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Development of Safety Performance Functions for Restricted Crossing U-Turn (RCUT) Intersections

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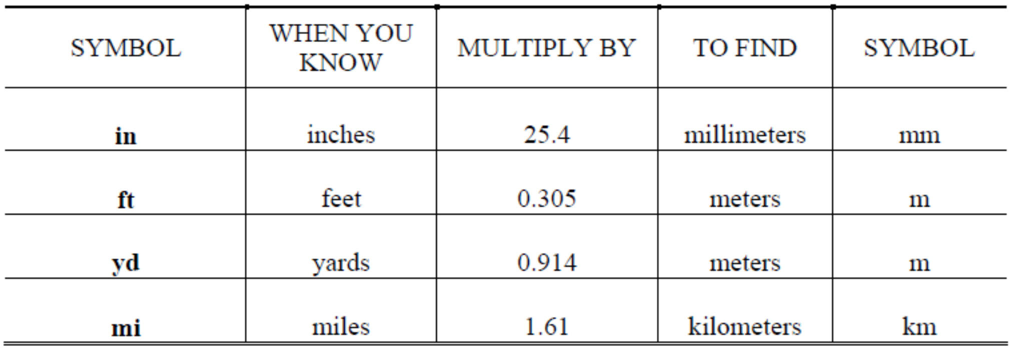

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
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yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

METRIC (SI) UNITS
TO U.S. UNITS

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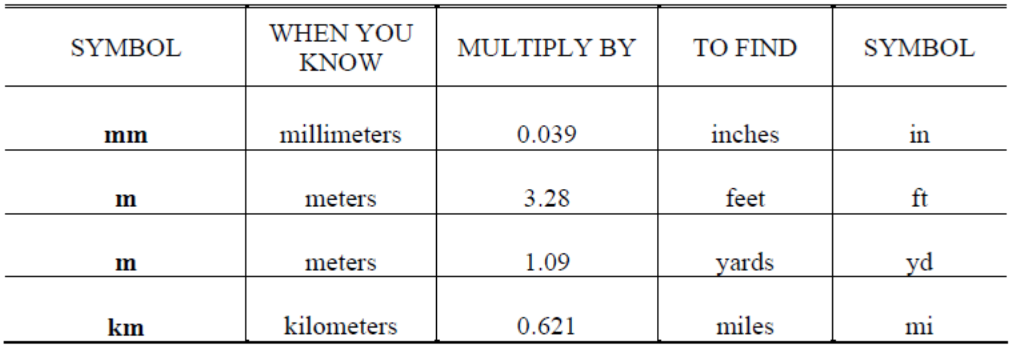

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m	meters	1.09	yards	yd
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16. Abstract
Conventional intersection designs are known to be problematic and unreliable when handling the complexity associated with the heavy traffic volume and travel demand on today’s roadways. Therefore, transportation agencies have been searching for more innovative and safer intersection design solutions in order to address these complex problems. One such alternative intersection design is the restricted crossing U-turn (RCUT) intersection. The overall goal of this project was to provide appropriate safety performance functions for different types of RCUT intersections for use by FDOT planners and engineers at various levels of project development and safety analysis. Consistent with this goal, the following tasks have been completed as part of the project: (a) a comprehensive search was performed to identify the experiences of other transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies) related to the RCUT implementations; (b) a survey questionnaire was prepared and used to solicit information on RCUT intersections from these agencies; (c) geometric, traffic, and crash data were collected for all the existing RCUT intersections in the U.S.; (d) significant factors influencing the RCUT intersection safety were determined; (e) safety performance functions (SPFs) were developed for signalized and unsignalized RCUT intersections based on the collected data; and (f) crash modification factors and functions (CMFs) were developed for various traffic and geometric variables. Meeting these objectives led to appropriate recommendations to Florida DOT in terms of evaluating and justifying the feasibility of RCUT intersections as safer intersection alternatives and identifying promising locations in Florida where intersection safety and operation will be significantly improved (those locations that may benefit the most from RCUT implementations). Results of this research will also be used with the new Intersection Control Evaluation (ICE) Policy and Procedure, and RCUT Safety Performance Functions (SPFs) will be incorporated into the Safety Performance for ICE (SPICE) Tool.

17. Key Word
Innovative intersections; restricted crossing U-turn (RCUT) intersections; safety performance functions (SPFs); crash modification factors and functions (CMFs)

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EXECUTIVE SUMMARY

Conventional intersection designs are known to be problematic and unreliable when handling the complexity associated with the heavy traffic volume and travel demand on today's roadways. Therefore, transportation agencies have been searching for more innovative and safer intersection design solutions in order to address these complex problems. One such alternative intersection design is the restricted crossing U-turn (RCUT) intersection. Several states in the U.S., such as Michigan, Maryland, and North Carolina, have already implemented this design since the early 2000s and have reported satisfactory results with their implementation programs. These reports have shown that RCUT intersections have the potential to reduce the conflict points and offer substantial safety advantages over conventional intersections for vehicles, pedestrians, and bicyclists. According to the FHWA's 2014 informational guide on the RCUTs (Hummer et al., 2014), however, there is still a wide gap in the literature with respect to the safety performance analysis of RCUT intersections. The existing studies also did not attempt to calculate the safety performance functions for RCUTs based on the Highway Safety Manual (HSM) guidelines. These SPFs will readily enable the implementation of RCUTs in the State of Florida. Therefore, a significant challenge in evaluating the safety performance of RCUTs is the lack of appropriate safety performance functions (SPFs) specifically developed for RCUTs. Crash modification factors (CMFs) were previously proposed in Missouri and North Carolina in order to convert unsignalized conventional intersections to unsignalized RCUT intersections. However, this approach may not reveal the actual performance of these intersections, which can depend on other factors such as the median offset and weaving lengths in addition to the AADTs for major and minor legs.

As such, the overall goal of this project was to provide appropriate safety performance functions for different types of RCUT intersections for use by FDOT planners and engineers at various levels of project development and safety analysis. Consistent with this goal, the following tasks have been completed as part of the project: (a) a comprehensive search was performed to identify the experiences of other transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies) related to the RCUT implementations; (b) a survey questionnaire was prepared and used to solicit information on RCUT intersections from these agencies; (c) geometric, traffic, and crash data were collected for all the existing RCUT intersections in the U.S.; (d) significant factors influencing the RCUT intersection safety were determined; (e) safety performance functions (SPFs) were developed for signalized and unsignalized RCUT intersections based on the collected data; and (f) crash modification factors and functions (CMFs) were developed for various traffic and geometric variables. Meeting these objectives led to appropriate recommendations to Florida DOT in terms of evaluating and justifying the feasibility of RCUT intersections as safer intersection alternatives, and identifying promising locations in Florida where intersection safety and operation will be significantly improved (those locations that may benefit the most from RCUT implementations). Results of this research will be used with the new Intersection Control Evaluation (ICE) Policy and Procedure, and RCUT Safety Performance Functions (SPFs) will be incorporated into the Safety Performance for ICE (SPICE) Tool.

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1. BACKGROUND STATEMENT

Conventional intersection designs are known to be problematic and unreliable when handling the complexity associated with the heavy traffic volume and travel demand on today's roadways. Therefore, transportation agencies have been searching for more innovative and safer intersection design solutions in order to address these complex problems. One such alternative intersection design is the restricted crossing U-turn (RCUT) intersection. Several states in the U.S., such as Michigan, Maryland, and North Carolina, have already implemented this design since the early 2000s and have reported satisfactory results with their implementation programs. These reports have shown that RCUT intersections have the potential to reduce the conflict points and offer substantial safety advantages over conventional intersections both for vehicles, pedestrians, and bicyclists. According to the FHWA's 2014 informational guide on the RCUTs (Hummer et al., 2014); however, there is still a wide gap in the literature with respect to the safety performance analysis of RCUT intersections. The existing studies also did not attempt to calculate the safety performance functions for RCUTs based on the Highway Safety Manual (HSM) guidelines. These SPFs would readily enable the implementation of RCUTs in the State of Florida.

Therefore, a significant challenge in evaluating the safety performance of RCUTs is the lack of appropriate safety performance functions (SPFs) specifically developed for RCUTs. Crash modification factors (CMFs) were previously proposed in Missouri (Edara et al., 2013) and North Carolina (Hummer et al., 2010) in order to convert unsignalized conventional intersections to unsignalized RCUT intersections. However, this approach may not reveal the actual performance of these intersections, which can depend on other factors such as the median offset and weaving lengths in addition to the AADTs for major and minor legs. As such, there is a need to conduct an extensive review of the literature and practice in order to (a) extract the vast amount of knowledge with respect to the already existing RCUT implementations and their safety benefits and (b) collect the geometric, traffic, and crash data from these sites in order to develop safety performance functions and crash modification factors in the presence of sufficient data as required by the Highway Safety Manual.

1.1. REPORT STRUCTURE

The remainder of this report is structured in the following manner. Chapter 2 describes Task 1, which includes the literature review and surveys. Chapter 3 presents Task 2, which includes the collection of geometric, traffic, and crash data from the states that have RCUT intersections and information on the site visit to North Carolina to observe the performance of RCUT implementations. Chapter 4 describes the efforts on the development of the safety performance functions (SPFs). Chapter 5 presents the development of the crash modification factors and functions (CMFs). Chapter 6 presents the conclusions, discussion, and future work.

2. TASK 1: CONDUCT LITERATURE REVIEW, SURVEYS, AND SITE VISITS

Task 1 aims to extract the vast amount of knowledge on RCUT intersections through literature reviews and state surveys. For this purpose, a review of literature has been conducted in order to discover published information that can help inform, shape, or guide the conduct this research project. The main focus of the literature review was to discover and evaluate past results on the RCUT intersection implementations. For this purpose, a comprehensive search was performed to identify the experiences of other transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies) related to the RCUT implementations. This was supported by the compilation of all existing documentation through the FSU library resources (books, databases, journals) as well as online resources (search engines, TRIS). This comprehensive search was followed by an extensive meta-analysis of the identified resources. In addition, a survey questionnaire was prepared and used to solicit information on RCUT intersections from other state DOTs, and selected counties, MPOs and cities. The survey questionnaire was administered by emailing and follow up calls.

2.1. LITERATURE REVIEW

A comprehensive search has been performed in order to identify the experiences of other transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies) related to the Restricted Crossing U-Turn (RCUT) implementations. This was supported by the compilation of all existing documentation through the online resources (books, databases, journals) as well as online resources (search engines, TRIS).

