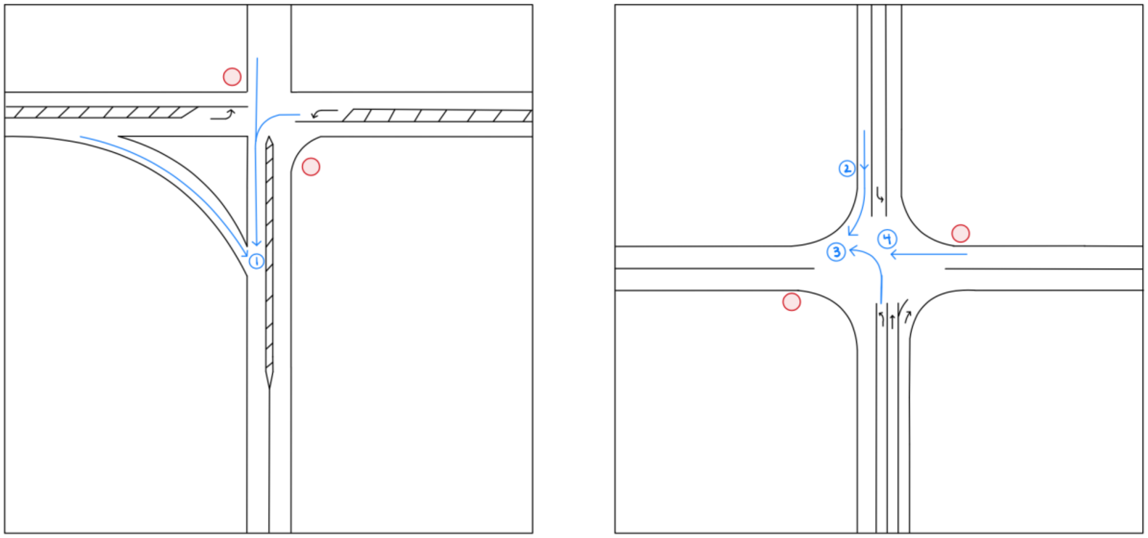

Figure 6-5 Medium AADT, 4-Leg Intersections for Conflict Analysis

6.3.5 Category 5: High AADT, 3-Leg

The intersection to the left of Figure 6-6 is the FRT ramp located at US-77/N-109 in Saunders County. For this case, the only conflict observed is the merging conflict of the right-turning vehicles using the FRT ramp and the crossing-through traffic. The intersection to the right of Figure 6-6 is a non-FRT intersection located at N-15/N-92 in Butler County. Because the FRT ramp is located on the major approach of the intersection, the right turn located on the non-FRT intersection that was observed was also on the major approach. The right-turning vehicles have an exclusive right-turn lane separated from the through traffic, therefore, the only conflict present at this intersection is an opposing left-turn conflict.

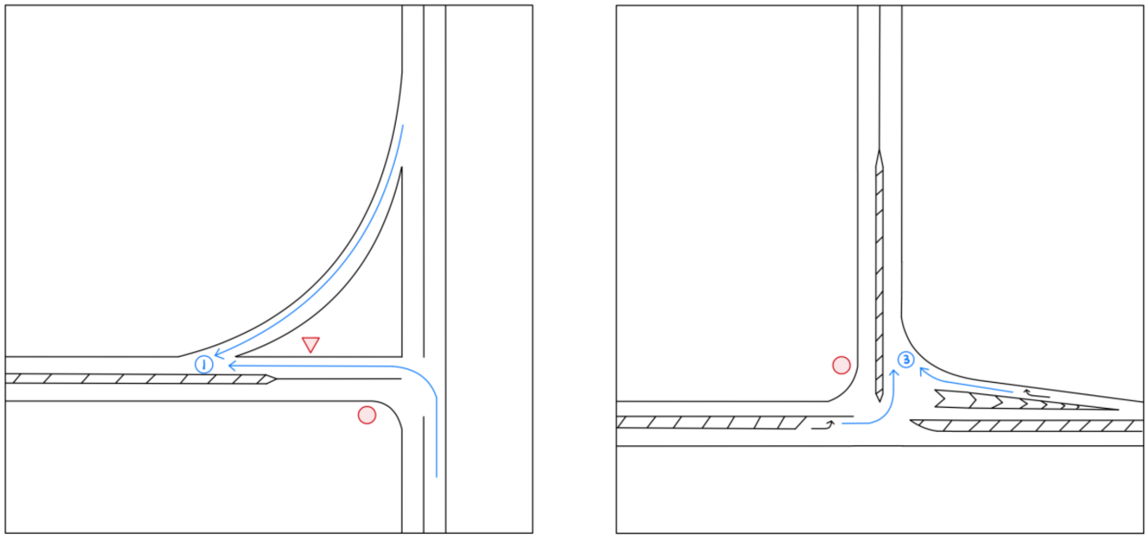

Figure 6-6 High AADT, 3-Leg Intersections for Conflict Analysis

6.3.6 Category 6: High AADT, 4-Leg

The intersection to the left of Figure 6-7, is the FRT ramp located at US-77/N-92 in Saunders County. This intersection has two FRT ramps, but only the FRT ramp on the minor approach was studied. For this case, the only conflict observed is the merging conflict of the right-turning vehicles using the FRT ramp and the crossing-through traffic. The intersection to the right of Figure 6-7 is a non-FRT intersection located at N-1/US-34 in Cass County. Because the FRT ramp of interest is located on the minor approach, the right turn located on the non-FRT intersection that was observed was also on the minor approach. Due to this, the conflicts of interest are the RTOR conflict involving the right-turning vehicles at the minor approach and the major through traffic, as well as an opposing left-turn conflict.

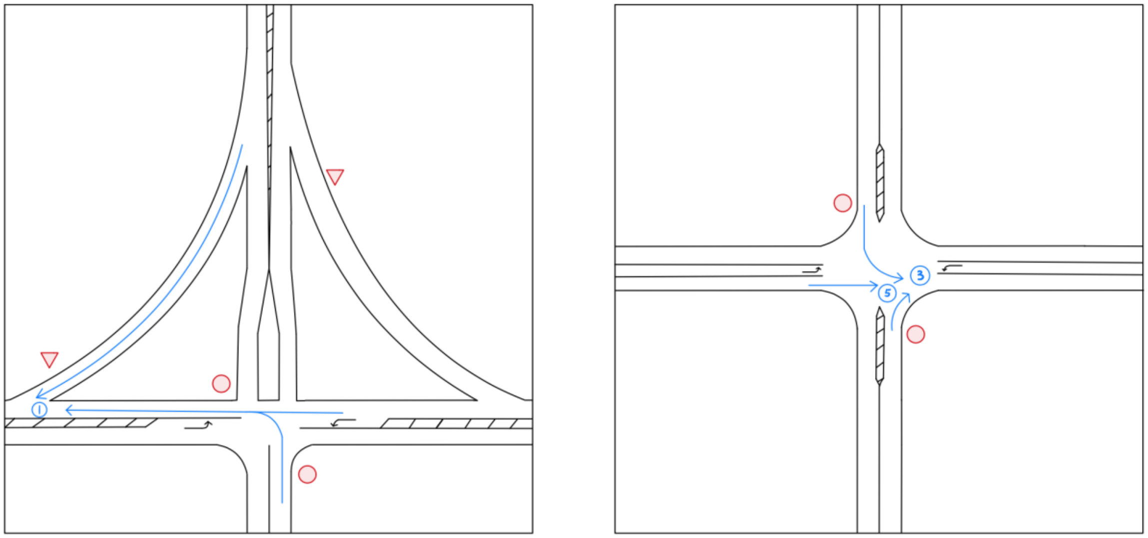

Figure 6-7 High AADT, 4-Leg Intersections for Conflict Analysis

6.4 Analysis and Results

For each intersection, approximately 72 hours of video were reviewed and various data were recorded. This data included: right-turning vehicles on the approach of interest, crossing-through vehicles that could conflict with the right-turning vehicles, potential traffic conflicts, and traffic conflicts. Using 15-minute increments, these variables were recorded and organized in an Excel spreadsheet. The characteristics of these sites and the conflict data are shown in detail in Appendix E. Due to this process being lengthy and spanning several months, each conflict was timestamped and revisited a second time to ensure uniformity in the traffic conflict definitions.

As noted, these intersections span a range of traffic volumes, with some being very high and some being very low. With a similar reasoning in using the crash rate in the crash analysis, for the conflicts – conflicts per 1000 entering right-turning vehicles was chosen as the primary metric to study. This places all of the intersections on an even playing field, regardless of the right-turning traffic volume.

Table 6-2 gives the results of the conflict analysis in both conflict per hour and conflict per 1000 entering right-turning vehicles. The values in bold indicate a higher value for viewing ease. As can be seen, in most cases, as well as overall, the non-FRT intersections experience higher values of both conflict metrics.

Table 6-2 Conflict Analysis Results

		RT APPROACH			
		Conflict/Hour		Conflict/1000 entering RT vehicles	
	AADT Range	FRT Site	Non-FRT Site	FRT Site	Non-FRT Site
3-Leg	Low	0.056	**0.818**	3.320	**39.773**
	Medium	**0.048**	0.000	**1.350**	0.000
	High	**0.188**	0.163	2.070	**2.558**
Average:		0.097	**0.327**	1.962	**11.778**
4-Leg	Low	0.000	**0.017**	0.000	**43.478**
	Medium	0.028	**0.167**	0.560	**36.697**
	High	**0.351**	0.116	4.637	**7.601**
Average:		**0.126**	0.100	3.048	**14.342**
Overall Average:		0.112	**0.214**	2.499	**12.275**

When conducting this analysis, in addition to the separation of the FRT and non-FRT intersections by traffic volume and the number of legs, three scenarios were observed that presented interesting findings:

1. FRT ramp located on the minor approach, with the non-FRT right-turn located on the stop-controlled minor approach
2. FRT ramp located on the major approach, with the non-FRT right-turn movement having no exclusive right-turn lane on the major approach
3. FRT ramp located on the major approach, with the non-FRT right-turn approach having an exclusive right-turn lane

Table 6-3 presents these findings. Again, the non-FRT intersections experience higher conflicts per 1000 right-turning vehicles. Scenario two, which compares the FRT ramp on the major approach and the non-FRT right-turn on the major approach with no exclusive right-turn lane, has the most significant difference. This is believed to be because of the right-turn, same-direction conflict. With the right-turning vehicles and through vehicles sharing a lane, whenever a vehicle slows to turn right, following-through vehicles often traveling at a high rate of speed must suddenly slow down or swerve over the centerline to avoid a rear-end crash.

Table 6-3 Traffic Conflict Scenario Results

Scenario	# of Int. Studied	FRT Conflict/1000 RT vehicles	Non-FRT Conflict/1000 RT vehicles
1	2	3.440	**7.048**
2	3	1.146	**39.297**
3	1	2.070	**2.558**

CHAPTER 7: SUMMARY AND CONCLUSIONS

This chapter first presents a summary of the research, including the data used and tests that were conducted, followed by their results. Then, based on the research findings, conclusions, limitations, and recommendations for future research will be given.

7.1 Research Summary and Results

The primary objectives of this research were to: identify rural free right-turn (FRT) ramp intersections in Nebraska and similar non-FRT intersections for comparison testing purposes, perform a safety analysis using police-reported crashes from 2010-2019, and perform a conflict analysis using Miovision Scout video recording equipment.

7.1.1 Inventory of FRT and non-FRT Intersections

In total, 68 rural FRT intersections were identified, with 57 intersections containing one FRT ramp and 11 intersections containing two FRT ramps. Intersection characteristics, such as intersection legs, presence of skew, and lighting were recorded for inventory purposes. Additionally, specific data relating to the FRT ramps themselves were recorded, such as signage, FRT length, FRT radius, island type, and the presence of acceleration and deceleration lanes. AADT ranges of low, medium and high were created using quartiles of the FRT intersection traffic volumes from 2018 to ensure that non-FRT intersections that were identified had a wide range of traffic volume. The year 2018 was chosen, as it was the latest traffic volume data available that was before the COVID-19 pandemic, in hopes of avoiding potentially "abnormal" values thereafter. Twenty-four non-FRT intersections were identified - 12 three-legged and 12 four-legged - and further divided into the low, medium, and high AADT categories. Similar intersection characteristics were obtained for the non-FRT intersections that were recorded for the FRT intersections.

7.1.2 Safety Analysis

For the safety analysis, a comparison of FRT intersection and non-FRT intersection crash frequencies and crash rates over the ten-year period (2010-2019) was performed to identify any differences. The raw data of the crashes occurring during the time period were compared first to search for any trends. Regarding crash severity, the most notable finding was that the FRT intersections (1.41%) experienced 0.40% more fatal crashes from 2010-2019 than the non-FRT intersections (1.01%). Regarding the crash type, the FRT intersections had 7.53% fewer rear-end crashes than the non-FRT intersections. Also, the FRT intersections had 9.35% more sideswipe crashes than non-FRT intersections.

Crash frequency and crash rate were calculated for each FRT and non-FRT intersection and several comparisons were made between the two groups to see how traffic volume, intersection type, and the presence of the FRT ramp on the major or minor approach affect the values. For crash frequency, 20 comparisons were made between the FRT and non-FRT intersections, with the FRT intersections having a higher crash frequency in 14 of them. For crash rate, the same comparisons were tested, with FRT intersections having a higher crash rate in 19 of the 20 comparisons.

Furthermore, a two-sample t-test was performed for these comparisons using an alpha value of 0.05, to identify any statistically significant findings. For the crash frequency comparisons, no statistically significant findings were determined. For crash rate, there was one statistically significant finding:

- For FRT intersections that have an FRT ramp on the major approach, either at three-legged or four-legged intersections, a statistically significant higher crash rate is observed when compared to non-FRT intersections of all-leg types

7.1.3 Conflict Analysis

For the conflict analysis, Miovision Scout video recording equipment were used to record vehicle interactions at several FRT and non-FRT intersections. The intersections were chosen based on AADT and the number of intersection legs. In total, 12 intersections were chosen: six three-legged and six four-legged, with one FRT and one non-FRT per low, medium, and high AADT category. For the FRT intersections, the conflicts were recorded between the vehicles using the FRT ramp and the crossing-through vehicles. For the non-FRT intersections, the right-turn movement to be observed was chosen based on the location of its FRT intersection counterpart. For example, for the low AADT category for three-legged intersections, the FRT ramp was located on the major approach, therefore for the non-FRT comparison, the right-turn movement of interest was the one also on the major approach. For the non-FRT intersections, several conflicts were observed, including right-turn, same direction, opposing left-turn, through, cross traffic from left, and right-turn-on-red (RTOR). The location of the right-turn movement on the major or minor approach, the number of intersection legs, and the presence of an exclusive right-turn lane determined what specific conflicts existed.

For the 12 intersections, with six being FRT intersections and six being non-FRT intersections, conflict per hour and conflict per 1000 entering right-turning vehicles were compared. For conflict per hour, it was split evenly with three FRT intersections having a higher value in some cases, and three non-FRT intersections having higher values in the other cases. However, across all of the tested intersections, the non-FRT intersections had higher conflicts per hour. For conflict per 1000 entering right-turning vehicles, five of the non-FRT intersections had higher values than their FRT intersection counterpart, and in total across all the tested sites, the non-FRT intersections had a much higher value. The choice to use conflict per 1000 entering right-turning vehicles as the primary metric was made in a similar way that crash rate was chosen for the safety analysis – the differences in traffic volume are no longer a significant factor when using this method.

To look at these intersections in a different way other than just AADT and the number of intersection legs, the intersections were categorized into three major scenarios:

1. FRT ramp located on the minor approach, with the non-FRT right-turn located on the stop-controlled minor approach
2. FRT ramp located on the major approach, with the non-FRT right-turn movement having no exclusive right-turn lane on the major approach
3. FRT ramp located on the major approach, with the non-FRT right-turn approach having an exclusive right-turn lane

Comparing these scenarios, the non-FRT intersections all had higher conflicts per 1000 entering right-turning vehicles, with the most significant difference in scenario two. When vehicles turn on the major approach of a rural highway with no exclusive right-turn lane present, the following-through vehicles, traveling at a high rate of speed, must suddenly slow down and brake, or swerve across the painted centerline to avoid a potential rear-end collision. The FRT ramp eliminates this conflict, as right-turning and through traffic are separated at the intersection. In scenario three, where there is an exclusive right-turn lane present on the major approach, the conflicts per 1000 entering right-turning vehicles are more similar, but the FRT intersections still produce lower values. Scenario one also has a smaller difference between FRT and non-FRT intersections, where the FRT ramp is located on the minor approach and the non-FRT right-turn is located on the minor approach which is stop-controlled. For the non-FRT intersections, it can be inferred that drivers are less likely to disobey the stop sign and impede on the major traffic’s right-of-way, but other conflicts are still present even when the vehicles make their right-turn because there is still interaction with the major traffic. Because of these other conflicts, the non-FRT intersections have a higher conflict per 1000 entering right-turning vehicles.

7.2 Conclusions

After analyzing the findings of the safety and conflict analyses the following conclusions were made:

- The presence of an FRT ramp at an intersection does not affect the crash frequency or crash rate experienced. Although the results indicated higher values for both crash frequency and crash rate, only one statistically significant finding existed.
- Conflict is reduced between right-turning vehicles and the other traffic present at the intersection when an FRT ramp is present. This is especially true when no exclusive right-turn lanes exist at non-FRT intersections.

Revisiting McCoy’s (1995) research study, similar findings were reported. McCoy stated that “the presence of an FRT lane does not affect the frequency, severity, or types of accidents that occur.” Regarding conflict, McCoy’s study focussed on the need for acceleration lanes, stating that "the absence of acceleration lanes increases conflict in the merge area." For this research, scenario three of the conflict analysis represents this finding as well. All of the FRT intersections had an acceleration lane, while the non-FRT intersections with exclusive right-turn lanes did not have acceleration lanes. In this case, the FRT intersections had a lower conflict per 1000 entering right-turning vehicles.

7.3 Limitations and Future Research

This research conducted its safety analysis assuming several factors. For example, because the construction dates of the FRT ramps were not known, the FRT intersections were assumed to have similar geometric and traffic characteristics for the ten-year period of interest (2010-2019). If a particular FRT intersection had an FRT ramp constructed within that time period, the changes in that intersection's crash frequency and crash rate were not known. Additionally, with limited traffic volume data (i.e., missing odd years), assumptions were made that interpolation of the known data to find the missing data was sufficient.

Another limitation of this research was the use of the two-sample t-test to test the statistical significance of the safety analysis. First, crashes are Poisson distributed, while the t-test is to be used for normal distributions, so typically the t-test would not be accepted. However, with the available data and testing of two populations, it was chosen as the best method. An Empirical-Bayes before-after test would be preferred, however, due to the lack of data detailing the construction of each FRT ramp, and the potential need for much older crash data for older FRT ramps, sufficient and precise data for a "before" and "after" period would be hard to obtain. For future research, if these dates and many more years of crash data could be obtained, it would presumably offer more precise results.

Also, regarding the use of t-tests in traffic studies, it has been argued that the term “not significant” can often be confused with “not important” (Hauer, 2004). Although the findings of the t-test in the case of this research found only one statistical finding out of 40 comparisons that were tested at the 95% confidence level, these findings are not irrelevant and do not entirely indicate that there was no change in safety observed. This paired with relatively few populations (68 FRT intersections and 24 non-FRT intersections) in the statistical sense, the results may not be fully indicative of what is actually true about the FRT ramp’s effect on safety. Therefore, in future research, a study of FRT intersections and non-FRT intersections across several states may provide more telling results.

The crash data obtained in this research did not have information identifying which crashes occurred because of the right-turn. For example, in the GIS data, crashes could be visually identified by their location, but assumptions would have to be made to state that the crashes occurred because of conflict at the FRT ramp (for FRT ramp intersections) and the standard right-turn lane or through lane used for turning right (for non-FRT ramp intersections). In future research, it would be suggested to obtain more descriptive crash data, so that only right-turn-related crashes could be analyzed, rather than the entire intersection, as was done in this analysis.

This research did not consider delay, queue length, or vehicle speeds. While viewing the recorded videos of FRT and non-FRT intersections, it could be logically inferred that the presence of an FRT ramp reduces queue length and delay, and allows for higher turning speeds, however, an analysis was not conducted in this study. With data now existing on the safety and conflicts experienced at FRT and non-FRT intersections, it would be useful to assess operational benefits of FRT ramps through the above-mentioned operational characteristics. Another recommendation would be to develop crash modification factors (CMFs) in future research. This was not an objective of this research, but could be done with the now available data.

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APPENDIX A: FRT RAMP INTERSECTION INVENTORY

Table A1. FRT Ramp Intersection Characteristics (1 of 13)

Variable	Description	Coding (if applicable)	Source of Information
FRT_ID	FRT ramp ID		
INT_ID	FRT ramp intersection ID		
ITEM_NO	Number of ramp in order of when listed in the logbook		
COORDINATE	Coordinates via pathweb, based on reference post that was associated with the ramp		Pathweb
HWY_MAIN	Main highway, as stated		Nebraska Highway Reference Logbook
COUNTY	County, as stated		
HWY_POINT	Short description of the point on the highway where the ramp is located		
RAMP_DIR	Direction of the ramp from the reference post given (logbook travels from west to east or south to north)		
REF_POST	Reference post listed		
MILES	Copied directly; typically, similar to the reference post number		
HWY_NO	Highway number given in existing FRT inventory spreadsheet		From "IntegratedHighwayInventory_IHIP0108" spreadsheet provided by NDOT
REF_BEG	Reference post number at the beginning of the ramp		
REF_END	Reference post number at the end of the ramp		
RAMP_ID	ID number given to each ramp		
RAMP_LOC	Short description of the location of the ramp; typically includes intersecting roads and city		
INT	Intersecting roadways where the ramp exists		
BEG_END	Beginning or end of the ramp indicator, for highway segment:	Beginning = 1 End = 0	Pathweb/Google Earth
CITY	City (or village) the ramp is located in		Pathweb
AREA_TYPE	Rural or urban area, based off of population (population of 5,000 or more is urban, per AASHTO)	Rural = 1 Urban = 0	Nebraska Census website

Table A1. FRT Ramp Intersection Characteristics (2 of 13)

Variable	Description	Coding (if applicable)	Source of Information
LEGS	Number of Intersection legs	4-leg intersection = 4 3-leg intersection = 3	Pathweb/Google Earth
SKEW	Presence of intersection skew	Yes = 1 No = 0	Pathweb/Google Earth
NAME_ENTR	Highway name of the road where the ramp entrance is located		Pathweb/Google Earth
LN_ENTR	Number of lanes on the road approaching the ramp		Pathweb/Google Earth
SHLDR_ENTR	Type of shoulder on the road approaching the ramp entrance	Paved = 2 Unpaved = 1 None = 0	Pathweb/Google Earth
DH_ENTR	Is the road approaching the ramp a divided highway?	Yes = 1 No = 0	Pathweb/Google Earth
DECEL_LN	Presence of a deceleration lane approaching the ramp entrance	Yes = 1 No = 0	Pathweb/Google Earth
MED_ENTR	Presence of a median on the road approaching the ramp entrance	Raised grass = 3 Raised pavement = 2 Painted = 1 None = 0	Pathweb/Google Earth
SL_ENTR	Speed limit (mph) of the road approaching the ramp entrance		Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (3 of 13)

Variable	Description	Coding (if applicable)	Source of Information
SL_SIGN_ENTR	Speed limit sign type	R2-1 = 1  R2-1 W13-1P = 0  W13-1P	Pathweb/Google Earth
SL_LOC_ENTR	Speed limit sign location (coordinates) on the road approaching the ramp entrance		Pathweb
SURF_ENTR	Surface type of road approaching ramp entrance	Gravel = 2 Asphalt = 1 Concrete = 0	Pathweb/Google Earth
CNTRL_THRU	Traffic control of through traffic for road approaching FRT ramp	Traffic signals = 3 STOP sign = 2 YIELD sign = 1 None = 0	Pathweb/Google Earth
NAME_EXIT	Highway name of the road where the ramp exits to		Pathweb/Google Earth
LN_EXT	Number of lanes on the road where the ramp exits to		Pathweb/Google Earth
SHLDR_EXIT	Type of shoulder on the road the ramp exits to	Paved = 2 Unpaved = 1 None = 0	Pathweb/Google Earth
DH_EXIT	Is the road the ramp exits to a divided highway?	Yes = 1 No = 0	Pathweb/Google Earth
ACCEL_LN	Presence of an acceleration lane after the ramp exit	Yes = 1	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (4 of 13)

Variable	Description	Coding (if applicable)	Source of Information
CNTRL_THRU	Traffic control of through traffic for road approaching FRT ramp	Traffic signals = 3 STOP sign = 2 YIELD sign = 1 None = 0	Pathweb/Google Earth
NAME_EXIT	Highway name of the road where the ramp exits to		Pathweb/Google Earth
LN_EXT	Number of lanes on the road where the ramp exits to		Pathweb/Google Earth
SHLDR_EXIT	Type of shoulder on the road the ramp exits to	Paved = 2 Unpaved = 1 None = 0	Pathweb/Google Earth
DH_EXIT	Is the road the ramp exits to a divided highway?	Yes = 1 No = 0	Pathweb/Google Earth
ACCEL_LN	Presence of an acceleration lane after the ramp exit	Yes = 1 No = 0	Pathweb/Google Earth
MED_EXIT	Presence of a median on the road exiting from the ramp	Raised grass = 3 Raised pavement = 2 Painted = 1 None = 0	Pathweb/Google Earth
SL_EXIT	Speed limit (mph) of the road exiting from the ramp		Pathweb/Google Earth
SL_SIGN_EXIT	Speed limit sign type	R2-1 = 1 W13-1P = 0	Pathweb/Google Earth
SL_LOC_EXIT	Speed limit sign location (coordinates) on the road exiting from the ramp		Pathweb/Google Earth
SURF_EXIT	Surface type of road after the ramp exit	Gravel = 2 Asphalt = 1 Concrete = 0	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (5 of 13)

Variable	Description	Coding (if applicable)	Source of Information
LENGTH	Length of FRT ramp (ft)		Google Earth
RADIUS	Radius of FRT ramp (ft)		Google Earth
ISLAND	Type of island present at the ramp	Grass island = 3 Raised pavement island = 2 Painted island = 1 None = 0	Pathweb/Google Earth
SHLDR_RAMP	Type of shoulder on the ramp	Paved = 2 Unpaved = 1 None = 0	Pathweb/Google Earth
SL_RAMP	Speed limit (mph) of the ramp, if applicable		Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (6 of 13)

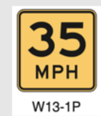
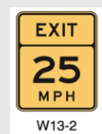
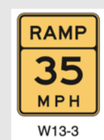
Variable	Description	Coding (if applicable)	Source of Information
SL_SIGN_RAMP	Speed limit sign on ramp	W13-1P w/ W1-6 = 4   R2-1 = 3  W13-2 = 2  W13-3 = 1  None = 0	Pathweb/Google Earth
DELIN	Presence of delineators on ramp roadway edge	Yes = 1 No = 0	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (7 of 13)

Variable	Description	Coding (if applicable)	Source of Information
HAW_SIGN_1	Number of W1-8 horizontal alignment warning signs present on the ramp		Pathweb/Google Earth
HAW_SIGN_2	Presence of W1-2 horizontal alignment warning sign on ramp	Yes = 1 No = 0 	Pathweb/Google Earth
SURF_RAMP	Surface type of the ramp	Gravel = 2 Asphalt = 1 Concrete = 0	Pathweb/Google Earth
CNTRL_RAMP	Traffic control at the exit of the ramp	STOP sign = 2  YIELD sign = 1  None = 0	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (8 of 13)

Variable	Description	Coding (if applicable)	Source of Information
ADV_TC_1	Presence of W3-2 advanced traffic control signing	Yes = 1 No = 0 	Pathweb/Google Earth
ADV_TC_2	Presence of W3-2a advanced traffic control signing	Yes = 1 No = 0 	Pathweb/Google Earth
JCT_SIGN	Presence of an M2-2 combination junction sign	Yes = 1 No = 0 	Pathweb/Google Earth
US_SIGN	Quantity of M1-4 U.S. route signs	Two = 2 One = 1 None = 0 	Pathweb/Google Earth
STATE_SIGN	Quantity of M1-5 state route signs	Two = 2 One = 1 None = 0 	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (9 of 13)

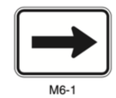
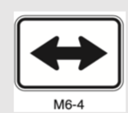
Variable	Description	Coding (if applicable)	Source of Information
DIR_SIGN_1	Quantity of M6-1 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0 	Pathweb/Google Earth
DIR_SIGN_2	Quantity of M6-2 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0 	Pathweb/Google Earth
DIR_SIGN_3	Quantity of M6-3 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0 	Pathweb/Google Earth
DIR_SIGN_4	Quantity of M6-4 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0 	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (10 of 13)

Variable	Description	Coding (if applicable)	Source of Information
DIR_SIGN_5	Quantity of M6-5 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0  M6-5	Pathweb/Google Earth
DIR_SIGN_6	Quantity of M6-6 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0  M6-6	Pathweb/Google Earth
DIR_SIGN_7	Quantity of M6-7 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0  M6-7	Pathweb/Google Earth
DIR_SIGN_8	Quantity of M5-1 advance turn and directional arrow auxiliary signs	Two = 2 One = 1 None = 0  M5-1	Pathweb/Google Earth
WARN_DA	Presence of a W12-1 double arrow sign	Yes = 1 No = 0  W12-1	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (11 of 13)

Variable	Description	Coding (if applicable)	Source of Information
OBJ_1	Presence of an OM1-3 object marker for obstruction sign	Yes = 1 No = 0  OM1-3	Pathweb/Google Earth
OBJ_2	Presence of an OM1-2 object marker for obstruction sign	Yes = 1 No = 0  OM1-2	Pathweb/Google Earth
MERGE_1	Presence of a W4-1 merge sign	Yes = 1 No = 0  W4-1	Pathweb/Google Earth
MERGE_2	Presence of a W4-5 merge sign	Yes = 1 No = 0  W4-5	Pathweb/Google Earth
EXCLSN_1	Presence of R5-1 selective exclusion signing at the exit of the ramp, from the opposing direction	Yes = 1 No = 0  R5-1	Pathweb/Google Earth

Table A1. FRT Ramp Intersection Characteristics (12 of 13)

Variable	Description	Coding (if applicable)	Source of Information
EXCLSN_2	Presence of R5-1a selective exclusion signing at the exit of the ramp, from the opposing direction	Yes = 1 No = 0  R5-1a	Pathweb/Google Earth
LIGHT	Presence of light posts in the area	Yes = 1 No = 0	Pathweb/Google Earth
RAIL	Presence of a railroad crossing near the intersection	Yes = 1 No = 0	Pathweb/Google Earth
BLDG	Presence of residential or commercial buildings near the intersection	Yes = 1 No = 0	Pathweb/Google Earth
COORD_CNTR_ID	Unique ID given for Google Earth labeling purposes		
COORD_CNTR	Coordinates of the center of the intersection		
COORD_N_ID	Unique ID given for Google Earth labeling purposes		
COORD_N	Coordinates of the leg north of the intersection, 1/4 quarter mile from center		
COORD_E_ID	Unique ID given for Google Earth labeling purposes		
COORD_E	Coordinates of the leg east of the intersection, 1/4 quarter mile from center		Google Earth
COORD_S_ID	Unique ID given for Google Earth labeling purposes		
COORD_S	Coordinates of the leg south of the intersection, 1/4 quarter mile from center		
COORD_W_ID	Unique ID given for Google Earth labeling purposes		
COORD_W	Coordinates of the leg west of the intersection, 1/4 quarter mile from center		