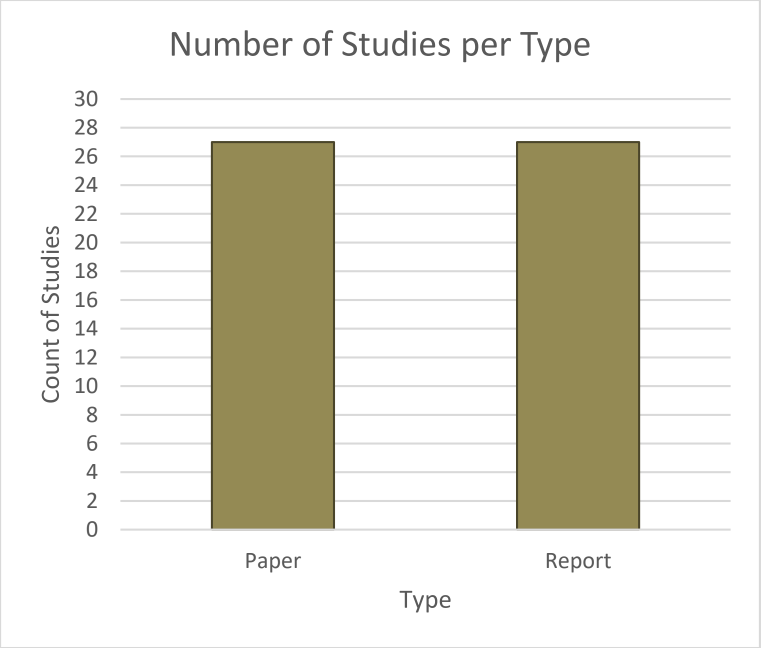
2.1.1. Meta-analysis of the Literature

The literature review conducted in this project included several steps. First, we introduced specific evaluation criteria for the review of the related work on RCUT implementations. Based on criteria, we reviewed state and federal reports as well as research articles covering a time period of 1999-2017, which resulted in a collection of 52 critical works. The meta-analysis table based on the conducted literature review is provided in Appendix A. Criteria used to evaluate the existing literature is listed as follows:

- Date
- Type
- Location
- Subject
- Focus
- Methods
- Key Findings

According to this analysis, the research team also categorized the available literature by type, year, location of interest, subject and method in order to obtain the visual illustrations given in Figure 1. According to Figure 1, there are equal number of research articles and agency reports, and there is an increasing focus on RCUT implementations especially since 2008. States such as North Carolina, Maryland and Missouri are found to be the leading states regarding the

RCUT intersections both due to the successful implementations in their states and also due to the extensive research and practical work being conducted. Results also show that safety is the most important subject studied in the literature with regards to the RCUT implementations followed by the traffic operations, design and geometry. Many studies in the literature have performed statistical analysis including descriptive statistics and regression analysis. Microscopic simulation and surveys have also been of interest with regards to the RCUT implementations. The following sections will study the literature in more detail.



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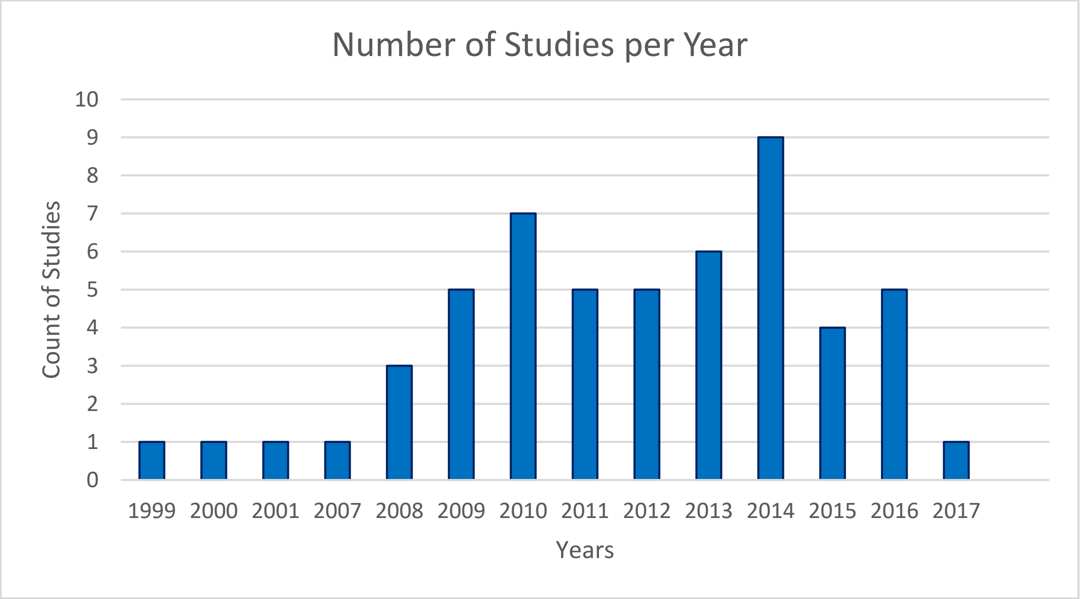
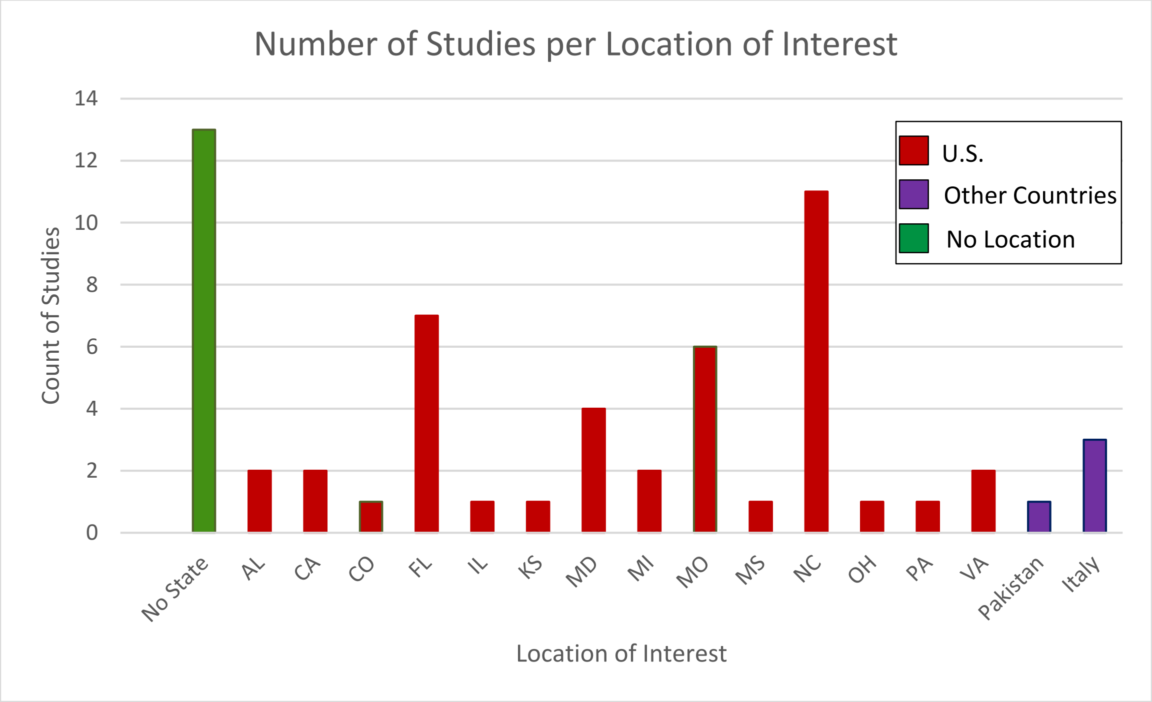


(b)

Figure 1. Analysis and categorization of the literature review: (a) Number of studies per type, (b) Number of studies per year, (c) Number of studies per location of interest, (d) Number of studies per subject, (e) Number of studies per method



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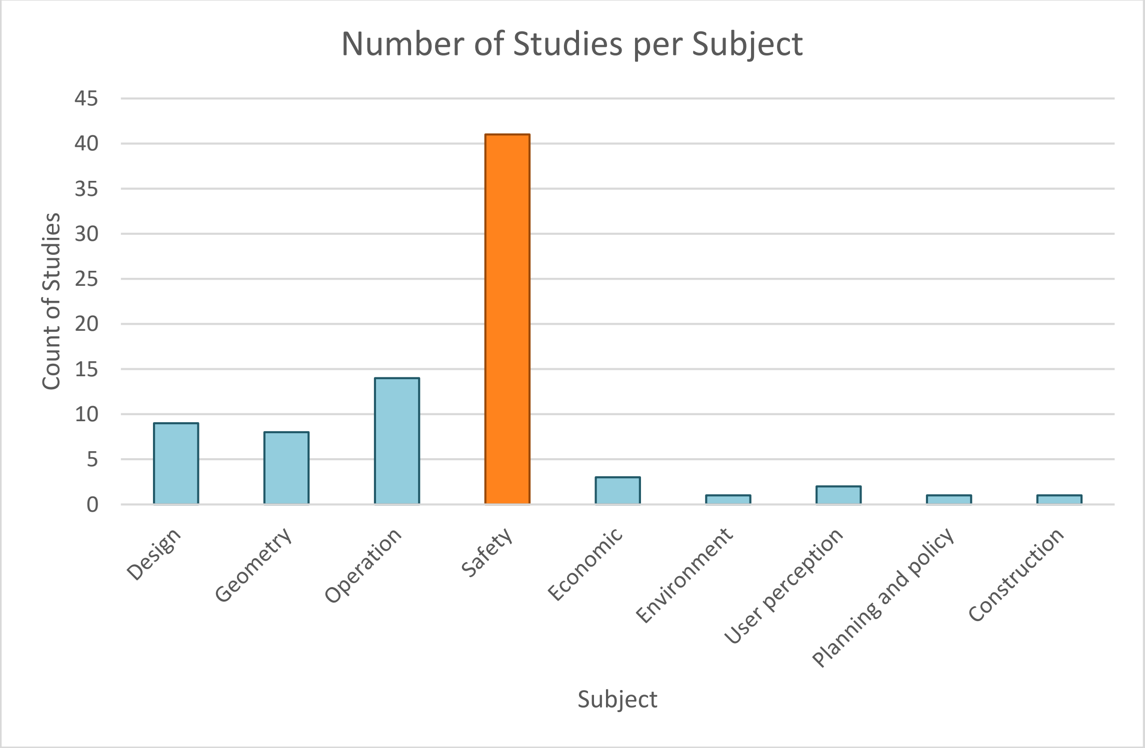
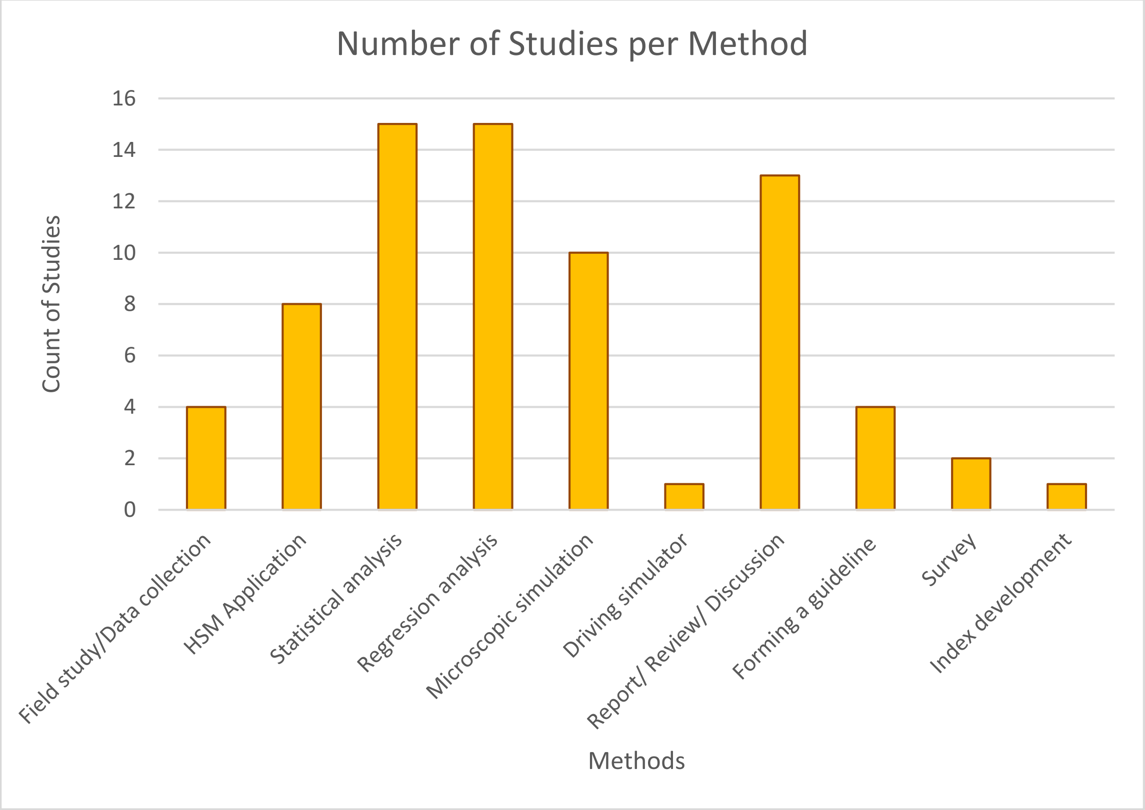