Table A1. FRT Ramp Intersection Characteristics (13 of 13)

Variable	Description	Coding (if applicable)	Source of Information
RAMP_BEG	Intersection leg where the ramp begins	North = 0 East = 1 South = 2 West = 3	Pathweb/Google Earth
RAMP_END	Intersection leg where the ramp ends	North = 0 East = 1 South = 2 West = 3	Pathweb/Google Earth

Table A2. FRT Intersection Basic Characteristics (1 of 2)

Note 1: items shaded in gray indicate two ramps of the same intersection

Note 2: FRT ramp ‘FRT11’ was removed, so although the last ramp is ‘FRT80’ there are 79 total ramps

Note 3: if an FRT radius is indicated as ‘N/A’ the ramp is a straight segment

Note 4: FRT length and FRT radius are rounded to the nearest 50 ft

SITE_ID	FRT_ID	COUNTY	INTERSECTION	LEGS	SKEW	LIGHT	FRT LENGTH (ft)	FRT RADIUS (ft)
FRT1	FRT1	BOX BUTTE	N-2/L-7E	3	Yes	Yes	150	350
FRT2	FRT2	BOX BUTTE	N-2/US-385	3	No	Yes	450	350
FRT3	FRT3	CUSTER	N-2/N-92	4	Yes	Yes	200	350
FRT4_5	FRT4	HAMILTON	N-2/US-34	4	Yes	Yes	100	150
	FRT5	HAMILTON	N-2/US-34	4	Yes	Yes	550	350
FRT6	FRT6	WEBSTER	N-4/US-281	3	Yes	No	550	N/A
FRT7	FRT7	GAGE	N-4/N-103	3	Yes	Yes	350	450
FRT8	FRT8	PAWNEE	N-4/N-99	4	No	No	100	150
FRT9	FRT9	PAWNEE	N-4/N-50	3	No	No	2000	1550
FRT10	FRT10	RICHARDSON	N-4/N-105	3	No	Yes	200	200
FRT12_13	FRT12	KEARNEY	US-6/34/N-44	4	Yes	Yes	800	600
	FRT13	KEARNEY	US-6/34/N-44	4	Yes	Yes	400	300
FRT14	FRT14	SALINE	US-6/N-33	3	No	Yes	1300	N/A
FRT15	FRT15	JEFFERSON	N-8/N-15	3	Yes	No	500	400
FRT16	FRT16	PAWNEE	N-8/N-99	4	No	No	100	250
FRT17	FRT17	CUMING	N-9/US-275	3	No	Yes	600	N/A
FRT18	FRT18	THURSTON	N-9/N-16	3	Yes	Yes	350	450
FRT19	FRT19	LINE	N-9/N-35	4	No	Yes	300	300
FRT20	FRT20	DIXON	N-9/N-35	4	No	Yes	1200	650
FRT21	FRT21	SHERMAN	N-10/L-82A	4	No	Yes	300	150
FRT22	FRT22	CEDAR	N-12/N-57	4	No	No	2000	1150
FRT23	FRT23	BOONE	N-14/N-39	3	Yes	No	850	1250
FRT24	FRT24	SALINE	N-14/N-41	4	No	No	300	250
FRT25	FRT25	BUTLER	N-15/N-92	4	No	Yes	200	150
FRT26	FRT26	BUTLER	N-15/N-64	3	Yes	Yes	1500	1100
FRT27	FRT27	STANTON	N-15/US-275	3	No	Yes	200	250
FRT28	FRT28	CEDAR	N-15/US-20	3	Yes	Yes	1150	N/A
FRT29	FRT29	CEDAR	N-15/N-59	4	No	No	1400	1150
FRT30	FRT30	DAWES	US-20/N-71	3	No	Yes	500	350
FRT31	FRT31	HOLT	US-20/US-281	4	No	Yes	150	200
FRT32	FRT32	HOLT	US-20/US-275	4	Yes	Yes	950	1700
FRT33_34	FRT33	PIERCE	US-20/US-81	4	No	Yes	750	600
	FRT34	PIERCE	US-20/US-81	4	No	Yes	200	200
FRT35	FRT35	NANCE	N-22/N-39	4	No	Yes	600	500
FRT36	FRT36	PERKINS	N-23/N-61	4	No	Yes	950	550
FRT37	FRT37	FRONTIER	N-23/US-83	4	Yes	Yes	150	100
FRT38_39	FRT38	HITCHCOCK	N-25/US-34	4	Yes	Yes	250	150
	FRT39	HITCHCOCK	N-25/US-34	4	Yes	Yes	250	250
FRT40	FRT40	MORRILL	US-26/L-62A	3	Yes	Yes	500	900

Table A2. FRT Intersection Basic Characteristics (2 of 2)

Note 1: items shaded in gray indicate two ramps of the same intersection

Note 2: FRT ramp 'FRT11' was removed, so although the last ramp is 'FRT80' there are 79 total ramps

Note 3: if an FRT radius is indicated as 'N/A' the ramp is a straight segment

Note 4: FRT length and FRT radius are rounded to the nearest 50 ft

SITE_ID	FRT_ID	COUNTY	INTERSECTION	LEGS	SKEW	LIGHT	FRT LENGTH (ft)	FRT RADIUS (ft)
FRT41	FRT41	MORRILL	US-26/N-92	3	No	Yes	200	200
FRT42	FRT42	CUMING	N-32/US-275	3	No	Yes	200	150
FRT43	FRT43	DUNDY	US-34/N-61	3	No	Yes	700	450
FRT44	FRT44	LANCASTER	US-34/S-55M	3	Yes	No	350	950
FRT45_46	FRT45	CASS	US-34/US-75	4	No	Yes	600	550
	FRT46	CASS	US-34/US-75	4	No	Yes	400	350
FRT47	FRT47	WAYNE	N-16/N-35	4	No	Yes	500	400
FRT48	FRT48	DOUGLAS	RD	3	No	Yes	250	200
FRT49	FRT49	BOONE	N-39/N-56	3	Yes	Yes	700	1000
FRT50	FRT50	FILLMORE	N-41/S-30H	4	No	Yes	200	200
FRT51	FRT51	FURNAS	N-46/N-89	3	No	Yes	600	950
FRT52	FRT52	CEDAR	N-57/N-59	4	No	No	1400	1200
FRT53_54	FRT53	KEITH	N-61/N SPRUCE ST	4	No	Yes	1350	1100
	FRT54	KEITH	N-61/N SPRUCE ST	4	No	Yes	1350	1200
FRT55	FRT55	SAUNDERS	N-64/S-78J	3	No	No	650	450
FRT56	FRT56	PAWNEE	N-65/S-67C	4	No	No	300	250
FRT57	FRT57	KIMBALL	N-71/OLD N-71	3	No	Yes	1450	1150
FRT58_59	FRT58	RICHARDSON	US-73/US-75	4	Yes	Yes	1400	1900
	FRT59	RICHARDSON	US-73/US-75	4	Yes	Yes	500	350
FRT60	FRT60	ADAMS	N-74/US-281	3	Yes	Yes	550	N/A
FRT61	FRT61	ADAMS	N-74/US-281	4	No	No	550	500
FRT62	FRT62	GAGE	US-77/W LOCUST RD	4	No	No	400	300
FRT63_64	FRT63	SAUNDERS	US-77/N-92	4	No	Yes	950	800
	FRT64	SAUNDERS	US-77/N-92	4	No	Yes	900	650
FRT65	FRT65	SAUNDERS	US-77N-109	3	Yes	Yes	400	300
FRT66	FRT66	SAUNDERS	AVE	3	No	Yes	400	400
FRT67_68	FRT67	POLK	US-81/N-92	4	No	Yes	850	700
	FRT68	POLK	US-81/N-92	4	No	Yes	850	700
FRT69_70	FRT69	POLK	US-81/N-92	4	No	Yes	1100	700
	FRT70	POLK	US-81/N-92	4	No	Yes	950	700
FRT71_72	FRT71	DODGE	N-91/US-275	3	Yes	Yes	350	250
	FRT72	DODGE	N-91/US-275	3	Yes	Yes	250	250
FRT73	FRT73	MADISON	N-121/US-275	4	No	Yes	350	50
FRT74	FRT74	HARLAN	N-89/US-136	4	Yes	Yes	250	500
FRT75	FRT75	GAGE	ROAD	3	Yes	Yes	750	1800
FRT76	FRT76	DOUGLAS	N-92/US-275	4	Yes	Yes	1100	550
FRT77	FRT77	MORRILL	N-92/US-385	3	Yes	Yes	850	750
FRT78	FRT78	MORRILL	US-385/L-62A	3	No	Yes	450	300
FRT79	FRT79	BUFFALO	L-10D/9TH ST	4	No	No	1000	800
FRT80	FRT80	CLAY	S-18A	4	No	No	550	450

Table A3. FRT Intersections and Ramps by County (1 of 2)

County	No. of FRT Ramp Intersections	No. of FRT Ramps
Adams	2	2
Boone	2	2
Box Butte	2	2
Buffalo	1	1
Butler	2	2
Cass	1	2
Cedar	4	4
Clay	1	1
Cuming	2	2
Custer	1	1
Dawes	1	1
Line	1	1
Dixon	1	1
Dodge	1	2
Douglas	2	2
Dundy	1	1
Fillmore	1	1
Frontier	1	1
Furnas	1	1
Gage	3	3
Hamilton	1	2
Harlan	1	1

Table A3. FRT Intersections and Ramps by County (2 of 2)

County	No. of FRT Ramp Intersections	No. of FRT Ramps
Hitchcock	1	2
Holt	2	2
Jefferson	1	1
Kearney	1	2
Keith	1	2
Kimball	1	1
Lancaster	1	1
Madison	1	1
Morrill	4	4
Nance	1	1
Pawnee	4	4
Perkins	1	1
Pierce	1	2
Polk	2	4
Richardson	2	3
Saline	2	2
Saunders	4	5
Sherman	1	1
Stanton	1	1
Thurston	1	1
Wayne	1	1
Webster	1	1
Total	**68**	**79**

Table A4. FRT Intersection AADT from 2010-2019 (1 of 2)

Site	2010 AADT	2011 AADT	2012 AADT	2013 AADT	2014 AADT	2015 AADT	2016 AADT	2017 AADT	2018 AADT	2019 AADT	AVERAGE 10 YR AADT
FRT1	3370	3348	3325	3510	3695	3745	3795	3755	3715	3945	3620
FRT2	6665	6628	6590	6925	7260	7213	7165	6858	6550	6523	6838
FRT3	5717	5736	5755	6072	6389	6955	7520	7107	6693	6334	6428
FRT4_5	12480	13100	13720	13500	13280	13425	13570	15373	17175	15960	14158
FRT6	3860	4103	4345	4278	4210	4158	4105	4280	4455	4680	4247
FRT7	5125	5075	5025	5260	5495	5498	5500	5480	5460	5555	5347
FRT8	2080	2075	2070	2003	1935	2020	2105	2163	2220	2390	2106
FRT9	3830	3828	3825	3763	3700	3945	4190	4059	3927	4002	3907
FRT10	4790	4698	4605	4800	4995	4863	4730	4645	4560	4725	4741
FRT12_13	12189	12327	12465	12331	12196	12241	12285	13087	13888	14612	12762
FRT14	8255	8805	9355	8953	8550	8863	9175	7968	6760	6860	8354
FRT15	4151	4088	4025	4325	4624	4547	4470	4580	4689	4441	4394
FRT16	1150	1060	970	1025	1080	1195	1310	1308	1305	1580	1198
FRT17	16625	16263	15900	16238	16575	17268	17960	18260	18560	16910	17056
FRT18	5110	5498	5885	6008	6130	6305	6480	6580	6680	6550	6123
FRT19	8255	8585	8915	9088	9260	9788	10315	10838	11360	9328	9573
FRT20	8090	8058	8025	8850	9675	9593	9510	10058	10605	9595	9206
FRT21	2295	2318	2340	2268	2195	2293	2390	2408	2425	2370	2330
FRT22	5481	5663	5845	5737	5628	5694	5760	5372	4984	4975	5514
FRT23	8115	8235	8355	7745	7135	7505	7875	8050	8225	7923	7916
FRT24	3457	3476	3495	3499	3503	3679	3855	3674	3493	3886	3602
FRT25	10827	10866	10905	10898	10890	11090	11290	11828	12366	12267	11323
FRT26	9420	9110	8800	8848	8895	9356	9818	9896	9975	9229	9335
FRT27	16085	15815	15545	15768	15990	16633	17275	17268	17260	16450	16409
FRT28	6780	6955	7130	6953	6775	7238	7700	8647	9593	9582	7735
FRT29	6040	6648	7255	7013	6770	7085	7400	7543	7685	6645	7008
FRT30	3020	3010	3000	3023	3045	3565	4085	4420	4755	4755	3668
FRT31	12355	11295	10235	10650	11065	12625	14185	15470	16755	15869	13050
FRT32	5298	5349	5400	5441	5482	5271	5060	5694	6328	5976	5530
FRT33_34	13390	13780	14170	14705	15240	14968	14695	14795	14895	13634	14427
FRT35	4350	4983	5615	5603	5590	5593	5595	5780	5965	5661	5473
FRT36	4983	5299	5615	5505	5394	5440	5485	5596	5706	5323	5434
FRT37	6175	6060	5945	6288	6630	6505	6380	6393	6405	6195	6298

Table A4. FRT Intersection AADT from 2010-2019 (2 of 2)

Site	2010 AADT	2011 AADT	2012 AADT	2013 AADT	2014 AADT	2015 AADT	2016 AADT	2017 AADT	2018 AADT	2019 AADT	AVERAGE 10 YR AADT
FRT38_39	5830	5848	5865	6305	6745	6085	5425	6433	7440	7090	6307
FRT40	8475	8708	8940	8888	8835	9915	10995	10510	10025	9405	9470
FRT41	8035	7823	7610	7680	7750	8370	8990	8435	7880	7275	7985
FRT42	18430	18310	18190	18470	18750	21425	24100	25575	27050	25195	21550
FRT43	3175	3393	3610	3578	3545	3558	3570	3473	3375	3718	3499
FRT44	12545	13123	13700	13285	12870	12095	11320	12603	13885	13275	12870
FRT45_46	17465	16420	15375	16278	17180	14583	11985	11166	10347	10830	14163
FRT47	9580	9493	9405	9990	10575	10660	10745	11578	12411	11416	10585
FRT48	565	565	565	565	565	565	565	565	565	565	565
FRT49	4780	4760	4740	4643	4545	4790	5035	5129	5223	4902	4855
FRT50	2605	2438	2270	2180	2090	2235	2380	2525	2670	2885	2428
FRT51	2175	2073	1970	1973	1975	2175	2375	1923	1470	1520	1963
FRT52	2645	2735	2825	2985	3145	3390	3635	3565	3495	3450	3187
FRT53_54	7945	7918	7890	7615	7340	6443	5545	5130	4714	4815	6535
FRT55	2725	2663	2600	2810	3020	3380	3740	4143	4545	4503	3413
FRT56	585	573	560	623	685	738	790	588	385	365	589
FRT57	5480	5913	6345	6260	6175	6208	6240	6615	6989	7052	6328
FRT58_59	7663	7732	7800	7855	7909	8287	8665	8867	9068	8615	8246
FRT60	5770	6015	6260	6253	6245	6135	6025	6180	6335	6550	6177
FRT61	6525	6718	6910	6748	6585	6918	7250	7033	6815	6863	6836
FRT62	9780	9303	8825	9110	9395	9625	9855	10106	10357	9816	9617
FRT63_64	12322	12396	12470	12802	13133	15919	18705	20160	21614	21458	16098
FRT65	17060	17388	17715	17423	17130	17263	17395	18893	20390	18183	17884
FRT66	2845	2908	2970	3078	3185	3188	3190	3230	3270	3133	3100
FRT67_68	8865	9565	10265	10430	10595	11065	11535	11438	11340	11275	10637
FRT69_70	12530	12650	12770	13175	13580	14150	14720	15233	15745	15330	13988
FRT71_72	14730	15553	16375	16258	16140	16428	16715	17673	18630	17170	16567
FRT73	12866	13548	14230	14186	14142	14956	15770	15565	15360	14982	14560
FRT74	2660	2703	2745	2711	2676	2516	2355	2449	2543	2664	2602
FRT75	6635	6475	6315	6549	6782	6404	6025	6410	6794	6570	6496
FRT76	21385	22110	22835	21333	19830	20445	21060	22199	23338	22924	21746
FRT77	6405	6225	6045	6325	6605	6245	5885	5975	6065	5685	6146
FRT78	9020	9383	9745	9350	8954	9182	9410	9864	10317	9987	9521
FRT79	900	973	1045	958	870	870	870	913	955	965	932
FRT80	1045	1025	1005	950	895	950	1005	970	935	1003	978