(d)

Figure 1. Analysis and categorization of the literature review: (a) Number of studies per type, (b) Number of studies per year, (c) Number of studies per location of interest, (d) Number of studies per subject, (e) Number of studies per method



(e)

Figure 1. Analysis and categorization of the literature review: (a) Number of studies per type, (b) Number of studies per year, (c) Number of studies per location of interest, (d) Number of studies per subject, (e) Number of studies per method

Following sections will provide detailed information on the RCUT intersections based on the literature focusing on the following: (a) design and geometry, (b) traffic operations and user perception, (c) safety, and (d) crash models and SPFs.

2.1.2. Design and Geometry

RCUT is an alternative intersection design that has a one-way median opening for left-turn movements from the major approach exclusively, and it restricts through and left-turn movements from the minor approach. Minor through and minor left-turn traffic have to make a right turn and then a U-turn from a designated downstream location to complete the desired movement (Figure 2). Figure 3, Figure 4 and Figure 5 show the schematic diagrams and example implementations of signalized, stop controlled, and with merges, respectively. There are several main components that prevail the geometry of RCUTs, including the following: sufficient median width, need for loons, and offsets between the intersection and U-turn location (Olarte, Bared, Sutherland, and Asokan, 2011). The median width, a crucial design component for RCUTs, is recommended to be between 40 feet and 70 feet at least, in order to enable the U-turn maneuver of large trucks (Hughes, Jagannathan, Sengupta, and Hummer, 2010; Mississippi Department of Transportation (MDOT), 2010; Olarte et al., 2011). When this specification cannot be met, the loons have to be considered for turning movement of large vehicles. The offset between intersection and the U-turn location, on the other hand, varies from 400 feet to 1,000 feet depending on the state agency or transportation department (Bared, 2009). As an important design rule for RCUTs to avoid conflicts and wrong way movements, the driveways should not be located very close to the main intersection or on opposite of the U-turn exits. Another important geometric feature is the acceleration/deceleration lanes before the downstream U-turns. Sun et al. (2016) and Inman and Haas (2012) recommended the implementation of both acceleration (for right-turns from the minor approach) and deceleration lanes instead of only deceleration lanes before the downstream U-turns. Moreover, it was stated that acceleration lanes are also helpful in minimizing delays. Note that, for locations with high traffic volume, it was recommended to implement longer acceleration/deceleration lanes up to 2,000 feet. In addition to these features, the maximum superelevation rate and clear zone distance for RCUTs were recommended to be 10% and 30 feet, respectively (Mississippi Department of Transportation (MDOT), 2010). The lane and shoulder widths were similar to the conventional roadways (12 feet and 10 feet, respectively) (Hughes et al., 2010).

Pedestrian crossings at RCUTs are different than the conventional designs due to the particular geometry of these intersections. There are several pedestrian crossing patterns serving different purposes. For instance, one of the most common patterns is the diagonal path which allow pedestrians to cross from one corner to the opposite corner. Another crossing pattern, namely the two-stage Barnes Dance, was recommended by Hummer et al. (2014a) when there is a high pedestrian volume since this crossing minimizes the stopped delay, number of stops, and travel time for pedestrians. When pedestrian volume is low, on the other hand, they recommended a combination of diagonal and midblock crossings. Moreover, a direct cross was found to minimize number of stops and travel time for bicyclists. Nevertheless, it is worth noting that Missouri Department of Transportation discourages the pedestrian crossings at unsignalized RCUTs (J-Turns).

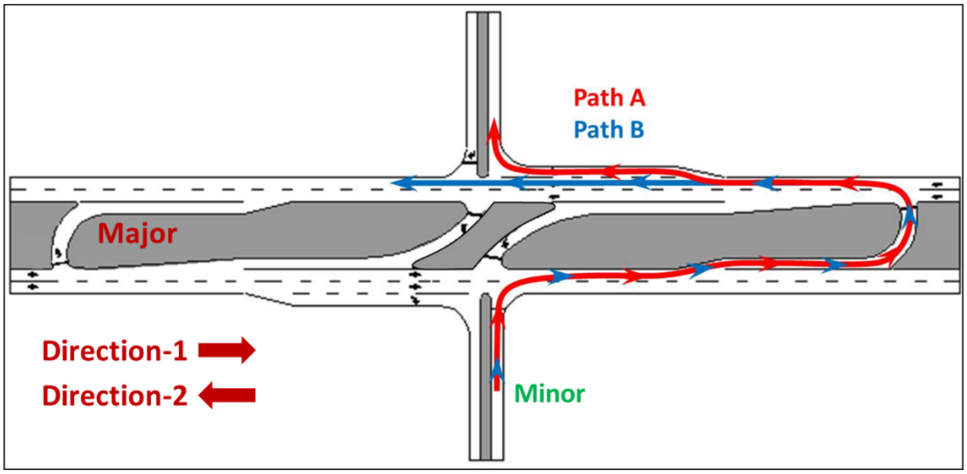
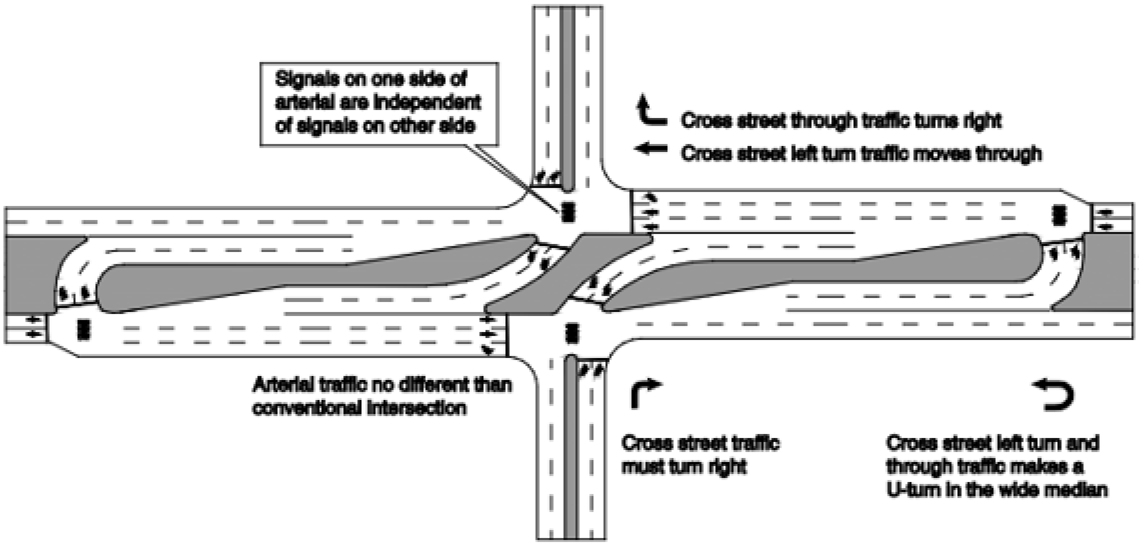


Figure 2. Schematic diagram of a RCUT intersection and movements from minor approach: Path A – through traffic, Path B – left-turning traffic (Source: https://safety.fhwa.dot.gov/intersection/innovative/uturn/)

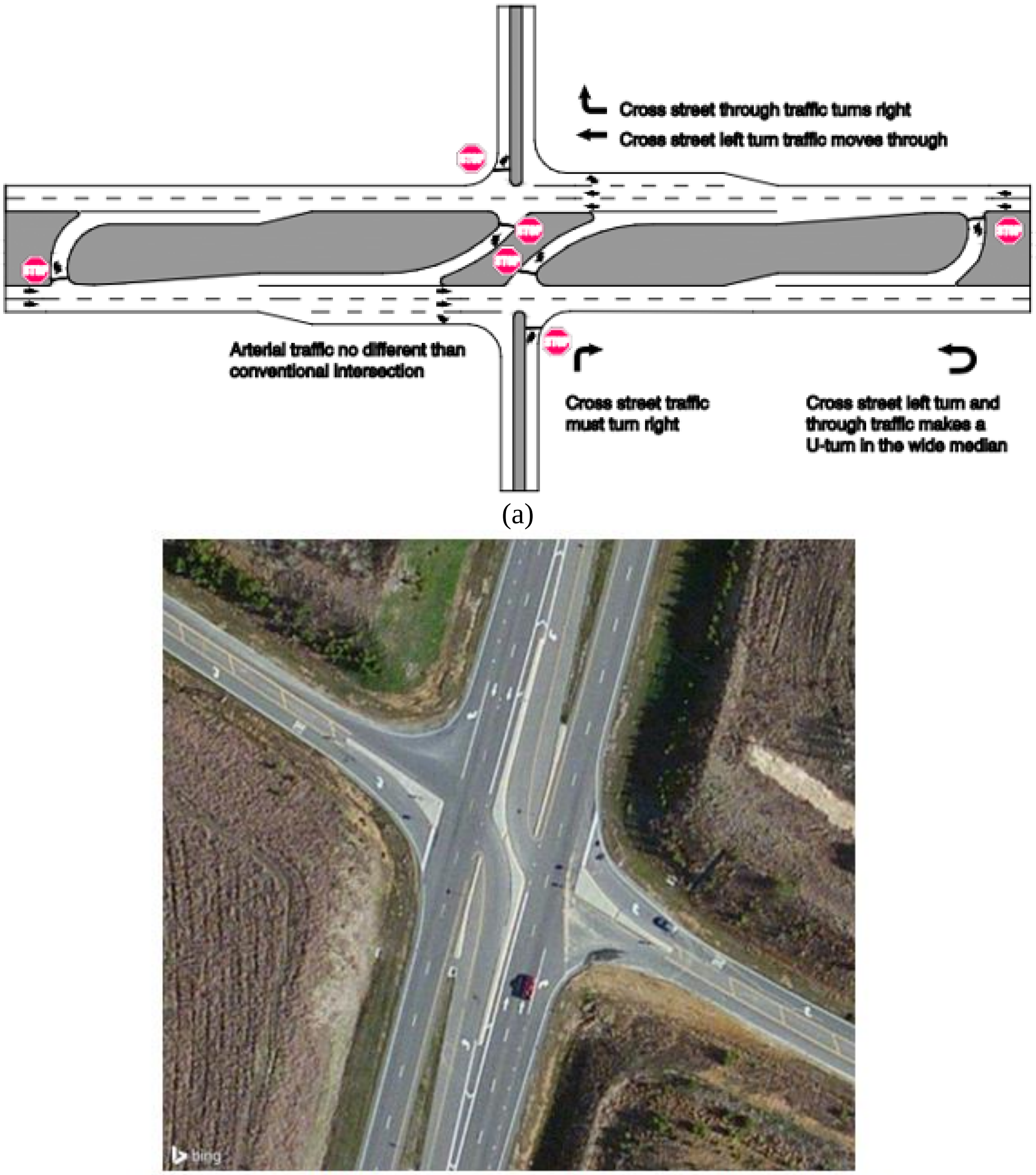


(a)

Signalized RCUT intersection in operation near San Antonio, TX showing a pedestrian "Z" crossing.

(b)

Figure 3. Signalized RCUT intersection: (a) Schematic diagram, (b) Example implementation in San Antonio, Texas (Inman and Haas, 2012)

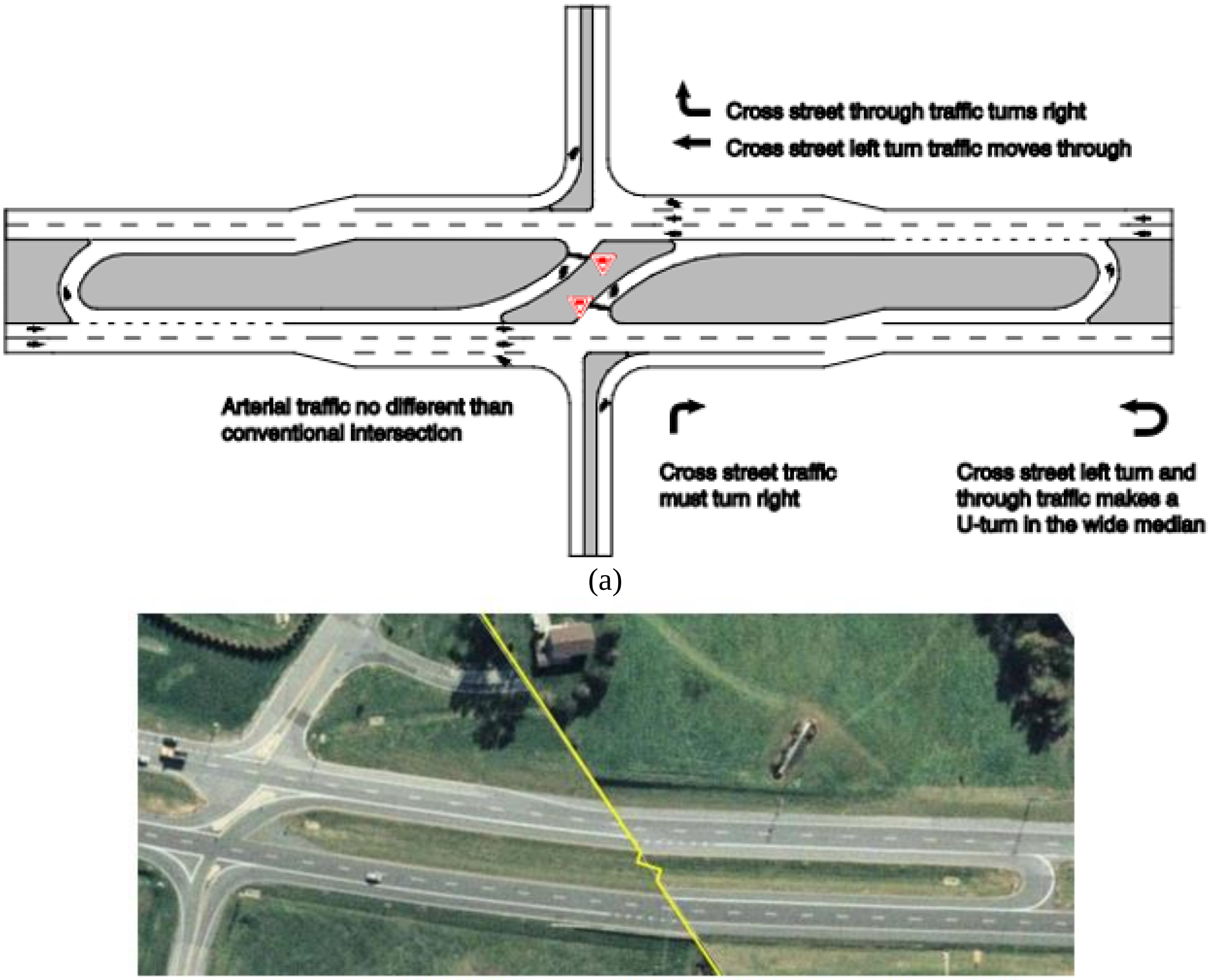


(a)

Stop-controlled RCUT intersection on US-1 near Southern Pines, NC.

(b)

Figure 4. Stop-controlled RCUT intersection: (a) Schematic diagram, (b) Example implementation in Southern Pines, North Carolina (Inman and Haas, 2012)



(a)

Merge-controlled RCUT intersection on US-15 in Emmitsburg, MD.

(b)

Figure 5. An RCUT intersection with merges: (a) Schematic diagram, (b) Example implementation in Emmitsburg, Maryland (Inman and Haas, 2012)

2.1.3. Traffic Operations and User Perception

RCUTs are alternative intersection types appropriate for locations where high volume major approach traffic intersects with low volume minor approach traffic. To be specific, MDOT (2010) recommends that minor approach volume should be less than 0.2 of the total intersection volume. Hummer et al. (2012), on the other hand, states that RCUTs function well up to the point when minor approach volume reaches to the half of the major approach traffic. There are three different types of traffic operations for RCUTs: (a) signalized, (b) unsignalized (stop controlled), and (c) merging. Note that RCUTs can be implemented back-to-back as a corridor treatment which can operate similar to a freeway, particularly when funding or other concerns do not allow implementation of interchanges (Xu, Yang, and Chang, 2017). This type of consecutive implementation of RCUTs was shown to provide better progression of traffic than conventional designs do (Haley et al., 2011).

The main advantage of RCUTs from a traffic and operation perspective is the considerable improvement in traffic flow. As such, improvements and benefits of RCUTs compared to conventional designs can be listed as follows: (a) reduced delay time, (b) shorter queue lengths, (c) reduced average travel time, (d) higher vehicle throughput, and (e) higher capacity at high demand levels (Bared, 2009; Haley et al., 2011; Hummer, Haley, Ott, Foyle, and Cunningham, 2010; T. Kim, Edara, and Bared, 2007; Naghawi and Idewu, 2014). Moreover, the difference between RCUTs and conventional designs, in terms delay and queue length, is larger in favor of RCUTs when intersection experiences higher volume minor approach left-turns (approximately 30% of movements from minor approach) and moderate volume of major approach left-turns (approximately 15% of movements from major approach) (Naghawi and Idewu, 2014). In addition, design and geometry of RCUTs allow independent operations of two directions of traffic, which also permits an arrangement of signal phasing to satisfy different demands from opposite directions independently (Bared, 2009; Hummer and Reid, 2000). Although overall traffic flow parameters experience an improvement with the RCUT implementation, it is worth noting that there can be slight deterioration in the traffic flow of minor approach. That is, RCUTs may impose increased delays, stops, travel distances and travel times for through and left-turn movements from the minor approach (Hummer and Reid, 2000; Naghawi and Idewu, 2014). Nonetheless, Inman et al. (2013) noted that this increase in traffic parameters is negligible compared to generated benefits. Moreover, despite the increased travel distance and time, Edara et al. (2015) stated that waiting time of vehicles reduces due to the smooth joining of traffic by the right turn movement from minor approach, instead of waiting for gaps in the major traffic. It is also worth noting that RCUTs can allow for higher speed limits up-to 65 mph, which is recommended for unsignalized RCUTs (J-Turns) (Mississippi Department of Transportation (MDOT), 2010).

The user perception of RCUTs directly depends on the type of user and affected area. Hummer and Reid (2000) argue that RCUTs may have a confusing effect on drivers and pedestrians, especially immediately after the treatment. For example, in order to improve the driver adaptation and familiarization, Sun et al. (2016) suggested public educational campaigns and trainings before RCUT implementations. Hummer et al. (2014b) and Inman and Haas (2012), on the other hand, states that lane change and weaving maneuvers while approaching to the RCUT intersection are akin to maneuvers of a conventional intersection from a driver expectation perspective. Previous studies have investigated RCUT users in three main groups (Hummer et al., 2010; Ott, Fiedler, Hummer, Foyle, and Cunningham, 2015): 1) Residents living around RCUT treatments, 2) commuters who use RCUTs for commuting purposes, and 3) business owners or managers who have businesses around RCUT locations. Residents stated that they have a positive perception of RCUTs due to improved safety even though they perceive increased travel time and high number of queued vehicles. Commuters, similarly, praised the improved safety, reduced travel time, and less number of stopped vehicles (contrary to residents) despite the perceived difficulties in navigating the intersection. Business owners, on the contrary, alleged that RCUT treatments create access difficulties to their businesses, which hinders business growth and operation and, in turn, bring about a negative perception.

2.1.4. Safety

The main advantage of the RCUTs, compared to conventional intersections, is the safety improvement brought about by implementation of these innovative design. Besides the benefits associated with operations and traffic flow of intersections, RCUTs improve the safety of problematic intersections substantially by reducing not only the crash rate and frequency but also the number of severe injuries and fatalities (Bared, 2009; Hummer et al., 2010). Edara et al. (2013) and Edara et al. (2015) showed that total and fatal crash frequencies were reduced by 31% and 64%, respectively, following the unsignalized RCUT implementations in Missouri intersections. Similarly, Inman et al. (2013) found that RCUTs considerably reduce the total number of crashes (44%) as well as those with injuries and fatalities (9%). One of the reasons for this reduction is the lower number of conflict points generated by RCUTs, compared to those generated by conventional intersections (Bared, 2009). That is, RCUTs have 18 conflict points, whereas conventional intersections have 32 conflict points, which implies a higher crash risk. Furthermore, RCUTs alter the types of crashes that occur at intersections, which also helps to reduce the severe crashes (i.e., severe injuries and fatalities). To clarify, the angle-type crashes, which are considered as the most serious type of crash in the literature, are substantially reduced by the implementation of RCUTs (Inman et al., 2013). Moreover, Hummer et al. (2014b) reported that there is a significant reduction in the number of all types of crashes (e.g., angle, right-turn, left-turn, etc.) except side-swipe and rear-end crashes. Indeed, Hummer et al. (2014b) observed a lower rate of reduction and even a slight increase in side-swipe and rear-end crashes after RCUT implementations.