APPENDIX B: NON-FRT INTERSECTION CHARACTERISTICS

Table B1. Non-FRT Comparison Intersection Basic Characteristics

SITE_ID	COUNTY	INTERSECTION	LEGS	SKEW	LIGHT
COMP1	BOX BUTTE	US-385/L-7E	4	No	Yes
COMP2	WEBSTER	N-4/US-281	3	No	Yes
COMP3	HOWARD	N-11/N-92	4	No	Yes
COMP4	HARLAN	N-4/US-183	4	No	Yes
COMP5	CLAY	US-6/N-14	4	No	Yes
COMP6	BUTLER	N-15/N-92	3	No	Yes
COMP7	NANCE	N-22/L-63A	3	No	Yes
COMP8	THURSTON	N-9/N-16	4	No	Yes
COMP9	NEMAHA	N-105/US-136	3	No	Yes
COMP10	CUSTER	N-2/US-183	3	Yes	Yes
COMP11	CUMING	N-51/US-275	3	No	Yes
COMP12	CEDAR	N-15/N-116	3	No	No
COMP13	CEDAR	N-12/US-81	4	No	Yes
COMP14	SAUNDERS	N-109/S-78H	3	No	Yes
COMP15	GAGE	N-41/N-43	3	No	Yes
COMP16	WASHINGTON	US-30/N-31	3	No	Yes
COMP17	SARPY	N-31/N-50	3	No	Yes
COMP18	JOHNSON	N-50/US-136	4	No	Yes
COMP19	CASS	N-1/US-34	4	No	Yes
COMP20	GAGE	N-4/N-136	3	No	Yes
COMP21	SAUNDERS	N-79/N-92	4	No	Yes
COMP22	NEMAHA	N-67/US-75	4	No	Yes
COMP23	CASS	US-34/N-50	4	No	Yes
COMP24	CASS	N-1/N-50	4	No	Yes

Table B2. Non-FRT Comparison Intersections by County

County	No. of Non-FRT Ramp Intersections
Box Butte	1
Butler	1
Cass	3
Cedar	2
Clay	1
Cuming	1
Custer	1
Gage	2
Harlan	1
Howard	1
Johnson	1
Nance	1
Nemaha	2
Sarpy	1
Saunders	2
Thurston	1
Washington	1
Webster	1
Total	**24**

Table B3. Non-FRT Intersection AADT from 2010-2019

Site	2010 AADT	2011 AADT	2012 AADT	2013 AADT	2014 AADT	2015 AADT	2016 AADT	2017 AADT	2018 AADT	2019 AADT	AVERAGE 10 YR AADT
COMP1	5360	5158	4955	5078	5200	4715	4230	4595	4960	4834	4908
COMP2	4316	4456	4595	4318	4040	4093	4145	4566	4986	5016	4453
COMP3	6610	6633	6655	6850	7045	7070	7095	7346	7596	7351	7025
COMP4	7180	7350	7520	7893	8265	8393	8520	8725	8930	8948	8172
COMP5	8255	8288	8320	7322	6324	7310	8295	8793	9290	9210	8141
COMP6	12705	12625	12545	12703	12860	13458	14055	13973	13891	13716	13253
COMP7	7385	7808	8230	8193	8155	7773	7390	7950	8510	8068	7946
COMP8	4905	5060	5215	5315	5415	6148	6880	6937	6994	6507	5938
COMP9	4765	4780	4795	4833	4870	5728	6585	5870	5155	5180	5256
COMP10	6730	6660	6590	6963	7335	6908	6480	6910	7340	7200	6912
COMP11	14640	14058	13475	13710	13945	13613	13280	13613	13945	13450	13773
COMP12	5090	5125	5160	5108	5055	5230	5405	5363	5320	5175	5203
COMP13	12580	13008	13435	13713	13990	13630	13270	12963	12655	13195	13244
COMP14	7455	7650	7845	7868	7890	7858	7825	7793	7760	7195	7714
COMP15	6385	6323	6260	6010	5760	6810	7860	7740	7620	7295	6806
COMP16	11640	12120	12600	12850	13100	13855	14610	13941	13272	12683	13067
COMP17	18425	18908	19390	19665	19940	20001	20063	20124	20185	20163	19686
COMP18	9252	9576	9900	10389	10878	12104	13329	14555	15780	15378	12114
COMP19	17465	16420	15375	16278	17180	17385	17590	18608	19625	18005	17393
COMP20	4739	4382	4025	3984	3943	4509	5075	5212	5349	5078	4630
COMP21	7370	7660	7950	8095	8240	8520	8800	9328	9855	9283	8510
COMP22	12675	12395	12115	12635	13155	13355	13555	13755	13955	13938	13153
COMP23	11795	11458	11120	11123	11125	11986	12848	13709	14570	13920	12365
COMP24	11520	10928	10335	11253	12170	13140	14110	13853	13595	13303	12421

APPENDIX C: CRASH DATA

Table C1. FRT Intersection Crashes by Year from 2010-2019

CRASH BY YEAR	
Year	No. of Crashes
2010	96
2011	92
2012	77
2013	83
2014	87
2015	82
2016	77
2017	67
2018	90
2019	91
Total	**842**

Table C2. Non-FRT Intersection Crashes by Year from 2010-2019

CRASH BY YEAR	
Year	No. of Crashes
2010	28
2011	24
2012	26
2013	21
2014	24
2015	37
2016	23
2017	33
2018	41
2019	40
Total	**297**

Table C3. FRT Intersection Crashes by Site (1 of 2)

CRASH BY SITE	
Site	No. of Crashes
FRT1	25
FRT2	7
FRT3	11
FRT4_5	34
FRT6	8
FRT7	10
FRT8	7
FRT9	18
FRT10	5
FRT11	0
FRT12_13	16
FRT14	7
FRT15	11
FRT16	1
FRT17	34
FRT18	5
FRT19	12
FRT20	14
FRT21	1
FRT22	7
FRT23	10
FRT24	18
FRT25	12
FRT26	7
FRT27	21
FRT28	7
FRT29	6
FRT30	7
FRT31	34
FRT32	11
FRT33_34	15
FRT35	5
FRT36	3
FRT37	11

Table C3. FRT Intersection Crashes by Site (2 of 2)

CRASH BY SITE	
Site	No. of Crashes
FRT38_39	14
FRT40	7
FRT41	13
FRT42	63
FRT43	3
FRT44	6
FRT45_46	15
FRT47	17
FRT48	18
FRT49	7
FRT50	4
FRT51	3
FRT52	1
FRT53_54	6
FRT55	3
FRT56	0
FRT57	7
FRT58_59	8
FRT60	7
FRT61	2
FRT62	18
FRT63_64	21
FRT65	42
FRT66	10
FRT67_68	9
FRT69_70	28
FRT71_72	27
FRT73	15
FRT74	7
FRT75	3
FRT76	27
FRT77	8
FRT78	18
FRT79	2
FRT80	3
Total	**842**

Table C4. Non-FRT Intersection Crashes by Site

CRASH BY SITE	
Site	No. of Crashes
COMP1	6
COMP2	6
COMP3	9
COMP4	15
COMP5	13
COMP6	20
COMP7	8
COMP8	7
COMP9	5
COMP10	5
COMP11	6
COMP12	2
COMP13	13
COMP14	19
COMP15	9
COMP16	25
COMP17	26
COMP18	17
COMP19	28
COMP20	8
COMP21	3
COMP22	6
COMP23	31
COMP24	10
Total	**297**

Table C5. FRT Intersection Crash Rates by Year (2010)

Site	2010 Crash	2010 AADT	2010 Crash Rate
FRT1	6	3370	4.878
FRT2	2	6665	0.822
FRT3	0	5717	0.000
FRT4_5	5	12480	1.098
FRT6	2	3860	1.420
FRT7	0	5125	0.000
FRT8	1	2080	1.317
FRT9	2	3830	1.431
FRT10	1	4790	0.572
FRT12_13	2	12189	0.450
FRT14	2	8255	0.664
FRT15	0	4151	0.000
FRT16	0	1150	0.000
FRT17	3	16625	0.494
FRT18	0	5110	0.000
FRT19	3	8255	0.996
FRT20	1	8090	0.339
FRT21	0	2295	0.000
FRT22	0	5481	0.000
FRT23	1	8115	0.338
FRT24	3	3457	2.378
FRT25	3	10827	0.759
FRT26	1	9420	0.291
FRT27	3	16085	0.511
FRT28	0	6780	0.000
FRT29	2	6040	0.907
FRT30	0	3020	0.000
FRT31	4	12355	0.887
FRT32	1	5298	0.517
FRT33_34	1	13390	0.205
FRT35	0	4350	0.000
FRT36	1	4983	0.550
FRT37	0	6175	0.000
FRT38_39	0	5830	0.000
FRT40	0	8475	0.000
FRT41	1	8035	0.341
FRT42	6	18430	0.892
FRT43	1	3175	0.863
FRT44	1	12545	0.218
FRT45_46	5	17465	0.784
FRT47	1	9580	0.286
FRT48	0	565	0.000
FRT49	1	4780	0.573
FRT50	0	2605	0.000
FRT51	0	2175	0.000
FRT52	0	2645	0.000
FRT53_54	1	7945	0.345
FRT55	1	2725	1.005
FRT56	0	585	0.000
FRT57	0	5480	0.000
FRT58_59	1	7663	0.358
FRT60	1	5770	0.475
FRT61	0	6525	0.000
FRT62	3	9780	0.840
FRT63_64	1	12322	0.222
FRT65	4	17060	0.642
FRT66	1	2845	0.963
FRT67_68	1	8865	0.309
FRT69_70	5	12530	1.093
FRT71_72	2	14730	0.372
FRT73	3	12866	0.639
FRT74	1	2660	1.030
FRT75	0	6635	0.000
FRT76	3	21385	0.384
FRT77	0	6405	0.000
FRT78	2	9020	0.607
FRT79	0	900	0.000
FRT80	0	1045	0.000
Total	96	501859	0.524

Table C6. FRT Intersection Crash Rates by Year (2011)

Site	2011 Crash	2011 AADT	2011 Crash Rate
FRT1	2	3348	1.637
FRT2	0	6628	0.000
FRT3	2	5736	0.955
FRT4_5	7	13100	1.464
FRT6	0	4103	0.000
FRT7	1	5075	0.540
FRT8	1	2075	1.320
FRT9	1	3828	0.716
FRT10	0	4698	0.000
FRT12_13	6	12327	1.334
FRT14	0	8805	0.000
FRT15	2	4088	1.340
FRT16	1	1060	2.585
FRT17	5	16263	0.842
FRT18	0	5498	0.000
FRT19	2	8585	0.638
FRT20	1	8058	0.340
FRT21	0	2318	0.000
FRT22	0	5663	0.000
FRT23	2	8235	0.665
FRT24	0	3476	0.000
FRT25	0	10866	0.000
FRT26	0	9110	0.000
FRT27	2	15815	0.346
FRT28	0	6955	0.000
FRT29	1	6648	0.412
FRT30	0	3010	0.000
FRT31	3	11295	0.728
FRT32	0	5349	0.000
FRT33_34	3	13780	0.596
FRT35	1	4983	0.550
FRT36	0	5299	0.000
FRT37	1	6060	0.452
FRT38_39	2	5848	0.937
FRT40	0	8708	0.000
FRT41	2	7823	0.700
FRT42	8	18310	1.197
FRT43	0	3393	0.000
FRT44	0	13123	0.000
FRT45_46	2	16420	0.334
FRT47	0	9493	0.000
FRT48	5	565	24.245
FRT49	1	4760	0.576
FRT50	0	2438	0.000
FRT51	0	2073	0.000
FRT52	0	2735	0.000
FRT53_54	0	7918	0.000
FRT55	0	2663	0.000
FRT56	0	573	0.000
FRT57	0	5913	0.000
FRT58_59	1	7732	0.354
FRT60	1	6015	0.455
FRT61	0	6718	0.000
FRT62	0	9303	0.000
FRT63_64	6	12396	1.326
FRT65	6	17388	0.945
FRT66	0	2908	0.000
FRT67_68	2	9565	0.573
FRT69_70	3	12650	0.650
FRT71_72	3	15553	0.528
FRT73	1	13548	0.202
FRT74	1	2703	1.014
FRT75	0	6475	0.000
FRT76	2	22110	0.248
FRT77	0	6225	0.000
FRT78	1	9383	0.292
FRT79	1	973	2.817
FRT80	0	1025	0.000
Total	92	507547	0.497

Table C7. FRT Intersection Crash Rates by Year (2012)

Site	2012 Crash	2012 AADT	2012 Crash Rate
FRT1	3	3325	2.472
FRT2	0	6590	0.000
FRT3	0	5755	0.000
FRT4_5	1	13720	0.200
FRT6	1	4345	0.631
FRT7	0	5025	0.000
FRT8	0	2070	0.000
FRT9	6	3825	4.298
FRT10	0	4605	0.000
FRT12_13	2	12465	0.440
FRT14	0	9355	0.000
FRT15	1	4025	0.681
FRT16	0	970	0.000
FRT17	3	15900	0.517
FRT18	0	5885	0.000
FRT19	1	8915	0.307
FRT20	1	8025	0.341
FRT21	1	2340	1.171
FRT22	0	5845	0.000
FRT23	1	8355	0.328
FRT24	3	3495	2.352
FRT25	1	10905	0.251
FRT26	0	8800	0.000
FRT27	1	15545	0.176
FRT28	0	7130	0.000
FRT29	0	7255	0.000
FRT30	0	3000	0.000
FRT31	5	10235	1.338
FRT32	2	5400	1.015
FRT33_34	0	14170	0.000
FRT35	1	5615	0.488
FRT36	1	5615	0.488
FRT37	2	5945	0.922
FRT38_39	3	5865	1.401
FRT40	0	8940	0.000
FRT41	1	7610	0.360
FRT42	3	18190	0.452
FRT43	0	3610	0.000
FRT44	1	13700	0.200
FRT45_46	2	15375	0.356
FRT47	3	9405	0.874
FRT48	3	565	14.547
FRT49	0	4740	0.000
FRT50	0	2270	0.000
FRT51	0	1970	0.000
FRT52	0	2825	0.000
FRT53_54	2	7890	0.694
FRT55	0	2600	0.000
FRT56	0	560	0.000
FRT57	2	6345	0.864
FRT58_59	1	7800	0.351
FRT60	0	6260	0.000
FRT61	0	6910	0.000
FRT62	3	8825	0.931
FRT63_64	1	12470	0.220
FRT65	3	17715	0.464
FRT66	0	2970	0.000
FRT67_68	2	10265	0.534
FRT69_70	1	12770	0.215
FRT71_72	4	16375	0.669
FRT73	0	14230	0.000
FRT74	1	2745	0.998
FRT75	0	6315	0.000
FRT76	0	22835	0.000
FRT77	2	6045	0.906
FRT78	2	9745	0.562
FRT79	0	1045	0.000
FRT80	0	1005	0.000
Total	77	513235	0.411

Table C8. FRT Intersection Crash Rates by Year (2013)

Site	2013 Crash	2013 AADT	2013 Crash Rate
FRT1	0	3510	0.000
FRT2	0	6925	0.000
FRT3	1	6072	0.451
FRT4_5	6	13500	1.218
FRT6	1	4278	0.640
FRT7	2	5260	1.042
FRT8	0	2003	0.000
FRT9	1	3763	0.728
FRT10	0	4800	0.000
FRT12_13	0	12331	0.000
FRT14	0	8953	0.000
FRT15	1	4325	0.634
FRT16	0	1025	0.000
FRT17	2	16238	0.337
FRT18	0	6008	0.000
FRT19	0	9088	0.000
FRT20	2	8850	0.619
FRT21	0	2268	0.000
FRT22	1	5737	0.478
FRT23	1	7745	0.354
FRT24	1	3499	0.783
FRT25	0	10898	0.000
FRT26	0	8848	0.000
FRT27	3	15768	0.521
FRT28	0	6953	0.000
FRT29	0	7013	0.000
FRT30	1	3023	0.906
FRT31	4	10650	1.029
FRT32	1	5441	0.504
FRT33_34	1	14705	0.186
FRT35	0	5603	0.000
FRT36	0	5505	0.000
FRT37	1	6288	0.436
FRT38_39	2	6305	0.869
FRT40	0	8888	0.000
FRT41	2	7680	0.713
FRT42	10	18470	1.483
FRT43	0	3578	0.000
FRT44	1	13285	0.206
FRT45_46	1	16278	0.168
FRT47	1	9990	0.274
FRT48	3	565	14.547
FRT49	0	4643	0.000
FRT50	0	2180	0.000
FRT51	1	1973	1.389
FRT52	1	2985	0.918
FRT53_54	0	7615	0.000
FRT55	0	2810	0.000
FRT56	0	623	0.000
FRT57	1	6260	0.438
FRT58_59	1	7855	0.349
FRT60	0	6253	0.000
FRT61	0	6748	0.000
FRT62	1	9110	0.301
FRT63_64	4	12802	0.856
FRT65	3	17423	0.472
FRT66	2	3078	1.780
FRT67_68	0	10430	0.000
FRT69_70	2	13175	0.416
FRT71_72	6	16258	1.011
FRT73	2	14186	0.386
FRT74	0	2711	0.000
FRT75	1	6549	0.418
FRT76	4	21333	0.514
FRT77	0	6325	0.000
FRT78	2	9350	0.586
FRT79	0	958	0.000
FRT80	2	950	5.768
Total	83	516476	0.440

Table C9. FRT Intersection Crash Rates by Year (2014)

Site	2014 Crash	2014 AADT	2014 Crash Rate
FRT1	4	3695	2.966
FRT2	2	7260	0.755
FRT3	2	6389	0.858
FRT4_5	2	13280	0.413
FRT6	0	4210	0.000
FRT7	0	5495	0.000
FRT8	0	1935	0.000
FRT9	3	3700	2.221
FRT10	1	4995	0.548
FRT12_13	0	12196	0.000
FRT14	2	8550	0.641
FRT15	2	4624	1.185
FRT16	0	1080	0.000
FRT17	2	16575	0.331
FRT18	1	6130	0.447
FRT19	1	9260	0.296
FRT20	2	9675	0.566
FRT21	0	2195	0.000
FRT22	0	5628	0.000
FRT23	0	7135	0.000
FRT24	3	3503	2.346
FRT25	3	10890	0.755
FRT26	1	8895	0.308
FRT27	2	15990	0.343
FRT28	3	6775	1.213
FRT29	1	6770	0.405
FRT30	2	3045	1.799
FRT31	3	11065	0.743
FRT32	1	5482	0.500
FRT33_34	3	15240	0.539
FRT35	1	5590	0.490
FRT36	0	5394	0.000
FRT37	3	6630	1.240
FRT38_39	0	6745	0.000
FRT40	1	8835	0.310
FRT41	1	7750	0.354
FRT42	3	18750	0.438
FRT43	0	3545	0.000
FRT44	0	12870	0.000
FRT45_46	1	17180	0.159
FRT47	1	10575	0.259
FRT48	0	565	0.000
FRT49	1	4545	0.603
FRT50	0	2090	0.000
FRT51	0	1975	0.000
FRT52	0	3145	0.000
FRT53_54	1	7340	0.373
FRT55	0	3020	0.000
FRT56	0	685	0.000
FRT57	2	6175	0.887
FRT58_59	0	7909	0.000
FRT60	1	6245	0.439
FRT61	0	6585	0.000
FRT62	1	9395	0.292
FRT63_64	1	13133	0.209
FRT65	4	17130	0.640
FRT66	2	3185	1.720
FRT67_68	0	10595	0.000
FRT69_70	3	13580	0.605
FRT71_72	1	16140	0.170
FRT73	2	14142	0.387
FRT74	0	2676	0.000
FRT75	0	6782	0.000
FRT76	8	19830	1.105
FRT77	0	6605	0.000
FRT78	3	8954	0.918
FRT79	0	870	0.000
FRT80	0	895	0.000
Total	87	519717	0.459

Table C10. FRT Intersection Crash Rates by Year (2015)

Site	2015 Crash	2015 AADT	2015 Crash Rate
FRT1	0	3745	0.000
FRT2	0	7213	0.000
FRT3	3	6955	1.182
FRT4_5	4	13425	0.816
FRT6	0	4158	0.000
FRT7	4	5498	1.993
FRT8	1	2020	1.356
FRT9	1	3945	0.694
FRT10	1	4863	0.563
FRT12_13	2	12241	0.448
FRT14	0	8863	0.000
FRT15	1	4547	0.603
FRT16	0	1195	0.000
FRT17	0	17268	0.000
FRT18	1	6305	0.435
FRT19	2	9788	0.560
FRT20	0	9593	0.000
FRT21	0	2293	0.000
FRT22	0	5694	0.000
FRT23	0	7505	0.000
FRT24	3	3679	2.234
FRT25	1	11090	0.247
FRT26	1	9356	0.293
FRT27	4	16633	0.659
FRT28	0	7238	0.000
FRT29	0	7085	0.000
FRT30	2	3565	1.537
FRT31	6	12625	1.302
FRT32	1	5271	0.520
FRT33_34	2	14968	0.366
FRT35	0	5593	0.000
FRT36	0	5440	0.000
FRT37	2	6505	0.842
FRT38_39	0	6085	0.000
FRT40	1	9915	0.276
FRT41	1	8370	0.327
FRT42	6	21425	0.767
FRT43	0	3558	0.000
FRT44	1	12095	0.227
FRT45_46	0	14583	0.000
FRT47	0	10660	0.000
FRT48	1	565	4.849
FRT49	1	4790	0.572
FRT50	1	2235	1.226
FRT51	0	2175	0.000
FRT52	0	3390	0.000
FRT53_54	0	6443	0.000
FRT55	0	3380	0.000
FRT56	0	738	0.000
FRT57	0	6208	0.000
FRT58_59	0	8287	0.000
FRT60	0	6135	0.000
FRT61	1	6918	0.396
FRT62	2	9625	0.569
FRT63_64	2	15919	0.344
FRT65	3	17263	0.476
FRT66	1	3188	0.860
FRT67_68	3	11065	0.743
FRT69_70	5	14150	0.968
FRT71_72	3	16428	0.500
FRT73	1	14956	0.183
FRT74	0	2516	0.000
FRT75	1	6404	0.428
FRT76	1	20445	0.134
FRT77	2	6245	0.877
FRT78	2	9182	0.597
FRT79	0	870	0.000
FRT80	1	950	2.884
Total	82	533310	0.421

Table C11. FRT Intersection Crash Rates by Year (2016)

Site	2016 Crash	2016 AADT	2016 Crash Rate
FRT1	2	3795	1.444
FRT2	2	7165	0.765
FRT3	1	7520	0.364
FRT4_5	3	13570	0.606
FRT6	0	4105	0.000
FRT7	0	5500	0.000
FRT8	0	2105	0.000
FRT9	1	4190	0.654
FRT10	1	4730	0.579
FRT12_13	1	12285	0.223
FRT14	0	9175	0.000
FRT15	3	4470	1.839
FRT16	0	1310	0.000
FRT17	8	17960	1.220
FRT18	0	6480	0.000
FRT19	0	10315	0.000
FRT20	2	9510	0.576
FRT21	0	2390	0.000
FRT22	1	5760	0.476
FRT23	2	7875	0.696
FRT24	1	3855	0.711
FRT25	0	11290	0.000
FRT26	0	9818	0.000
FRT27	3	17275	0.476
FRT28	0	7700	0.000
FRT29	0	7400	0.000
FRT30	0	4085	0.000
FRT31	3	14185	0.579
FRT32	0	5060	0.000
FRT33_34	0	14695	0.000
FRT35	1	5595	0.490
FRT36	0	5485	0.000
FRT37	1	6380	0.429
FRT38_39	0	5425	0.000
FRT40	1	10995	0.249
FRT41	2	8990	0.610
FRT42	9	24100	1.023
FRT43	2	3570	1.535
FRT44	0	11320	0.000
FRT45_46	0	11985	0.000
FRT47	1	10745	0.255
FRT48	1	565	4.849
FRT49	1	5035	0.544
FRT50	1	2380	1.151
FRT51	0	2375	0.000
FRT52	0	3635	0.000
FRT53_54	1	5545	0.494
FRT55	0	3740	0.000
FRT56	0	790	0.000
FRT57	1	6240	0.439
FRT58_59	3	8665	0.949
FRT60	0	6025	0.000
FRT61	0	7250	0.000
FRT62	1	9855	0.278
FRT63_64	4	18705	0.586
FRT65	5	17395	0.788
FRT66	1	3190	0.859
FRT67_68	1	11535	0.238
FRT69_70	0	14720	0.000
FRT71_72	0	16715	0.000
FRT73	1	15770	0.174
FRT74	1	2355	1.163
FRT75	0	6025	0.000
FRT76	3	21060	0.390
FRT77	1	5885	0.466
FRT78	0	9410	0.000
FRT79	0	870	0.000
FRT80	0	1005	0.000
Total	77	546903	0.386

Table C12. FRT Intersection Crash Rates by Year (2017)

Site	2017 Crash	2017 AADT	2017 Crash Rate
FRT1	5	3755	3.648
FRT2	0	6858	0.000
FRT3	1	7107	0.386
FRT4_5	2	15373	0.356
FRT6	0	4280	0.000
FRT7	2	5480	1.000
FRT8	1	2163	1.267
FRT9	0	4059	0.000
FRT10	0	4645	0.000
FRT12_13	0	13087	0.000
FRT14	0	7968	0.000
FRT15	0	4580	0.000
FRT16	0	1308	0.000
FRT17	3	18260	0.450
FRT18	1	6580	0.416
FRT19	0	10838	0.000
FRT20	3	10058	0.817
FRT21	0	2408	0.000
FRT22	0	5372	0.000
FRT23	0	8050	0.000
FRT24	2	3674	1.491
FRT25	2	11828	0.463
FRT26	3	9896	0.831
FRT27	1	17268	0.159
FRT28	1	8647	0.317
FRT29	1	7543	0.363
FRT30	0	4420	0.000
FRT31	2	15470	0.354
FRT32	1	5694	0.481
FRT33_34	1	14795	0.185
FRT35	0	5780	0.000
FRT36	0	5596	0.000
FRT37	0	6393	0.000
FRT38_39	1	6433	0.426
FRT40	0	10510	0.000
FRT41	0	8435	0.000
FRT42	4	25575	0.429
FRT43	0	3473	0.000
FRT44	0	12603	0.000
FRT45_46	1	11166	0.245
FRT47	4	11578	0.947
FRT48	2	565	9.698
FRT49	0	5129	0.000
FRT50	2	2525	2.170
FRT51	0	1923	0.000
FRT52	0	3565	0.000
FRT53_54	1	5130	0.534
FRT55	2	4143	1.323
FRT56	0	588	0.000
FRT57	0	6615	0.000
FRT58_59	0	8867	0.000
FRT60	2	6180	0.887
FRT61	0	7033	0.000
FRT62	2	10106	0.542
FRT63_64	0	20160	0.000
FRT65	0	18893	0.000
FRT66	1	3230	0.848
FRT67_68	0	11438	0.000
FRT69_70	6	15233	1.079
FRT71_72	2	17673	0.310
FRT73	0	15565	0.000
FRT74	2	2449	2.237
FRT75	0	6410	0.000
FRT76	0	22199	0.000
FRT77	0	5975	0.000
FRT78	3	9864	0.833
FRT79	0	913	0.000
FRT80	0	970	0.000
Total	67	562330	0.326

Table C13. FRT Intersection Crash Rates by Year (2018)

Site	2018 Crash	2018 AADT	2018 Crash Rate
FRT1	0	3715	0.000
FRT2	0	6550	0.000
FRT3	1	6693	0.409
FRT4_5	3	17175	0.479
FRT6	0	4455	0.000
FRT7	0	5460	0.000
FRT8	1	2220	1.234
FRT9	1	3927	0.698
FRT10	1	4560	0.601
FRT12_13	2	13888	0.395
FRT14	0	6760	0.000
FRT15	0	4689	0.000
FRT16	0	1305	0.000
FRT17	3	18560	0.443
FRT18	1	6680	0.410
FRT19	1	11360	0.241
FRT20	2	10605	0.517
FRT21	0	2425	0.000
FRT22	3	4984	1.649
FRT23	3	8225	0.999
FRT24	2	3493	1.569
FRT25	0	12366	0.000
FRT26	1	9975	0.275
FRT27	2	17260	0.317
FRT28	0	9593	0.000
FRT29	1	7685	0.357
FRT30	1	4755	0.576
FRT31	1	16755	0.164
FRT32	4	6328	1.732
FRT33_34	2	14895	0.368
FRT35	1	5965	0.459
FRT36	1	5706	0.480
FRT37	0	6405	0.000
FRT38_39	5	7440	1.841
FRT40	2	10025	0.547
FRT41	2	7880	0.695
FRT42	10	27050	1.013
FRT43	0	3375	0.000
FRT44	0	13885	0.000
FRT45_46	0	10347	0.000
FRT47	4	12411	0.883
FRT48	1	565	4.849
FRT49	1	5223	0.525
FRT50	0	2670	0.000
FRT51	2	1470	3.728
FRT52	0	3495	0.000
FRT53_54	0	4714	0.000
FRT55	0	4545	0.000
FRT56	0	385	0.000
FRT57	0	6989	0.000
FRT58_59	1	9068	0.302
FRT60	0	6335	0.000
FRT61	1	6815	0.402
FRT62	2	10357	0.529
FRT63_64	1	21614	0.127
FRT65	6	20390	0.806
FRT66	1	3270	0.838
FRT67_68	0	11340	0.000
FRT69_70	2	15745	0.348
FRT71_72	1	18630	0.147
FRT73	1	15360	0.178
FRT74	1	2543	1.077
FRT75	1	6794	0.403
FRT76	2	23338	0.235
FRT77	2	6065	0.903
FRT78	3	10317	0.797
FRT79	0	955	0.000
FRT80	0	935	0.000
Total	90	577757	0.427