Edara et al. (2016) found that most of these side-swipe and rear-end crashes occur either while merging into traffic following a right turn or due to lane changing while making a U-turn. The main reasons behind these crashes were identified as inattention and the difference in speed between minor roadway and major roadway. This problem, however, can be mitigated by extending the distance between the minor approach and downstream U-turn (offset distance) (Edara et al., 2016; Liu, Lu, and Chen, 2008). For instance, Edara et al. (2016) recommends 1,500 feet or larger offset distance since the lowest crash rates were attained by the RCUTs which have these longer offset distances. Xu et al. (2017), on the other hand, stated that there is no significant difference between 1,500-foot and 1,100-foot offset distances in terms of safety performance, whereas the lane changing conflicts and severity of collisions are substantially increased when offset distance is 700 feet. Another possible remedy for lane change-related conflicts was proposed by Sun et al. (2016), who recommend the implementation of acceleration lane(s) following right turns together with deceleration lane(s) before U-turns, instead of implementing only deceleration lane(s). Furthermore, they stated that addition of acceleration lane(s) does not require elongating the offset distance. That is, rather than using a full-length deceleration lane, half acceleration-half deceleration lane configuration can be adopted to enhance the safety. Several researchers also reported that lane configuration is the most important factor for the unsignalized RCUT safety, adding that locations with high traffic demand should implement longer acceleration/deceleration lane(s) (e.g., 2,000 feet; Sun et al., 2016). From the traffic volume perspective, a microscopic simulation-based study reported that volumes between 1,605 to 1,708 passenger cars per hour per lane are critical since the most conflicts were experienced within these ranges (Olarte et al., 2011). It is worth noting that Hummer and Reid (2000) stated that RCUTs are safer for crossing pedestrians than conventional intersections.

2.1.5. Crash Models and Safety Performance Functions

Crash models are crucial in terms of traffic safety in order to understand the factors affecting the crash rates, frequencies, and severities. For instance, among other factors, AADT (Annual Average Daily Traffic), lane width, curvature change rate, length, and vertical grade were identified as important variables affecting the crash severities (Russo, Busiello, and Dell'Acqua, 2016). Findley et al. (2012) also noted that AADT, curve radius, and curve length of a segment are necessary for an accurate crash prediction on roadway segments. Savolainen et al. (2015) stated that following geometry-, operation-, and traffic-related information are useful for the crash analysis: (a) number of intersection legs, (b) type of traffic control, (c) AADT for the major and minor roadways, (d) number of approaches with left-turn lanes, (e) number of approaches with right-turn lanes, (f) presence of lighting, (g) presence of one-way or two-way traffic, (h) intersection sight distance, (i) intersection skew angle, (j) presence/type of left-turn phasing, (k) pedestrian volumes, (l) presence of bus stops, (m) presence of on-street parking, and (n) presence of median.

There are different statistical models implemented for the analysis of crashes. An exhaustive review of these models can be found in Lord and Mannering (2010). These methods vary from simple multiple linear regression models to complex statistical models. Among others, the most common and convenient approach, which is also recommended by the Highway Safety Manual (HSM) and Safety Analyst (AASHTO, 2010; Exelis Inc, 2013; Kweon and Lim, 2014), is the negative binomial regression. Negative binomial regression is an extension or generalization of Poisson regression; however, different than Poisson regression, it can account for the overdispersion issue, which is commonly experienced with the crash data. That is, the crash data usually has a larger variability (overdispersion) than what a Poisson regression can handle. Note that mean and variance is equal to each other for a Poisson distribution. Therefore, Poisson regression models result in biased estimates. This larger variability can be introduced into the negative binomial model using an overdispersion parameter, which increases the accuracy of estimates. This overdispersion parameter constitutes the basis of before-after crash analysis conducted using the empirical Bayes approach (Hauer, 2001). The overdispersion parameter is estimated in the model along with the coefficients of variables (e.g., AADT, length, etc.) employed in order to create the model itself. Hauer (2001) showed that, instead using a fixed overdispersion value, it is better to model this parameter per unit length of roadway in order to increase the accuracy of estimations.

Safety performance functions (SPFs) constitute the foundation of the safety analysis procedures presented in the Highway Safety Manual (HSM) based on the use of calibration factors (CFs) and crash modification factors (CMFs). SPFs are crash prediction models established based on the statistical analysis of crash data, in which crash frequencies are modeled with several predictor variables related to traffic or geometry such as AADT, median width, and length. Several SPFs were developed for different roadway facilities (e.g., rural 2 lane highway, urban 4 lane arterial, etc.) and are used for predicting the expected crash numbers on certain roadway facilities. CFs, on the other hand, are used to calibrate the predicted crash numbers estimated by SPFs to roadway facility types, which do not have specific SPFs. Srinivasan et al. (2013) provides a comprehensive step-by-step guideline to develop SPFs and CFs. In addition to SPFs and CFs, CMFs are used to estimate crash frequencies for facilities which have design variations from the base conditions which SPFs were developed. That is, SPFs were developed for roadway facilities using base conditions for number of lanes, lane widths, median widths, lighting conditions, etc. When a roadway facility has a different design compared to the base conditions, appropriate CMFs should be used to adjust the SPFs accordingly in order to find accurate crash frequencies.

An important task for developing SPFs is the data collection which is burdensome and was defined as labor extensive (Findley et al., 2012). Srinivasan et al. (2013) recommended 100 to 200 sites (e.g., intersections) with a total of 300 crashes at least for 3 years at each intersection in order to develop a proper SPF for a facility type. They also stated that CFs can be developed if the data is insufficient to produce SPFs. For example, in a study by Savolainen et al. (2015), 353 three-legged stop-controlled intersections, 350 four-legged stop-controlled intersections, 210 three-legged signalized intersections, and 349 four-legged signalized intersections were used to develop SPFs whereas only 50 sites were used for regional CFs on average. For calibration factors of roadway segments, Findley et al. (2012) stated that at least 300 segments, randomly selected if possible, were required for North Carolina. However, note that the HSM recommends that at least 30 to 50 sites be used for calibration, and that the selected sites should include a total of at least 100 crashes per year (AASHTO, 2010; Sun et al., 2013). Nevertheless, the site and crash numbers as well as time period thresholds recommended in HSM are not always possible to fit the situation due to data and site limitations. Sun et al. (2013) noted that HSM recommendations should be flexible since the accuracy of models and factors depend on the nature and variability of the employed data. For example, Vogt (1999) used 84 sites of the three-legged intersections, 72 sites of the four-legged intersections, and 49 sites of the signalized intersections in order to develop SPFs, which were also adopted by HSM for rural two-lane two-way intersections. Moreover, Donnell et al. (2016) used 50 intersections with 100 crashes per year in total to develop SPFs in their study. A study from Italy reported that researchers used 7 years of crash data comprising of 644 crashes that occurred at 92 unsignalized urban intersections (Giuffrè, Granà, Giuffrè, Marino, and Marino, 2014). In some cases, due to data limitations, researchers also combined crashes that have different severities such as fatality and incapacitating injuries in order to obtain a reasonable data size (Savolainen et al., 2015). Some researchers also reported that even HSM recommendations are not sufficient to develop accurate crash prediction and calibration factors, adding that same thresholds do not always fit for different facility types (Alluri, Saha, and Gan, 2014; Alluri, Saha, Liu, and Gan, 2014; J. Kim, Anderson, and Gholston, 2015).

In order to develop SPFs, CFs, and CMFs, geometry-, traffic-, and operation- related variables are needed along with the crash data. The crash data is usually obtained from crash reports of the security forces (e.g., police). The traffic and geometry data are usually provided by the responsible branches of departments of transportation in the format of shapefiles or as-built drawings in the case of geometry. However, it is usually very difficult to obtain as-built drawings especially for older facilities. In these situations, as well as for quality assurance, several researchers found it practical and accurate enough to use satellite imagery provided by Google Earth® or other companies (Donnell et al., 2016; Savolainen et al., 2015; Wang, Xie, Abdel-Aty, Chen, and Tremont, 2014).

SPFs are intended to be simple mathematical equations. Therefore, complex models or high number of variables are not favored due to practical and computational reasons. This is because SPFs are crash frequency models commonly used by practitioners who do not have statistical expertise. As such, complex and hard to apply models are unfavorable. The number of variables, on the other hand, are also kept limited in order to ease the data collection process. Savolainen et al. (2015) created two SPFs in their study: (a) a simple SPF comprised only of major and minor approach AADTs, and (b) a complex SPF including AADTs and other variables. For practical purposes, agencies usually prefer the simpler SPFs. In addition, Giuffrè et al. (2014) reported that minor and major approach AADTs along with number of lanes are the best variables that should be used while developing SPFs for intersections. Vogt (1999), on the other hand, employed more variables to establish crash models: major and minor approach volume, peak left-turning percentages, number of driveways, median widths, vertical alignment, presence of protected left-turn phases (if signalized), and peak truck percentage. It was also noted that major and minor approach traffic volumes should be introduced separately into the models in order to enhance the accuracy, and that minor approach volume is more important than major approach volume (Maze, Hochstein, Souleyrette, Preston, and Storm, 2010). Nonetheless, some researchers stated that the unaccounted variables such as weather and demographics, which are not included in the base SPFs of the HSM, may largely enhance the quality and accuracy of SPFs (Mehta and Lou, 2013; Tegge, Jo, and Ouyang, 2010). Furthermore, Mehta and Lou (2013) and Sun et al. (2013) showed that SPFs based on HSM might be over- or underestimating the site specific crash frequencies due to regional differences. Therefore, they reported that state-specific SPFs are more accurate in predicting crash frequencies than HSM-based SPFs even if these HSM-based SPFs are calibrated. In addition, Donnell et al. (2016) found out that statewide SPFs may also perform poorly compared to the regional (within the state) models with county calibration factors while predicting the crashes. Therefore, Donnell et al. (2016) and Kweon and Lim (2014) recommended the development of intrastate regional models (or calibration of state SPFs) particularly when there are geographical differences between regions within a state, adding that extreme localization should be avoided. Nevertheless, it is usually difficult to develop state-specific models, let alone intrastate regional models, due to the limitation in data and number of facilities for which the SPF is needed. In these cases, data from multiple states (pooled data) have to be used to obtain reasonable number of samples and to develop accurate SPFs. This unavailability of state-specific SPFs also leads to another issue called transferability of readily available SPFs. For instance, Farid et al. (2016) used the negative binomial regression model with additional state parameters while developing SPFs through pooled data from multiple states. In this study, they showed that the transferability of SPFs to other states increased when pooled data from multiple states was used to develop the SPFs, which is a crucial finding especially for the adequacy of SPFs developed for rare roadway facility types. Another important note on SPFs is that the developed SPFs are not conclusive models which can be used for a long period of time. The SPFs should be updated regularly (every 3 or 5 years) either by developing new SPFs or by calibrating already available SPFs using recently available data (Srinivasan and Carter, 2011).