Table C14. FRT Intersection Crash Rates by Year (2019)

Site	2019 Crash	2019 AADT	2019 Crash Rate
FRT1	3	3945	2.083
FRT2	1	6523	0.420
FRT3	0	6334	0.000
FRT4_5	1	15960	0.172
FRT6	4	4680	2.342
FRT7	1	5555	0.493
FRT8	2	2390	2.293
FRT9	2	4002	1.369
FRT10	0	4725	0.000
FRT12_13	1	14612	0.188
FRT14	3	6860	1.198
FRT15	1	4441	0.617
FRT16	0	1580	0.000
FRT17	5	16910	0.810
FRT18	1	6550	0.418
FRT19	2	9328	0.587
FRT20	0	9595	0.000
FRT21	0	2370	0.000
FRT22	2	4975	1.102
FRT23	0	7923	0.000
FRT24	0	3886	0.000
FRT25	2	12267	0.447
FRT26	0	9229	0.000
FRT27	0	16450	0.000
FRT28	3	9582	0.858
FRT29	0	6645	0.000
FRT30	1	4755	0.576
FRT31	3	15869	0.518
FRT32	0	5976	0.000
FRT33_34	2	13634	0.402
FRT35	0	5661	0.000
FRT36	0	5323	0.000
FRT37	1	6195	0.442
FRT38_39	1	7090	0.386
FRT40	2	9405	0.583
FRT41	1	7275	0.377
FRT42	4	25195	0.435
FRT43	0	3718	0.000
FRT44	2	13275	0.413
FRT45_46	3	10830	0.759
FRT47	2	11416	0.480
FRT48	2	565	9.698
FRT49	1	4902	0.559
FRT50	0	2885	0.000
FRT51	0	1520	0.000
FRT52	0	3450	0.000
FRT53_54	0	4815	0.000
FRT55	0	4503	0.000
FRT56	0	365	0.000
FRT57	1	7052	0.389
FRT58_59	0	8615	0.000
FRT60	2	6550	0.837
FRT61	0	6863	0.000
FRT62	3	9816	0.837
FRT63_64	1	21458	0.128
FRT65	8	18183	1.205
FRT66	1	3133	0.875
FRT67_68	0	11275	0.000
FRT69_70	1	15330	0.179
FRT71_72	5	17170	0.798
FRT73	4	14982	0.731
FRT74	0	2664	0.000
FRT75	0	6570	0.000
FRT76	4	22924	0.478
FRT77	1	5685	0.482
FRT78	0	9987	0.000
FRT79	1	965	2.839
FRT80	0	1003	0.000
Total	91	556153	0.448

Table C15. FRT Intersection Crash Rates by Year (Ten-Year Total)

Site	TOTAL CRASH	TOTAL AADT	TOTAL CRASH RATE
FRT1	25	36203	1.892
FRT2	7	68375	0.280
FRT3	11	64277	0.469
FRT4_5	34	141583	0.658
FRT6	8	42473	0.516
FRT7	10	53473	0.512
FRT8	7	21060	0.911
FRT9	18	39068	1.262
FRT10	5	47410	0.289
FRT12_13	16	127619	0.343
FRT14	7	83543	0.230
FRT15	11	43939	0.686
FRT16	1	11983	0.229
FRT17	34	170558	0.546
FRT18	5	61225	0.224
FRT19	12	95731	0.343
FRT20	14	92058	0.417
FRT21	1	23300	0.118
FRT22	7	55138	0.348
FRT23	10	79163	0.346
FRT24	18	36017	1.369
FRT25	12	113226	0.290
FRT26	7	93346	0.205
FRT27	21	164088	0.351
FRT28	7	77351	0.248
FRT29	6	70083	0.235
FRT30	7	36678	0.523
FRT31	34	130504	0.714
FRT32	11	55299	0.545
FRT33_34	15	144271	0.285
FRT35	5	54734	0.250
FRT36	3	54345	0.151
FRT37	11	62975	0.479
FRT38_39	14	63065	0.608
FRT40	7	94695	0.203
FRT41	13	79848	0.446
FRT42	63	215495	0.801
FRT43	3	34993	0.235
FRT44	6	128700	0.128
FRT45_46	15	141628	0.290
FRT47	17	105852	0.440
FRT48	18	5650	8.728
FRT49	7	48546	0.395
FRT50	4	24278	0.451
FRT51	3	19628	0.419
FRT52	1	31870	0.086
FRT53_54	6	65354	0.252
FRT55	3	34128	0.241
FRT56	0	5890	0.000
FRT57	7	63276	0.303
FRT58_59	8	82460	0.266
FRT60	7	61768	0.310
FRT61	2	68363	0.080
FRT62	18	96171	0.513
FRT63_64	21	160978	0.357
FRT65	42	178838	0.643
FRT66	10	30995	0.884
FRT67_68	9	106373	0.232
FRT69_70	28	139883	0.548
FRT71_72	27	165670	0.447
FRT73	15	145605	0.282
FRT74	7	26021	0.737
FRT75	3	64958	0.127
FRT76	27	217459	0.340
FRT77	8	61460	0.357
FRT78	18	95210	0.518
FRT79	2	9318	0.588
FRT80	3	9783	0.840
Total	842	5335286	0.432

Table C16. Non-FRT Intersection Crash Rates by Year (2010)

Site	2010 Crash	2010 AADT	2010 Crash Rate
COMP1	0	5360	0.000
COMP2	1	4316	0.635
COMP3	1	6610	0.414
COMP4	0	7180	0.000
COMP5	0	8255	0.000
COMP6	0	12705	0.000
COMP7	2	7385	0.742
COMP8	0	4905	0.000
COMP9	0	4765	0.000
COMP10	2	6730	0.814
COMP11	0	14640	0.000
COMP12	0	5090	0.000
COMP13	3	12580	0.653
COMP14	2	7455	0.735
COMP15	1	6385	0.429
COMP16	5	11640	1.177
COMP17	3	18425	0.446
COMP18	0	9252	0.000
COMP19	2	17465	0.314
COMP20	0	4739	0.000
COMP21	0	7370	0.000
COMP22	0	12675	0.000
COMP23	1	11795	0.232
COMP24	5	11520	1.189
Total	28	219242	0.350

Table C17. Non-FRT Intersection Crash Rates by Year (2011)

Site	2011 Crash	2011 AADT	2011 Crash Rate
COMP1	0	5158	0.000
COMP2	1	4456	0.615
COMP3	1	6633	0.413
COMP4	4	7350	1.491
COMP5	0	8288	0.000
COMP6	2	12625	0.434
COMP7	1	7808	0.351
COMP8	1	5060	0.541
COMP9	0	4780	0.000
COMP10	0	6660	0.000
COMP11	0	14058	0.000
COMP12	0	5125	0.000
COMP13	0	13008	0.000
COMP14	1	7650	0.358
COMP15	0	6323	0.000
COMP16	1	12120	0.226
COMP17	1	18908	0.145
COMP18	2	9576	0.572
COMP19	3	16420	0.501
COMP20	1	4382	0.625
COMP21	0	7660	0.000
COMP22	1	12395	0.221
COMP23	3	11458	0.717
COMP24	1	10928	0.251
Total	24	218824	0.300

Table C18. Non-FRT Intersection Crash Rates by Year (2012)

Site	2012 Crash	2012 AADT	2012 Crash Rate
COMP1	1	4955	0.553
COMP2	1	4595	0.596
COMP3	1	6655	0.412
COMP4	1	7520	0.364
COMP5	1	8320	0.329
COMP6	4	12545	0.874
COMP7	1	8230	0.333
COMP8	1	5215	0.525
COMP9	0	4795	0.000
COMP10	1	6590	0.416
COMP11	0	13475	0.000
COMP12	0	5160	0.000
COMP13	3	13435	0.612
COMP14	4	7845	1.397
COMP15	1	6260	0.438
COMP16	1	12600	0.217
COMP17	3	19390	0.424
COMP18	0	9900	0.000
COMP19	1	15375	0.178
COMP20	0	4025	0.000
COMP21	0	7950	0.000
COMP22	0	12115	0.000
COMP23	1	11120	0.246
COMP24	0	10335	0.000
Total	26	218405	0.326

Table C19. Non-FRT Intersection Crash Rates by Year (2013)

Site	2013 Crash	2013 AADT	2013 Crash Rate
COMP1	0	5078	0.000
COMP2	0	4318	0.000
COMP3	1	6850	0.400
COMP4	1	7893	0.347
COMP5	2	7322	0.748
COMP6	2	12703	0.431
COMP7	1	8193	0.334
COMP8	0	5315	0.000
COMP9	0	4833	0.000
COMP10	0	6963	0.000
COMP11	3	13710	0.600
COMP12	1	5108	0.536
COMP13	0	13713	0.000
COMP14	1	7868	0.348
COMP15	1	6010	0.456
COMP16	1	12850	0.213
COMP17	3	19665	0.418
COMP18	2	10389	0.527
COMP19	1	16278	0.168
COMP20	0	3984	0.000
COMP21	0	8095	0.000
COMP22	0	12635	0.000
COMP23	1	11123	0.246
COMP24	0	11253	0.000
Total	21	222143	0.259

Table C20. Non-FRT Intersection Crash Rates by Year (2014)

Site	2014 Crash	2014 AADT	2014 Crash Rate
COMP1	0	5200	0.000
COMP2	0	4040	0.000
COMP3	0	7045	0.000
COMP4	0	8265	0.000
COMP5	4	6324	1.733
COMP6	3	12860	0.639
COMP7	0	8155	0.000
COMP8	1	5415	0.506
COMP9	1	4870	0.563
COMP10	1	7335	0.374
COMP11	1	13945	0.196
COMP12	0	5055	0.000
COMP13	0	13990	0.000
COMP14	2	7890	0.694
COMP15	0	5760	0.000
COMP16	2	13100	0.418
COMP17	3	19940	0.412
COMP18	0	10878	0.000
COMP19	1	17180	0.159
COMP20	0	3943	0.000
COMP21	0	8240	0.000
COMP22	1	13155	0.208
COMP23	2	11125	0.493
COMP24	2	12170	0.450
Total	24	225880	0.291

Table C21. Non-FRT Intersection Crash Rates by Year (2015)

Site	2015 Crash	2015 AADT	2015 Crash Rate
COMP1	1	4715	0.581
COMP2	1	4093	0.669
COMP3	0	7070	0.000
COMP4	0	8393	0.000
COMP5	1	7310	0.375
COMP6	1	13458	0.204
COMP7	2	7773	0.705
COMP8	1	6148	0.446
COMP9	1	5728	0.478
COMP10	0	6908	0.000
COMP11	1	13613	0.201
COMP12	1	5230	0.524
COMP13	0	13630	0.000
COMP14	0	7858	0.000
COMP15	3	6810	1.207
COMP16	3	13855	0.593
COMP17	3	20001	0.411
COMP18	2	12104	0.453
COMP19	6	17385	0.946
COMP20	4	4509	2.430
COMP21	0	8520	0.000
COMP22	1	13355	0.205
COMP23	5	11986	1.143
COMP24	0	13140	0.000
Total	37	233587	0.434

Table C22. Non-FRT Intersection Crash Rates by Year (2016)

Site	2016 Crash	2016 AADT	2016 Crash Rate
COMP1	1	4230	0.648
COMP2	0	4145	0.000
COMP3	2	7095	0.772
COMP4	3	8520	0.965
COMP5	1	8295	0.330
COMP6	0	14055	0.000
COMP7	1	7390	0.371
COMP8	0	6880	0.000
COMP9	0	6585	0.000
COMP10	0	6480	0.000
COMP11	0	13280	0.000
COMP12	0	5405	0.000
COMP13	1	13270	0.206
COMP14	1	7825	0.350
COMP15	1	7860	0.349
COMP16	1	14610	0.188
COMP17	0	20063	0.000
COMP18	2	13329	0.411
COMP19	5	17590	0.779
COMP20	0	5075	0.000
COMP21	0	8800	0.000
COMP22	1	13555	0.202
COMP23	2	12848	0.426
COMP24	1	14110	0.194
Total	23	241294	0.261

Table C23. Non-FRT Intersection Crash Rates by Year (2017)

Site	2017 Crash	2017 AADT	2017 Crash Rate
COMP1	2	4595	1.192
COMP2	0	4566	0.000
COMP3	2	7346	0.746
COMP4	2	8725	0.628
COMP5	3	8793	0.935
COMP6	2	13973	0.392
COMP7	0	7950	0.000
COMP8	1	6937	0.395
COMP9	0	5870	0.000
COMP10	1	6910	0.396
COMP11	0	13613	0.000
COMP12	0	5363	0.000
COMP13	2	12963	0.423
COMP14	4	7793	1.406
COMP15	0	7740	0.000
COMP16	4	13941	0.786
COMP17	1	20124	0.136
COMP18	1	14555	0.188
COMP19	2	18608	0.294
COMP20	0	5212	0.000
COMP21	2	9328	0.587
COMP22	0	13755	0.000
COMP23	4	13709	0.799
COMP24	0	13853	0.000
Total	33	246216	0.367

Table C24. Non-FRT Intersection Crash Rates by Year (2018)

Site	2018 Crash	2018 AADT	2018 Crash Rate
COMP1	0	4960	0.000
COMP2	2	4986	1.099
COMP3	1	7596	0.361
COMP4	0	8930	0.000
COMP5	1	9290	0.295
COMP6	4	13891	0.789
COMP7	0	8510	0.000
COMP8	0	6994	0.000
COMP9	2	5155	1.063
COMP10	0	7340	0.000
COMP11	0	13945	0.000
COMP12	0	5320	0.000
COMP13	1	12655	0.216
COMP14	3	7760	1.059
COMP15	0	7620	0.000
COMP16	1	13272	0.206
COMP17	7	20185	0.950
COMP18	5	15780	0.868
COMP19	4	19625	0.558
COMP20	2	5349	1.024
COMP21	0	9855	0.000
COMP22	0	13955	0.000
COMP23	8	14570	1.504
COMP24	0	13595	0.000
Total	41	251138	0.447

Table C25. Non-FRT Intersection Crash Rates by Year (2019)

Site	2019 Crash	2019 AADT	2019 Crash Rate
COMP1	1	4834	0.567
COMP2	0	5016	0.000
COMP3	0	7351	0.000
COMP4	4	8948	1.225
COMP5	0	9210	0.000
COMP6	2	13716	0.400
COMP7	0	8068	0.000
COMP8	2	6507	0.842
COMP9	1	5180	0.529
COMP10	0	7200	0.000
COMP11	1	13450	0.204
COMP12	0	5175	0.000
COMP13	3	13195	0.623
COMP14	1	7195	0.381
COMP15	2	7295	0.751
COMP16	6	12683	1.296
COMP17	2	20163	0.272
COMP18	3	15378	0.534
COMP19	3	18005	0.456
COMP20	1	5078	0.540
COMP21	1	9283	0.295
COMP22	2	13938	0.393
COMP23	4	13920	0.787
COMP24	1	13303	0.206
Total	40	244085	0.449

Table C26. Non-FRT Intersection Crash Rates by Year (Ten-Year Total)

Site	TOTAL CRASH	TOTAL AADT	TOTAL CRASH RATE
COMP1	6	49084	0.335
COMP2	6	44529	0.369
COMP3	9	70250	0.351
COMP4	15	81723	0.503
COMP5	13	81406	0.438
COMP6	20	132530	0.413
COMP7	8	79460	0.276
COMP8	7	59376	0.323
COMP9	5	52560	0.261
COMP10	5	69115	0.198
COMP11	6	137728	0.119
COMP12	2	52030	0.105
COMP13	13	132438	0.269
COMP14	19	77138	0.675
COMP15	9	68063	0.362
COMP16	25	130671	0.524
COMP17	26	196863	0.362
COMP18	17	121140	0.384
COMP19	28	173930	0.441
COMP20	8	46296	0.473
COMP21	3	85100	0.097
COMP22	6	131533	0.125
COMP23	31	123653	0.687
COMP24	10	124205	0.221
Total	297	2320813	0.351

APPENDIX D: T-TEST RESULTS

Table D1. T Table

t Table

cum. prob	$t_{.50}$	$t_{.75}$	$t_{.80}$	$t_{.85}$	$t_{.90}$	$t_{.95}$	$t_{.975}$	$t_{.99}$	$t_{.995}$	$t_{.999}$	$t_{.9995}$
one-tail	0.50	0.25	0.20	0.15	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
two-tails	1.00	0.50	0.40	0.30	0.20	0.10	0.05	0.02	0.01	0.002	0.001
df											
1	0.000	1.000	1.376	1.963	3.078	6.314	12.71	31.82	63.66	318.31	636.62
2	0.000	0.816	1.061	1.386	1.886	2.920	4.303	6.965	9.925	22.327	31.599
3	0.000	0.765	0.978	1.250	1.638	2.353	3.182	4.541	5.841	10.215	12.924
4	0.000	0.741	0.941	1.190	1.533	2.132	2.776	3.747	4.604	7.173	8.610
5	0.000	0.727	0.920	1.156	1.476	2.015	2.571	3.365	4.032	5.893	6.869
6	0.000	0.718	0.906	1.134	1.440	1.943	2.447	3.143	3.707	5.208	5.959
7	0.000	0.711	0.896	1.119	1.415	1.895	2.365	2.998	3.499	4.785	5.408
8	0.000	0.706	0.889	1.108	1.397	1.860	2.306	2.896	3.355	4.501	5.041
9	0.000	0.703	0.883	1.100	1.383	1.833	2.262	2.821	3.250	4.297	4.781
10	0.000	0.700	0.879	1.093	1.372	1.812	2.228	2.764	3.169	4.144	4.587
11	0.000	0.697	0.876	1.088	1.363	1.796	2.201	2.718	3.106	4.025	4.437
12	0.000	0.695	0.873	1.083	1.356	1.782	2.179	2.681	3.055	3.930	4.318
13	0.000	0.694	0.870	1.079	1.350	1.771	2.160	2.650	3.012	3.852	4.221
14	0.000	0.692	0.868	1.076	1.345	1.761	2.145	2.624	2.977	3.787	4.140
15	0.000	0.691	0.866	1.074	1.341	1.753	2.131	2.602	2.947	3.733	4.073
16	0.000	0.690	0.865	1.071	1.337	1.746	2.120	2.583	2.921	3.686	4.015
17	0.000	0.689	0.863	1.069	1.333	1.740	2.110	2.567	2.898	3.646	3.965
18	0.000	0.688	0.862	1.067	1.330	1.734	2.101	2.552	2.878	3.610	3.922
19	0.000	0.688	0.861	1.066	1.328	1.729	2.093	2.539	2.861	3.579	3.883
20	0.000	0.687	0.860	1.064	1.325	1.725	2.086	2.528	2.845	3.552	3.850
21	0.000	0.686	0.859	1.063	1.323	1.721	2.080	2.518	2.831	3.527	3.819
22	0.000	0.686	0.858	1.061	1.321	1.717	2.074	2.508	2.819	3.505	3.792
23	0.000	0.685	0.858	1.060	1.319	1.714	2.069	2.500	2.807	3.485	3.768
24	0.000	0.685	0.857	1.059	1.318	1.711	2.064	2.492	2.797	3.467	3.745
25	0.000	0.684	0.856	1.058	1.316	1.708	2.060	2.485	2.787	3.450	3.725
26	0.000	0.684	0.856	1.058	1.315	1.706	2.056	2.479	2.779	3.435	3.707
27	0.000	0.684	0.855	1.057	1.314	1.703	2.052	2.473	2.771	3.421	3.690
28	0.000	0.683	0.855	1.056	1.313	1.701	2.048	2.467	2.763	3.408	3.674
29	0.000	0.683	0.854	1.055	1.311	1.699	2.045	2.462	2.756	3.396	3.659
30	0.000	0.683	0.854	1.055	1.310	1.697	2.042	2.457	2.750	3.385	3.646
40	0.000	0.681	0.851	1.050	1.303	1.684	2.021	2.423	2.704	3.307	3.551
60	0.000	0.679	0.848	1.045	1.296	1.671	2.000	2.390	2.660	3.232	3.460
80	0.000	0.678	0.846	1.043	1.292	1.664	1.990	2.374	2.639	3.195	3.416
100	0.000	0.677	0.845	1.042	1.290	1.660	1.984	2.364	2.626	3.174	3.390
1000	0.000	0.675	0.842	1.037	1.282	1.646	1.962	2.330	2.581	3.098	3.300
z	0.000	0.674	0.842	1.036	1.282	1.645	1.960	2.326	2.576	3.090	3.291
	0%	50%	60%	70%	80%	90%	95%	98%	99%	99.8%	99.9%
	Confidence Level										

Table D2. Crash Frequency Comparison (alpha = 0.10)

Comparison1	Comparison2	n1	n2	CrashFreq1	CrashFreq2	Critical F-Value	F-Statistic	Variance	df	T-Statistic	Critical T-Value (alpha = 0.05)	Significance?
Low AADT, 3-Leg FRT	Low AADT, 3-Leg Non-FRT	16	4	**0.856**	0.525	5.20	5.31	unequal	18	1.74	2.101	NO
Low AADT, 4-Leg FRT	Low AADT, 4-Leg Non-FRT	22	4	0.664	**0.925**	5.18	1.73	equal	24	0.93	2.064	NO
Low AADT, All Legs FRT	Low AADT, All Legs Non-FRT	38	8	**0.760**	0.725	2.56	2.14	equal	44	0.10	1.960	NO
Medium AADT, 3-Leg FRT	Medium AADT, 3-Leg Non-FRT	8	4	0.763	**1.025**	3.07	4.47	unequal	10	0.82	2.228	NO
Medium AADT, 4-Leg FRT	Medium AADT, 4-Leg Non-FRT	8	4	**1.413**	0.975	3.07	2.48	equal	10	1.98	2.228	NO
Medium AADT, All Legs FRT	Medium AADT, All Legs Non-FRT	16	8	**1.088**	1.000	2.16	1.32	equal	22	0.44	2.074	NO
High AADT, 3-Leg FRT	High AADT, 3-Leg Non-FRT	7	4	**3.014**	1.925	5.29	4.04	equal	9	1.08	2.262	NO
High AADT, 4-Leg FRT	High AADT, 4-Leg Non-FRT	7	4	**2.486**	2.050	3.29	1.99	equal	9	0.75	2.262	NO
High AADT, All Legs FRT	High AADT, All Legs Non-FRT	14	8	**2.750**	1.988	2.66	2.12	equal	20	1.36	2.066	NO
All 3-Leg FRT	All AADT, 3-Leg Non-FRT	31	12	**1.319**	1.158	2.08	2.43	unequal	41	0.47	1.960	NO
All 4-Leg FRT	All AADT, 4-Leg Non-FRT	37	12	1.170	**1.317**	2.06	1.06	equal	47	0.50	1.960	NO
All FRT	All AADT, All Legs Non-FRT	68	24	**1.245**	1.238	1.62	1.71	unequal	90	0.00	1.960	NO
FRT on Major Road, 3-Leg	All 3-Leg Non-FRT	26	12	1.112	**1.158**	2.10	1.29	equal	36	0.14	1.960	NO
FRT on Minor Road, 3-Leg	All 3-Leg Non-FRT	4	12	**2.625**	1.158	2.66	10.19	unequal	14	1.07	2.145	NO
FRT on Major Road, 4-Leg	All 4-Leg Non-FRT	19	12	1.095	**1.317**	2.14	1.13	equal	29	0.67	2.045	NO
FRT on Minor Road, 4-Leg	All 4-Leg Non-FRT	8	12	0.738	**1.317**	2.68	2.31	equal	18	1.66	2.101	NO
FRT on Both Major and Minor Road , 4-Leg	All 4-Leg Non-FRT	10	12	**1.660**	1.317	2.28	1.05	equal	20	0.91	2.086	NO
FRT on Major Road, All Legs	All Non-FRT	45	24	**1.104**	1.238	1.65	1.23	equal	67	0.58	1.960	NO
FRT on Minor Road, All Legs	All Non-FRT	12	24	**1.367**	1.238	1.87	4.32	unequal	34	0.24	1.960	NO
FRT on Both Major and Minor Road, All Leg	All Non-FRT	11	24	**1.755**	1.238	1.89	1.14	equal	33	1.65	1.960	NO

Table D3. Crash Frequency Comparison (alpha = 0.10)

Comparison1	Comparison2	n1	n2	CrashFreq1	CrashFreq2	Critical F-Value	F-Statistic	Variance	df	T-Statistic	Critical T-Value (alpha = 0.10)	Significance?
Low AADT, 3-Leg FRT	Low AADT, 3-Leg Non-FRT	16	4	**0.856**	0.525	5.20	5.31	unequal	18	1.74	1.734	YES
Low AADT, 4-Leg FRT	Low AADT, 4-Leg Non-FRT	22	4	0.664	**0.925**	5.18	1.73	equal	24	0.93	1.711	NO
Low AADT, All Legs FRT	Low AADT, All Legs Non-FRT	38	8	**0.760**	0.725	2.56	2.14	equal	44	0.10	1.645	NO
Medium AADT, 3-Leg FRT	Medium AADT, 3-Leg Non-FRT	8	4	0.763	**1.025**	3.07	4.47	unequal	10	0.82	1.812	NO
Medium AADT, 4-Leg FRT	Medium AADT, 4-Leg Non-FRT	8	4	**1.413**	0.975	3.07	2.48	equal	10	1.98	1.812	YES
Medium AADT, All Legs FRT	Medium AADT, All Legs Non-FRT	16	8	**1.088**	1.000	2.16	1.32	equal	22	0.44	1.717	NO
High AADT, 3-Leg FRT	High AADT, 3-Leg Non-FRT	7	4	**3.014**	1.925	5.29	4.04	equal	9	1.08	1.833	NO
High AADT, 4-Leg FRT	High AADT, 4-Leg Non-FRT	7	4	**2.486**	2.050	3.29	1.99	equal	9	0.75	1.833	NO
High AADT, All Legs FRT	High AADT, All Legs Non-FRT	14	8	**2.750**	1.988	2.66	2.12	equal	20	1.36	1.725	NO
All 3-Leg FRT	All AADT, 3-Leg Non-FRT	31	12	**1.319**	1.158	2.08	2.43	unequal	41	0.47	1.645	NO
All 4-Leg FRT	All AADT, 4-Leg Non-FRT	37	12	1.170	**1.317**	2.06	1.06	equal	47	0.50	1.645	NO
All FRT	All AADT, All Legs Non-FRT	68	24	**1.245**	1.238	1.62	1.71	unequal	90	0.00	1.645	NO
FRT on Major Road, 3-Leg	All 3-Leg Non-FRT	26	12	1.112	**1.158**	2.10	1.29	equal	36	0.14	1.645	NO
FRT on Minor Road, 3-Leg	All 3-Leg Non-FRT	4	12	**2.625**	1.158	2.66	10.19	unequal	14	1.07	1.761	NO
FRT on Major Road, 4-Leg	All 4-Leg Non-FRT	19	12	1.095	**1.317**	2.14	1.13	equal	29	0.67	1.699	NO
FRT on Minor Road, 4-Leg	All 4-Leg Non-FRT	8	12	0.738	**1.317**	2.68	2.31	equal	18	1.66	1.734	NO
FRT on Both Major and Minor Road , 4-Leg	All 4-Leg Non-FRT	10	12	**1.660**	1.317	2.28	1.05	equal	20	0.91	1.725	NO
FRT on Major Road, All Legs	All Non-FRT	45	24	**1.104**	1.238	1.65	1.23	equal	67	0.58	1.645	NO
FRT on Minor Road, All Legs	All Non-FRT	12	24	**1.367**	1.238	1.87	4.32	unequal	34	0.24	1.645	NO
FRT on Both Major and Minor Road, All Leg	All Non-FRT	11	24	**1.755**	1.238	1.89	1.14	equal	33	1.65	1.645	YES

Table D4. Crash Rate Comparison (alpha = 0.05)

Comparison1	Comparison2	n1	n2	CrashRate1	CrashRate2	Critical F-Value	F-Statistic	Variance	df	T-Statistic	Critical T-Value (alpha = 0.05)	Significance?
Low AADT, 3-Leg FRT	Low AADT, 3-Leg Non-FRT	16	4	**0.546**	0.294	5.20	177.03	unequal	18	1.38	2.101	NO
Low AADT, 4-Leg FRT	Low AADT, 4-Leg Non-FRT	22	4	**0.428**	0.389	5.18	19.44	unequal	24	0.99	2.064	NO
Low AADT, All Legs FRT	Low AADT, All Legs Non-FRT	38	8	**0.478**	0.349	2.54	126.47	unequal	44	1.59	1.960	NO
Medium AADT, 3-Leg FRT	Medium AADT, 3-Leg Non-FRT	8	4	0.263	**0.382**	3.05	4.46	unequal	10	1.04	2.228	NO
Medium AADT, 4-Leg FRT	Medium AADT, 4-Leg Non-FRT	8	4	**0.352**	0.253	3.05	2.33	equal	10	1.53	2.228	NO
Medium AADT, All Legs FRT	Medium AADT, All Legs Non-FRT	16	8	**0.315**	0.306	2.16	2.87	unequal	22	0.09	2.074	NO
High AADT, 3-Leg FRT	High AADT, 3-Leg Non-FRT	7	4	**0.517**	0.353	5.29	1.58	equal	9	1.08	2.262	NO
High AADT, 4-Leg FRT	High AADT, 4-Leg Non-FRT	7	4	**0.441**	0.408	3.29	1.61	equal	9	0.36	2.262	NO
High AADT, All Legs FRT	High AADT, All Legs Non-FRT	14	8	**0.480**	0.379	2.65	1.02	equal	20	1.07	2.066	NO
All 3-Leg FRT	All AADT, 3-Leg Non-FRT	31	12	**0.459**	0.350	2.08	83.64	unequal	41	1.32	1.960	NO
All 4-Leg FRT	All AADT, 4-Leg Non-FRT	37	12	**0.410**	0.351	2.06	3.36	unequal	47	1.37	1.960	NO
All FRT	All AADT, All Legs Non-FRT	68	24	**0.432**	0.351	1.62	42.50	unequal	90	1.65	1.960	NO
FRT on Major Road, 3-Leg	All 3-Leg Non-FRT	26	12	**0.417**	0.350	2.10	4.27	unequal	36	1.24	1.960	NO
FRT on Minor Road, 3-Leg	All 3-Leg Non-FRT	4	12	**0.547**	0.350	2.66	626.18	unequal	14	1.03	2.145	NO
FRT on Major Road, 4-Leg	All 4-Leg Non-FRT	19	12	**0.448**	0.351	2.14	4.90	unequal	29	1.60	2.045	NO
FRT on Minor Road, 4-Leg	All 4-Leg Non-FRT	8	12	**0.360**	0.351	2.34	2.71	unequal	18	0.24	2.101	NO
FRT on Both Major and Minor Road , 4-Leg	All 4-Leg Non-FRT	10	12	**0.388**	0.351	2.43	1.05	equal	20	0.52	2.086	NO
FRT on Major Road, All Legs	All Non-FRT	45	24	**0.429**	0.351	1.65	4.67	unequal	67	2.00	1.960	YES
FRT on Minor Road, All Legs	All Non-FRT	12	24	**0.448**	0.351	1.87	225.72	unequal	34	1.05	1.960	NO
FRT on Both Major and Minor Road, All Leg	All Non-FRT	11	24	**0.395**	0.351	2.18	1.12	equal	33	0.75	1.960	NO