In order to successfully assess the safety on roadway facilities, crash data collection, processing and classification are critical. For the crash data collection, researchers have used complete footprints of segments and/or intersections along with the influence areas of these facilities. For example, Edara et al. (2016) noted that they collected crash data to assess the safety benefits of unsignalized RCUTs at the entire footprint of the intersection and influence areas including 1,000 feet beyond both U-turns on the major approach and 250 feet from the intersection on the minor approach. The collected crash data is usually divided by the time period that data covers in order to obtain annual crash frequencies. In addition to total crash frequency, it is very common to disaggregate the data according to severity levels and types of crashes. For example, Edara et al. (2015) divided the crash data into following 4 severity levels for unsignalized RCUTs: property damage only, minor (possible, non-incapacitating) injury, disabling (incapacitating) injury, and fatality. Moreover, data was disaggregated based on the type of crashes to assess the effect of RCUT treatments on the numbers of prevailing crash types. These crash types were listed as follows: angle, right turn, left-turn, rear-end, side-swipe, and passing.

There are different SPF models developed in different studies and for different states. Examples of these SPFs are listed in Table 1. The common features for all these SPFs, either for segments or intersections, is the simplicity and low number of predictive variables in the equations used to model crash frequencies. The roadway segment SPFs generally include AADT and segment length, whereas a few models also introduce speed limit, lane widths and shoulder widths into the SPFs. Intersection SPFs, on the other hand, generally employ major and minor AADTs (Srinivasan and Carter, 2011) also used the number of legs at intersection in addition) in order to model crash frequencies. The logarithmic transformation (natural logarithm) is a commonly used approach to introduce AADT (major and/or minor) and segment length into SPFs whereas no transformation was preferred in some models. For example, Kim et al. (2015) stated that non-transformed AADT fits better to the crash prediction models than the log-transformed AADT for Alabama. The effects of these variables on the crash frequency are determined based on the sign of variable coefficients. That is, a positive sign means an increase in the crash frequency whereas a negative sign indicates a reduction in crash frequency. For example, it can be assumed that the sign of coefficient of “shoulder width” variable should possibly be negative since larger shoulder width implies safer roadway. Similarly, the coefficient of “AADT” can be positive since higher number of vehicles usually generate more crashes. Mehta and Lou (2013), however, highlighted a critical property of crash prediction models, which is related to the sign of coefficients. They stated that the sign of coefficient may change depending on the set of variables used to model the crash frequencies. This is very important since the sign of coefficient is virtually the only thing that indicate the direction of the effect of the variable. Therefore, researchers should pay extra attention to the set of variables as well as the resultant coefficients of the variables when establishing a crash prediction model. The goodness-of-fit of the fitted models is usually determined based on several indicators such as likelihood ratio test, Akaike Information Criterion, Bayesian Information Criterion, or Pearson's chi-squared test. For the roadway crash prediction analysis, generally, the statistical significance of the model coefficients are controlled by p values reported in the conducted analyses. In these analyses, it is customary to assume a coefficient with a significance level lower than 0.05 as a significance coefficient (based on the 95% confidence level). However, Kweon and Lim (2014) reported that, if the sample size is limited, the variable coefficients may be found not statistically significant, therefore, it may be acceptable to assume significance coefficients up to 0.20 depending on the conditions (80% confidence level). For instance, Tegge et al. (2010) used a 0.10 significance coefficient (90% confidence level) in their study while developing SPFs.

Table 1 Example SPF models in the literature

SPF Models	Variables	Location, Facility	Study
Model 1: $N = \exp(\alpha + \beta * \ln(AADT) + \ln(L))$ Model 2: $N = \exp(\alpha + \beta_1 * \text{AADT} + \beta_2 * \text{L})$ Model 3: $N = \exp(\alpha + \beta * \text{AADT} + \ln(L))$	AADT L: Segment length	Alabama urban and suburban arterials	Kim et al., (2015)
Model 1: $N = \beta_0 * AADT^{\beta_1} * L$ Model 2: $N = \beta_0 * AADT^{\beta_1} * L^{\beta_2} * \exp(\frac{\beta_3 * n}{L})$ Model 3: $N = \exp(\beta_0 + \beta_1 * DY + \beta_2 * \ln(AADT) + \beta_3 * \ln(L) + \beta_4 * LW + \beta_5 * S)$ Model 4: $N = \exp(\beta_0 + \beta_1 * SW + \beta_2 * LW) * AADT^{\beta_3} * L$	AADT L: segment length S: speed limit n: number of minor junctions or driveways LW: lane width SW: shoulder width DY: dummy variable for the effect of year	Alabama two-lane two-way rural roads and four-lane divided highways	Mehta and Lou, (2013)
Model: $N = \exp(\alpha + \beta_1 * \ln(AADT_t) * \ln(L_t))$	AADT L: Segment length t: year index for panel data analysis	Virginia multilane highway and freeway segments	Kweon and Lim, (2014)
Model: $N = \exp\big(\beta_0 + \beta_1 * \ln(AADT_{maj}) + \beta_2 * \ln(AADT_{min})\big)$	AADT_{maj}: major approach AADT AADT_{min}: minor approach AADT	Urban signalized Intersection	Sun et al., (2013) and Tegge et al., (2010)

2.1.6. Advantages and Disadvantages

In general the advantages and disadvantages of RCUTs can be listed as follows (Hughes et al., 2010; Mississippi Department of Transportation (MDOT), 2010):

Advantages:

- Provides less disturbed (without stopping) through movement of major traffic.
- Reduces the need for traffic signalization.
- Vehicle-vehicle conflict points are reduced.
- Crashes are less severe compared to crashes of conventional designs.
- Provides substantial time savings due to requirement of 2 signal phases (instead of conventional 4 phase) which also leads to reduced emissions and fuel consumption.
- Less disturbed progress of traffic platoons.

Disadvantages:

- May have disadvantages for pedestrians in terms of delay, inconvenience, and increased traffic exposure.
- Safety of pedestrian should be considered as RCUT design might be counter-intuitive.
- May not be suitable for locations with high through and left-turn volumes from minor approach.

- Usually drivers easily adapt, yet driver confusion was also noted especially immediately after implementation.
- Large vehicles should be considered for U-turn maneuvers (median and lane width need to be adjusted accordingly).
- May require loon construction for large vehicles (e.g., truck trailers).
- Roadside businesses may be affected adversely, local residents, commuters, and business owners should be considered.
- Higher construction and maintenance costs.
- Additional crossing time for pedestrians since pedestrians need to cross longer distance compared to conventional designs.

In addition to these advantages and disadvantages of RCUTs, the situations for which an implementation of RCUTs is recommended is as follows (Bared, 2009; Hughes et al., 2010; Mississippi Department of Transportation (MDOT), 2010; Ott, Haley, Hummer, Foyle, and Cunningham, 2012):

- Major approach has high through and left-turn volume while minor approach has relatively low.
- The ratio of minor approach volume to intersection volume is less than 0.2 (which may differ from state to state).
- The ratio of major approach left-turn volume per lane to minor road volume per lane is greater than 0.80 when these two movements occur at the same signal phase.
- The through and left-turn traffic on major approach is highly congested due to signal phasing.
- When there is available area to have median widths larger than 40 feet (some sources state 64 feet), or availability for additional design elements for U-turns (e.g., loons).
- When right-angle collisions are a major concern for the intersection.
- When there is no sufficient gaps for minor approach maneuvers to efficiently and safely conduct minor road through and left-turn movements.

2.1.7. Summary

Restricted Crossing U-Turn (RCUT) intersections are one of the alternative solutions for conventional unsignalized/signalized urban or rural arterials, which possess preeminent volumes on major route and relatively low through volumes on the minor approach (Hughes et al., 2010). According to the FHWA (Hummer, Ray, et al., 2014), the RCUT is an innovative intersection design that improves safety and operations by changing how minor road traffic crosses or turns left at a major road. RCUTs are also known with different names depending on the traffic flow characteristics, such as superstreet intersections (signalized RCUTs) and J-Turn intersections (unsignalized RCUTs). In several states, they are also known as reduced conflict intersections or synchronized street intersections. RCUTs are evaluated to enhance the efficiency and safety as well as capacity of intersections compared to the conventional designs with similar traffic volumes (Hughes et al., 2010). Moreover, it is possible, and even more advantageous, to implement multiple RCUTs consecutively, as a corridor treatment along unsignalized or signalized routes to minimize travel times, while maximizing capacity and managing traffic speed (Bared, 2009; Haley et al., 2011; Hughes et al., 2010; Xu et al., 2017). Note that RCUTs do not change any of the movements that are possible from the major roadway such as right turns and left-turns. The minor route traffic, on the other hand, has to make a right turn followed by a U-turn at a designated location (usually at 400 to 1,000 feet downstream) – either signalized or unsignalized – in order to continue in the desired direction (Hughes et al., 2010; Hummer and Jagannathan, 2008). To clarify, from the minor approach, drivers have to make a right turn first and a U-turn after the right turn in order to make a left-turn whereas through movement requires a right turn, a U-turn, and another right turn. This adjustment helps drivers that stop at the minor roadway to avoid navigating and monitoring a complex intersection with two directions of traffic, where the major roadway drivers are often traveling at high speed, during a crossing or left-turning maneuver.

In addition to the operational advantages, RCUTs have various safety benefits. For example, crashes at RCUT intersections were found to be less severe than crashes at conventionally designed intersections. Moreover, several studies state that there are very few crashes occurring due to the downstream U-turns (Hughes et al., 2010; Hummer and Jagannathan, 2008). This is partially due to the reduced number of conflict points. That is, a RCUT intersection has 18 conflict points, whereas a conventional intersection has 32 (Hummer and Jagannathan, 2008). Moreover, one of the most important contributions of RCUTs to traffic safety is the reduction in the number of left-turn and angle crashes, which are also considered as serious conflict types. Furthermore, after the implementation of RCUTs, number of fatalities and number of injuries were observed to decrease, and even better, in some locations, no fatalities or injuries were observed (Hughes et al., 2010; Inman and Haas, 2012). In general, RCUTs are found to be much safer in terms of crash rates or crash frequencies compared to conventional intersections, and they substantially enhance the safety of an intersection after the implementation.

2.2. KNOWLEDGE ACQUISITION THROUGH SURVEYS

This section of the report discusses how the data were collected from the selected state DOTs in order to gather the information on RCUT intersections. The following aspects will be discussed throughout this section: (1) data collection methodology; (2) data collection difficulties and issues; and (3) responsiveness of state DOTs.

2.2.1. Data Collection Methodology

The research team developed a detailed survey as part of the project. Twenty-six state DOTs have been identified as important contributors to this project in order to gather information on the RCUT implementations (also referred to as J-turns, superstreets, reduced conflict intersections, and synchronized street intersections) in their states. A copy of this survey is provided in Appendix B. This questionnaire had a total of 17 questions, and the state contacts were asked to complete these questions based on the agency's experience with the RCUT intersections. They had also been asked to provide information on the availability and access of geometric, traffic, and crash data for the RCUT intersections in their states because the research team has also been planning to collect these data from the states that already have RCUT implementations (see Task 3). The questions are categorized as follows:

- Personal information (of the state DOT representative, who is filling out the questionnaire)
- RCUT intersections in their state,
- General perspectives and planning,
- Traffic safety and operations,
- Prospective RCUT implementations in their state.