Table D5. Crash Rate Comparison (alpha = 0.05)

Comparison1	Comparison2	n1	n2	CrashRate1	CrashRate2	Critical F-Value	F-Statistic	Variance	df	T-Statistic	Critical T-Value (alpha = 0.10)	Significance?
Low AADT, 3-Leg FRT	Low AADT, 3-Leg Non-FRT	16	4	**0.546**	0.294	5.20	177.03	unequal	18	1.38	1.734	NO
Low AADT, 4-Leg FRT	Low AADT, 4-Leg Non-FRT	22	4	**0.428**	0.389	5.18	19.44	unequal	24	0.99	1.711	NO
Low AADT, All Legs FRT	Low AADT, All Legs Non-FRT	38	8	**0.478**	0.349	2.54	126.47	unequal	44	1.59	1.645	NO
Medium AADT, 3-Leg FRT	Medium AADT, 3-Leg Non-FRT	8	4	0.263	**0.382**	3.05	4.46	unequal	10	1.04	1.812	NO
Medium AADT, 4-Leg FRT	Medium AADT, 4-Leg Non-FRT	8	4	**0.352**	0.253	3.05	2.33	equal	10	1.53	1.812	NO
Medium AADT, All Legs FRT	Medium AADT, All Legs Non-FRT	16	8	**0.315**	0.306	2.16	2.87	unequal	22	0.09	1.717	NO
High AADT, 3-Leg FRT	High AADT, 3-Leg Non-FRT	7	4	**0.517**	0.353	5.29	1.58	equal	9	1.08	1.833	NO
High AADT, 4-Leg FRT	High AADT, 4-Leg Non-FRT	7	4	**0.441**	0.408	3.29	1.61	equal	9	0.36	1.833	NO
High AADT, All Legs FRT	High AADT, All Legs Non-FRT	14	8	**0.480**	0.379	2.65	1.02	equal	20	1.07	1.725	NO
All 3-Leg FRT	All AADT, 3-Leg Non-FRT	31	12	**0.459**	0.350	2.08	83.64	unequal	41	1.32	1.645	NO
All 4-Leg FRT	All AADT, 4-Leg Non-FRT	37	12	**0.410**	0.351	2.06	3.36	unequal	47	1.37	1.645	NO
All FRT	All AADT, All Legs Non-FRT	68	24	**0.432**	0.351	1.62	42.50	unequal	90	1.65	1.645	YES
FRT on Major Road, 3-Leg	All 3-Leg Non-FRT	26	12	**0.417**	0.350	2.10	4.27	unequal	36	1.24	1.645	NO
FRT on Minor Road, 3-Leg	All 3-Leg Non-FRT	4	12	**0.547**	0.350	2.66	626.18	unequal	14	1.03	1.761	NO
FRT on Major Road, 4-Leg	All 4-Leg Non-FRT	19	12	**0.448**	0.351	2.14	4.90	unequal	29	1.60	1.699	NO
FRT on Minor Road, 4-Leg	All 4-Leg Non-FRT	8	12	**0.360**	0.351	2.34	2.71	unequal	18	0.24	1.734	NO
FRT on Both Major and Minor Road , 4-Leg	All 4-Leg Non-FRT	10	12	**0.388**	0.351	2.43	1.05	equal	20	0.52	1.725	NO
FRT on Major Road, All Legs	All Non-FRT	45	24	**0.429**	0.351	1.65	4.67	unequal	67	2.00	1.645	YES
FRT on Minor Road, All Legs	All Non-FRT	12	24	**0.448**	0.351	1.87	225.72	unequal	34	1.05	1.645	NO
FRT on Both Major and Minor Road, All Leg	All Non-FRT	11	24	**0.395**	0.351	2.18	1.12	equal	33	0.75	1.645	NO

APPENDIX E: CONFLICT ANALYSIS RESULTS

Table E1. FRT Intersection Test Site Summary Data

SITE	FRT7	FRT61	FRT26	FRT25	FRT65	FRT63
AADT RANGE	LOW	LOW	MEDIUM	MEDIUM	HIGH	HIGH
2018 AADT	5,460	6,815	9,975	12,366	20,390	21,614
INTERSECTION LEGS	3	4	3	4	3	4
RT APPROACH THRU CONTROL	UNCONTROLLED	UNCONTROLLED	STOP-CONTROLLED	UNCONTROLLED	UNCONTROLLED	STOP-CONTROLLED
VIDEO HRS	72	69	104	72	64	85.5
TOTAL THRU	588	89	1282	472	660	10432
THRU/HR	8.17	1.29	12.33	6.56	10.31	122.01
TOTAL RT	1205	460	3704	3569	5797	6470
RT/HR	16.74	6.67	35.62	49.57	90.58	75.67
TOTAL CONFLICT	4	0	5	2	12	30
TOTAL POT CONFLICT	8	1	64	12	49	632

Table E2. Non-FRT Intersection Test Site Summary Data

SITE	COMP20	COMP8	COMP7	COMP24	COMP6	COMP23
AADT RANGE	LOW	LOW	MEDIUM	MEDIUM	HIGH	HIGH
2018 AADT	5,349	6,994	8,510	13,595	13,891	14,570
INTERSECTION LEGS	3	4	3	4	3	4
RT APPROACH THRU CONTROL	UNCONTROLLED	UNCONTROLLED	STOP-CONTROLLED	UNCONTROLLED	UNCONTROLLED	STOP-CONTROLLED
VIDEO HRS	77	59.5	69	71.75	73.75	77.75
TOTAL THRU	256	889	3306	690	1398	2454
THRU/HR	3.32	14.94	47.91	9.62	18.96	31.56
TOTAL RT	1584	23	93	327	4691	1184
RT/HR	20.57	0.39	1.35	4.56	63.61	15.23
TOTAL CONFLICT	63	1	0	12	12	9
TOTAL POT CONFLICT	44	4	3	17	192	135
CONFLICT/HR	0.82	0.02	0.00	0.17	0.16	0.12

Table E3. Low AADT, 3-Leg Sites

	LOW AADT, 3-LEG					
	FRT SITE (FRT7)			NON-FRT SITE (COMP20)		
Time Period	Conflicts	Hours of Data	RT Vehicles	Conflicts	Hours of Data	RT Vehicles
12AM-1AM	0	3	3	0	3	2
1AM-2AM	0	3	3	0	3	4
2AM-3AM	0	3	2	0	3	2
3AM-4AM	0	3	3	0	3	3
4AM-5AM	0	3	17	0	3	5
5AM-6AM	0	3	54	0	3	10
6AM-7AM	1	3	97	1	3	51
7AM-8AM	0	3	80	5	3	128
8AM-9AM	1	3	51	3	3	77
9AM-10AM	0	3	63	5	3	75
10AM-11AM	1	3	62	1	3	84
11AM-12PM	0	3	50	2	3	87
12PM-1PM	0	3	68	1	3	91
1PM-2PM	0	3	66	2	3	93
2PM-3PM	0	3	80	1	3	95
3PM-4PM	1	3	96	8	3	107
4PM-5PM	0	3	105	14	3	160
5PM-6PM	0	3	77	17	3	166
6PM-7PM	0	3	60	0	3	91
7PM-8PM	0	3	55	2	4	99
8PM-9PM	0	3	36	0	4	64
9PM-10PM	0	3	37	1	4	45
10PM-11PM	0	3	20	0	4	32
11PM-12AM	0	3	20	0	4	13
Total	4	72	1205	63	77	1584
Conflict/hr	0.056			0.818		
Conflict/1000 RT vehicles	3.320			39.773		

Table E4. Low AADT, 4-Leg Sites

	LOW AADT, 4-LEG					
	FRT SITE (FRT61)			NON-FRT SITE (COMP8)		
Time Period	Conflicts	Hours of Data	RT Vehicles	Conflicts	Hours of Data	RT Vehicles
12AM-1AM	0	3	0	0	2	0
1AM-2AM	0	3	0	0	2	0
2AM-3AM	0	3	1	0	2	0
3AM-4AM	0	3	2	0	2	0
4AM-5AM	0	3	3	0	2	0
5AM-6AM	0	3	19	0	2	0
6AM-7AM	0	3	18	0	3	0
7AM-8AM	0	3	69	0	3	0
8AM-9AM	0	3	29	0	3	2
9AM-10AM	0	3	23	0	3	2
10AM-11AM	0	3	24	0	3	3
11AM-12PM	0	3	32	0	3	2
12PM-1PM	0	2	13	0	3	2
1PM-2PM	0	2	17	0	3	1
2PM-3PM	0	2	18	1	3	3
3PM-4PM	0	3	34	0	3	1
4PM-5PM	0	3	30	0	3	3
5PM-6PM	0	3	41	0	2.5	2
6PM-7PM	0	3	35	0	2	1
7PM-8PM	0	3	13	0	2	1
8PM-9PM	0	3	18	0	2	0
9PM-10PM	0	3	11	0	2	0
10PM-11PM	0	3	7	0	2	0
11PM-12AM	0	3	3	0	2	0
Total	0	69	460	1	59.5	23
Conflict/hr	0.000			0.017		
Conflict/1000 RT vehicles	0.000			43.478		

Table E5. Medium AADT, 3-Leg Sites

	MEDIUM AADT, 3-LEG					
	FRT SITE (FRT26)			NON-FRT SITE (COMP7)		
Time Period	Conflicts	Hours of Data	RT Vehicles	Conflicts	Hours of Data	RT Vehicles
12AM-1AM	0	4	7	0	3	0
1AM-2AM	0	4	3	0	3	0
2AM-3AM	0	4	22	0	3	0
3AM-4AM	0	4	37	0	3	0
4AM-5AM	0	4	80	0	3	0
5AM-6AM	0	4	78	0	3	0
6AM-7AM	0	4	148	0	2.25	3
7AM-8AM	0	4	175	0	2.75	18
8AM-9AM	0	4	165	0	3	6
9AM-10AM	0	4	202	0	3	5
10AM-11AM	1	4	200	0	3	4
11AM-12PM	0	4	211	0	3	6
12PM-1PM	0	4	175	0	3	3
1PM-2PM	0	4	202	0	2.25	7
2PM-3PM	0	4	207	0	2.75	8
3PM-4PM	0	4.75	241	0	3	2
4PM-5PM	2	5	634	0	3	8
5PM-6PM	1	5	345	0	3	8
6PM-7PM	1	5	197	0	3	6
7PM-8PM	0	5	127	0	3	4
8PM-9PM	0	5	95	0	2.25	1
9PM-10PM	0	5	87	0	2.75	4
10PM-11PM	0	5	49	0	3	0
11PM-12AM	0	4.25	17	0	3	0
Total	5	104	3704	0	69	93
Conflict/hr	0.048			0.000		
Conflict/1000 RT vehicles	1.350			0.000		

Table E6. Medium AADT, 4-Leg Sites

	MEDIUM AADT, 4-LEG					
	FRT SITE (FRT25)			NON-FRT SITE (COMP24)		
Time Period	Conflicts	Hours of Data	RT Vehicles	Conflicts	Hours of Data	RT Vehicles
12AM-1AM	0	3	6	0	3	2
1AM-2AM	0	3	5	0	3	1
2AM-3AM	0	3	5	0	3	0
3AM-4AM	0	3	10	0	3	0
4AM-5AM	0	3	30	0	3	0
5AM-6AM	0	3	84	0	3	3
6AM-7AM	0	3	91	0	3	6
7AM-8AM	1	3	130	0	3	17
8AM-9AM	1	3	190	1	3	17
9AM-10AM	0	3	209	0	3	25
10AM-11AM	0	3	237	0	3	17
11AM-12PM	0	3	268	0	3	13
12PM-1PM	0	3	285	0	3	15
1PM-2PM	0	3	246	0	3	12
2PM-3PM	0	3	219	3	2.75	30
3PM-4PM	0	3	288	0	3	38
4PM-5PM	0	3	313	0	3	38
5PM-6PM	0	3	245	7	3	35
6PM-7PM	0	3	211	1	3	27
7PM-8PM	0	3	155	0	3	8
8PM-9PM	0	3	121	0	3	12
9PM-10PM	0	3	92	0	3	5
10PM-11PM	0	3	85	0	3	5
11PM-12AM	0	3	44	0	3	1
Total	2	72	3569	12	71.75	327
Conflict/hr	0.028			0.167		
Conflict/1000 RT vehicles	0.560			36.697		

Table E7. High AADT, 3-Leg Sites

	HIGH AADT, 3-LEG					
	FRT SITE (FRT65)			NON-FRT SITE (COMP6)		
Time Period	Conflicts	Hours of Data	RT Vehicles	Conflicts	Hours of Data	RT Vehicles
12AM-1AM	0	2	5	0	3	122
1AM-2AM	0	2	6	0	3	25
2AM-3AM	0	2	1	0	3	13
3AM-4AM	0	2	6	0	3	11
4AM-5AM	0	2	11	0	3	27
5AM-6AM	0	2	52	0	3	69
6AM-7AM	0	3	162	1	3	115
7AM-8AM	3	3	387	3	3	249
8AM-9AM	0	3	245	0	3	248
9AM-10AM	0	3	254	0	3	227
10AM-11AM	0	3	290	0	3	239
11AM-12PM	1	3	307	0	3	275
12PM-1PM	1	3	329	0	3	271
1PM-2PM	0	3	341	0	3	292
2PM-3PM	1	3	385	0	3	314
3PM-4PM	1	3	540	3	3	343
4PM-5PM	3	3	634	2	4	553
5PM-6PM	1	3	624	2	3.75	453
6PM-7PM	0	3	427	0	3	305
7PM-8PM	0	3	297	0	3	198
8PM-9PM	1	3	259	0	3	134
9PM-10PM	0	3	148	0	3	103
10PM-11PM	0	2	56	0	3	64
11PM-12AM	0	2	31	1	3	41
Total	12	64	5797	12	73.75	4691
Conflict/hr	0.188			0.163		
Conflict/1000 RT vehicles	2.070			2.558		

Table E8. High AADT, 4-Leg Sites

	HIGH AADT, 4-LEG					
	FRT SITE (FRT63)			NON-FRT SITE (COMP23)		
Time Period	Conflicts	Hours of Data	RT Vehicles	Conflicts	Hours of Data	RT Vehicles
12AM-1AM	0	3	20	0	3	4
1AM-2AM	0	3	23	0	3	1
2AM-3AM	0	3	21	0	3	2
3AM-4AM	0	3	32	0	3	1
4AM-5AM	0	3	49	0	3	12
5AM-6AM	0	3	138	0	3	30
6AM-7AM	1	3	188	3	3	61
7AM-8AM	0	3	341	1	3	66
8AM-9AM	3	3	327	0	2.75	88
9AM-10AM	2	3	301	0	2	60
10AM-11AM	1	3.5	338	1	2	53
11AM-12PM	1	4	420	1	2	60
12PM-1PM	1	4	424	0	3	60
1PM-2PM	4	4	437	0	3	68
2PM-3PM	4	4	493	0	3	58
3PM-4PM	3	4	510	1	4	115
4PM-5PM	4	4	662	2	4	142
5PM-6PM	3	4	569	0	4	145
6PM-7PM	2	4	368	0	4	67
7PM-8PM	0	4	285	0	4	25
8PM-9PM	0	4	185	0	4	33
9PM-10PM	0	4	139	0	4	20
10PM-11PM	0	4	124	0	4	9
11PM-12AM	1	4	76	0	4	4
Total	30	85.5	6470	9	77.75	1184
Conflict/hr	0.351			0.116		
Conflict/1000 RT vehicles	4.637			7.601		