Once the questionnaire was finalized, the research team started contacting the state DOTs. First, the research team sent out the survey e-mails to the state contacts provided by Federal Highway Administration. Second, if any state contact did not respond, the research team made follow-up phone calls in order to confirm his/her participation. If the state contact did not confirm participation in the study, the research team had to determine an alternative DOT representative with sufficient knowledge to fill out the survey.

2.2.2. Data Collection Difficulties and Issues

Throughout the data collection process, the FAMU-FSU research team encountered a number of difficulties/issues, including the following:

1) ***Differences in time zones***

The FAMU-FSU research team had difficulties in contacting state DOTs located on the West Coast (e.g., Alaska, Oregon, California) due to time zone differences with the State of Florida.

2) ***Identification of the appropriate DOT representative***

Initially, the research team contacted by phone the DOT representatives, provided by the Federal Highway Administration. In several states, the research team also had to determine an alternative DOT representative with sufficient knowledge to fill out the survey.

3) ***Workload of DOT representatives***

Many State DOT representatives mentioned that they were not able to fill out the questionnaire in a short span of time due to their workload, and asked for more time to complete the survey.

4) ***Missing participations***

States of Tennessee and Maryland have not agreed on participating the survey due to a variety of reasons including their workload. The research team has been constantly in contact with the Tennessee and Maryland DOTs in order to solve this problem, or at least, to get the RCUT related data needed to complete Task 3 (See Task 3).

2.2.3. Responsiveness of State DOTs

The responsiveness of State DOTs was estimated after collecting the surveys. The responsiveness value (measured in days) was calculated as a difference between the time of receiving the filled survey and the time of the first contact by e-mail. The responsiveness values are presented in Figure 6. It can be observed that responsiveness among State DOTs significantly varies. Some States were able to respond within 1 day, while certain States returned the filled survey after 30 days (Note that some states have not completed the survey yet – N/A). Such a significant difference in responsiveness can be explained by workload of the State DOT representatives responsible for the task.

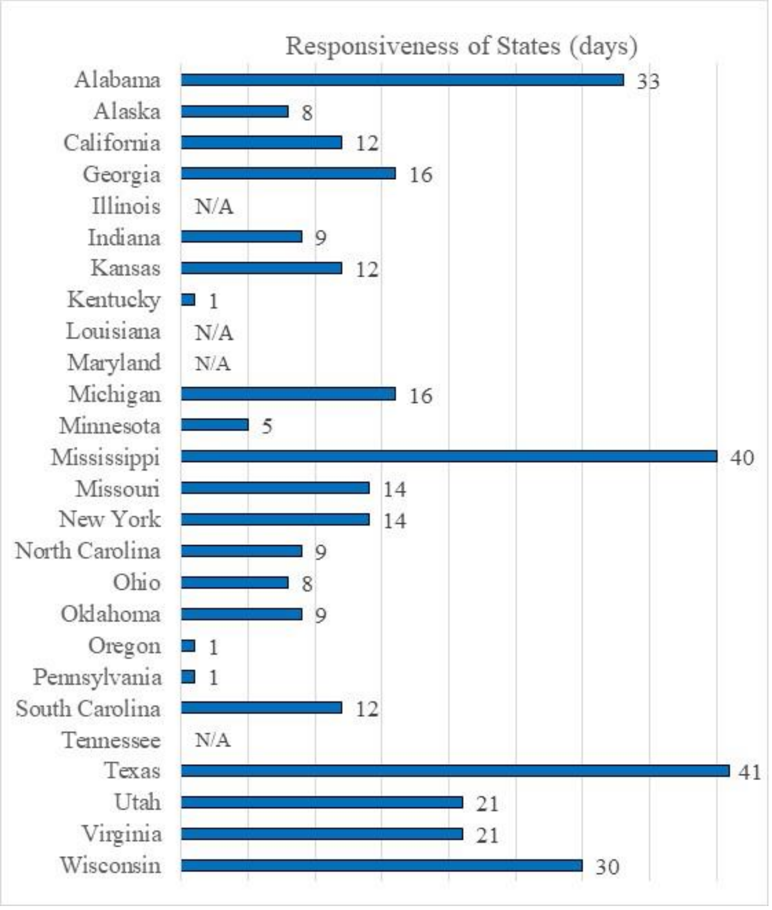


Figure 6. Responsiveness of State DOTs

2.3. KNOWLEDGE EXTRACTION FROM THE SURVEY RESPONSES

2.3.1. Personal Information

Q1. Please identify yourself

A detailed information for each State DOT representative (including name, title, agency, address, telephone, fax, and e-mail), participated in this study, is presented in Appendix J that accompanies this report.

Q2. What category best describes the main function of your office? Please feel free to mark two choices as needed.

A total of nine unique functions of the State DOT offices, which participated in the survey, were identified, including the following: 1) Construction; 2) Design; 3) Environmental Management; 4) Maintenance; 5) Policy; 6) Program Management; 7) Right of Way; 8) Traffic Operations; and 9) Other. Please see Table 2, Table 3 and Figure 7 for details.

Table 2 List of State DOT offices by the main function.

Office Function / State	Alabama	Alaska	Alaska 2	California	Georgia	Illinois	Indiana	Kansas	Kentucky	Louisiana	Maryland	Michigan	Minnesota	Mississippi	Missouri	New York	North Carolina	Ohio	Oklahoma	Oregon	Pennsylvania	South Carolina	Tennessee	Texas	Utah	Virginia	Wisconsin
Construction																											
Design																				✓				✓			
Maintenance																											
Planning and Development			✓										✓					✓						✓			
Safety	✓		✓		✓			✓	✓				✓	✓	✓	✓		✓		✓	✓	✓				✓	✓
Traffic Operations					✓			✓				✓			✓	✓	✓			✓				✓			✓
Transportation Statistics								✓																			
Research																											
Other		✓	✓				✓					✓															

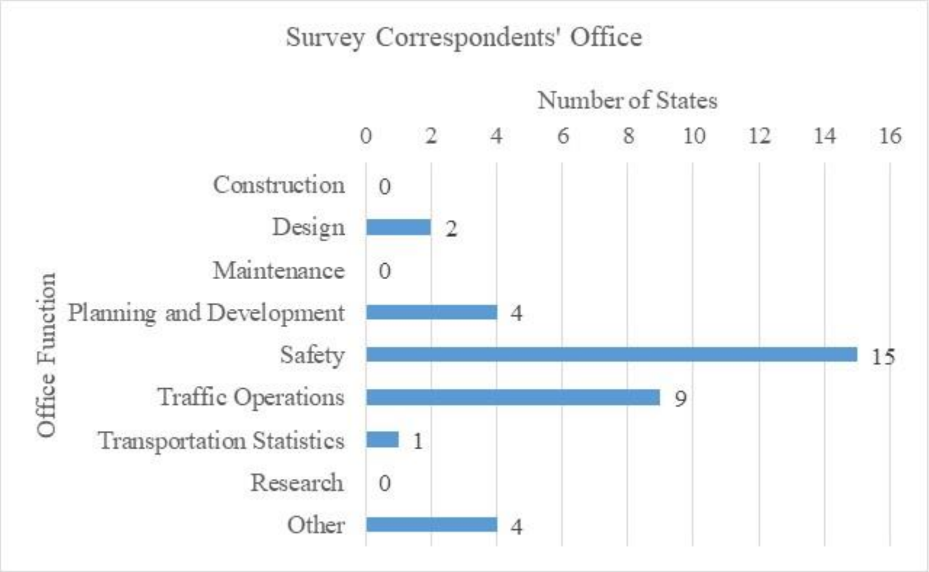


Figure 7. Distribution of State DOT offices by the main function

Table 3 List of DOT office functions classified as "Other".

State	DOT Office Function
Alaska - Jeff Jeffers	Standards, Policy, and Procedure Development
Alaska - Matt Walker	Design standards
Indiana	Traffic Engineering (including traffic safety)
Michigan	Geometrics

2.3.2. RCUT Intersections in Your State

Q3. Does your state have RCUT intersections, whether they are under the state DOT jurisdiction or not? If your answer is no, you do not have to fill the table, please proceed with Question 14.

Table 4, Figure 8 and Figure 9 show the responses by the DOTs in detail.

Table 4 Number and type of RCUTs in the contacted states

States	Number of RCUTs	Urban	Rural	Signalized	Stop	Merge
Alabama	6	5	1	5	1	
Georgia**	23	16	7	0	18	5
Indiana	3	0	3	0	3	0
Kentucky	1	0	1	0	1	0
Maryland*	14	N/A	N/A	1	13	0
Michigan	1	1	0	0	1	0
Minnesota	12	3	9	0	12	0
Mississippi	8	1	7	0	0	8
Missouri	19	N/A	N/A	0	19	0
North Carolina	105	N/A	N/A	12	93	0
Ohio	3	3	0	3	0	0
South Carolina	3	0	3	0	1	2
Tennessee*	4	N/A	N/A	0	4	0
Texas	5	5	0	5	0	0
Wisconsin	8	N/A	N/A	0	8	0
Total	**215**	**N/A**	**N/A**	**26**	**174**	**15**

***** The number has not been confirmed by the state DOT yet.

****** Georgia DOT may have not provided the RCUT locations but rather other type of intersections.

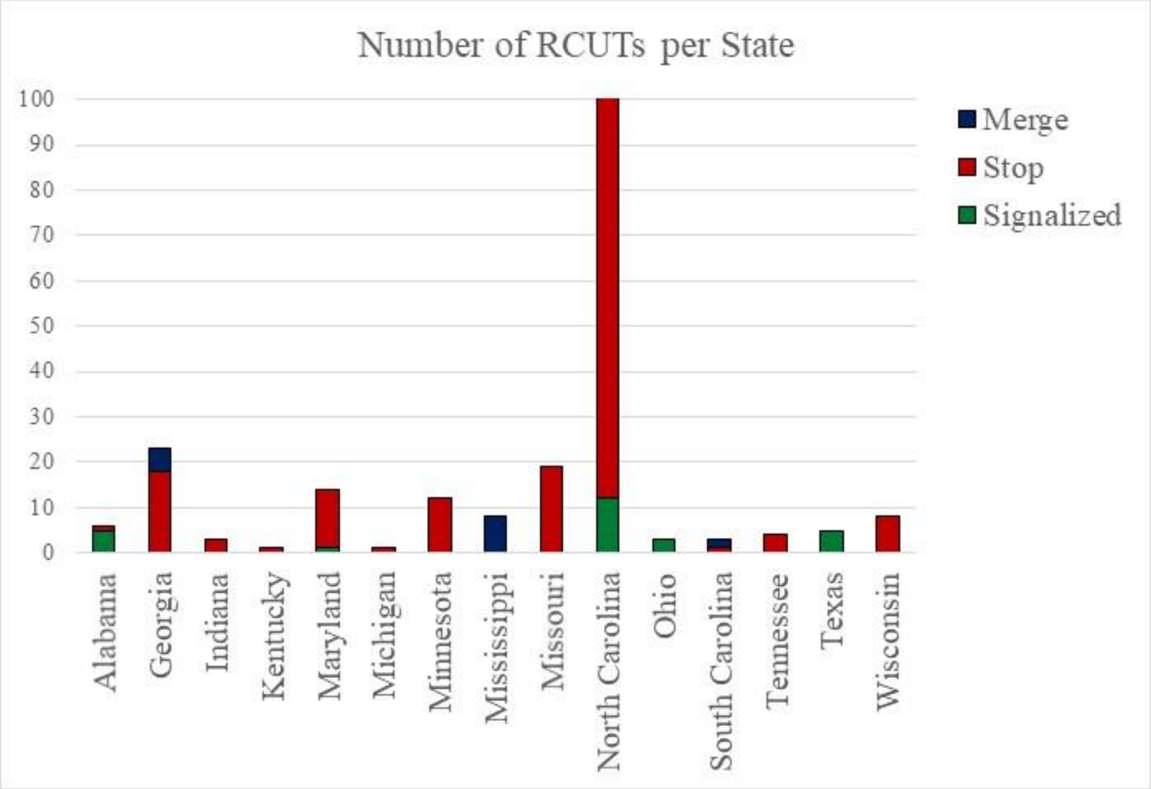


Figure 8. Number of RCUTs per state

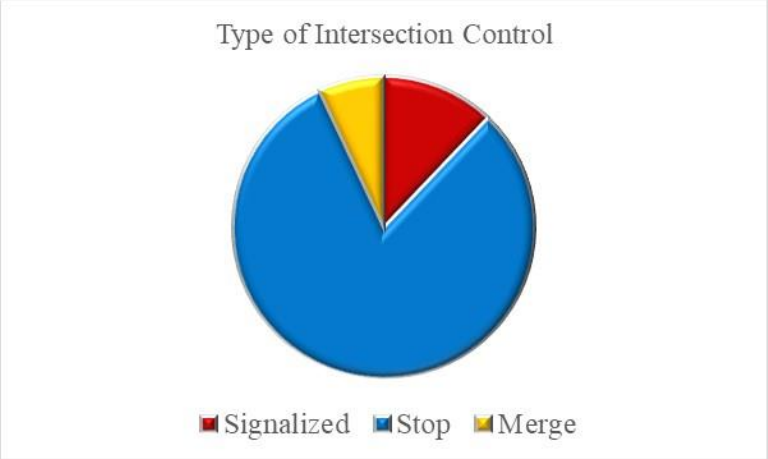


Figure 9. Type of intersection control

Q4. The research team would also like to gather some data for these RCUT locations. Can you provide information on how to gather these data (offline or online availability, shapefiles)?

Table 5 shows the responses by the DOTs in detail.

Table 5 Information on the available RCUT data

States	Crash	AADT	Geometry	Signalization	Construction
Alabama	Private - Contact DOT	Public	Aerial Images	Private - Contact DOT	Not Available
Georgia	Public	Public	Private - Contact DOT	Private - Contact DOT	Private - Contact DOT
Indiana	Private - Contact DOT	Public	Aerial Images Private - Contact DOT	N/A	In Survey
Kentucky	In Survey	In Survey	In Survey	N/A	In Survey
Michigan	N/A	In Survey	In Survey	N/A	Not Available
Minnesota	Private - Contact DOT	Public	Private - Contact DOT	N/A	Private - Contact DOT
Mississippi	Private - Contact DOT	Public	Private - Contact DOT	N/A	In Survey
Missouri	Private - Contact DOT	Public Contact DOT	Aerial Images	N/A	In Survey
North Carolina	DOT will provide	DOT will provide	DOT will provide	DOT will provide	DOT will provide
Ohio	Public	In survey	Aerial Images	Not Available	Not Available
South Carolina	In Survey	In Survey	In Survey	N/A	In Survey
Texas	Public	Public	Private - Contact DOT	Private - Contact DOT	Private - Contact DOT
Wisconsin	Private - Contact DOT	In Survey	Private - Contact DOT	N/A	Not Available

2.3.3. General Perspectives and Planning

Q5. Based on your experience with the RCUTs, what are the most important geometric design parameters that should be considered while designing a new RCUT (lengths of merging/offset/transition, median and shoulder widths, number of lanes, etc.)? How did these parameters affect the operations after the construction?

Table 6, Table 7 and Figure 10 show the responses by the DOTs in detail.

Table 6 RCUT's most important geometric design parameters according to DOTs

States	Comments
Alabama	Spacing of the U-turn operation in line with ultimate signal progression desired.
Georgia	The length of the acceleration lane on the mainline for vehicles turning right from the side-street has been shown to be important. At SR 74 @ Sandy Creek Rd. there have been difficulties merging and an occurrence of rear end vehicular crashes for vehicles in the acceleration lane due to potentially inadequate acceleration lane length. The size of the median island and the overlap between the island and median itself is also important, because an RCUT becomes ineffective if drivers are still able to make a left-turn from the side-street at the intersection location. We've also found that providing adequate distance between side-streets and U-turn locations is important, especially in rural settings, because there must be enough distance for vehicles from the side-streets to merge over multiple lanes of potentially high-speed traffic before turning into the turn lane, but not so long that it causes the RCUT to operate poorly.
Indiana	Offset of the U-turn points from the center intersection. Ample accommodation of turning radius at the two U-turn points (loons). Signing and pavement markings.
Kentucky	Signing and pavement markings.
Michigan	No response
Minnesota	We have not found any set distinction in safety performance after the building of these as of yet. Pulling the U-turn locations in closer to the intersection seems to help with selling these to the public and providing a minimum amount of inconvenience. Median width seems to be important in selecting sites as it is easier to accommodate the U-turns of large vehicles.
Mississippi	In more recent RCUT designs, MDOT has worked to reduce the distance between minor road right turns onto the major roadway (the new primary movement) and the beginning of the deceleration lane to make the new median U-turn movement. This has been an intentional effort to reduce the time that a lower speed vehicle is in the major roadway, mixing with higher speed vehicles, before entering a refuge lane. Additionally, new right turn lanes from the major roadway turning onto the minor roadway have been designed with significant length, beginning in parallel with the median U-turns. This effort was again made to ensure that low speed vehicles are not mixing with major roadway, higher speed vehicles for too long of a distance, if at all. Also, these extended right turn lanes essentially act as the "bulb out" areas, present in RCUT installations in other states, which accommodate the turning movements of larger vehicles. While most MDOT RCUT locations feature small minor roadway truck volumes, this design ensures that larger trucks can use the median U-turns if they so desire or are required to.
Missouri	The University of Missouri – Columbia (MIZZOU) did a driver simulator study for acceleration and deceleration lanes for RCUTs. I can forward you a copy of this study.
North Carolina	The side street ADT must be below 25,000 vehicle/day.
Ohio	The DOT Rep hasn't been involved in the design of any RCUTs, so he would have to ask his roadway/design team for further information.
South Carolina	1. Offset of U-turn from side street – typical design is 600-800 feet 2. Concrete channelizing islands to clearly direct mainline turning traffic and prohibit/discourage wrong-way movements from the side streets. 3. Most designs have been on four lane-divided highways with 20-30 feet medians, providing adequate width for RCUT movements within the median and minimizing loon dimensions for WB62.
Texas	Auxiliary lanes between intersections. Driveway locations near r-cut locations Turn radius to accommodate trucks. Use of Triple left-turns is new concept, did not meet driver expectancy, but worked better over time.
Wisconsin	1. U-turn/J-turn placement – on tangent, away from existing median openings, etc. 2. Median width – narrow medians require loons at the U-turn/J-turn locations to accommodate large turning trucks 3. Adequate weaving distance between side road and U-turn/J-turn based on AADT, number of mainline lanes and mainline speeds.

Table 7 Summary of the most important geometric design parameters for DOTs.

Important Geometric Design Parameters / State	Alabama	Georgia	Illinois	Indiana	Kansas	Kentucky	Louisiana	Maryland	Michigan	Minnesota	Mississippi	Missouri	North Carolina	Ohio	South Carolina	Tennessee	Texas	Wisconsin
Offset Distance	✓	✓		✓						✓					✓			✓
Acceleration Lanes and Length		✓										✓					✓	
Deceleration Lanes and Length												✓					✓	
Median Opening Size		✓																
Median Width										✓					✓			✓
Turning Radius at U-turn				✓													✓	
Signing and Marking				✓		✓												
Weaving Distance											✓							✓
Right Turn Lanes from Major Road											✓							
Concrete Channelization															✓			
Major Road # of Lanes and Speed																		✓
Minor Road Volume													✓					
Driveways																	✓	

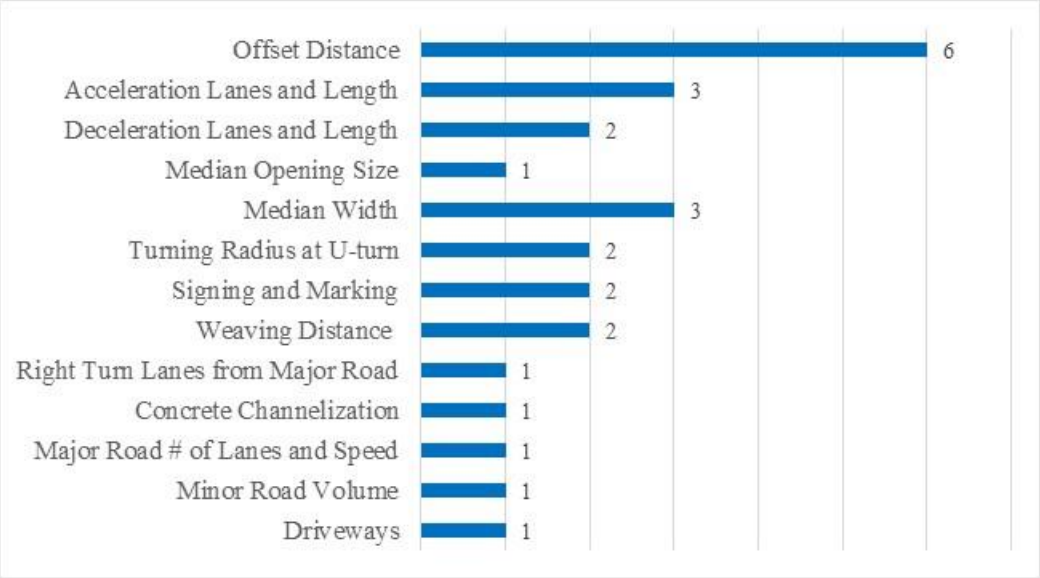


Figure 10. The most important design parameters

Q6. In your state, what is the ratio of the minor roadway traffic volume over the total intersection volume (or major roadway traffic volume) for the selected RCUT locations?

Table 8 and Figure 11 show the responses by the DOTs in detail.

Table 8 The ratio of the minor roadway traffic volume to the total intersection volume at RCUTs

States	Comments
Alabama	Not available.
Georgia	It varies. Operation Analysis is performed for select RCUT Locations.
Indiana	That you can calculate from the AADT data I provided above/earlier.
Kentucky	Not available – locations have been based on crash experience. ADT on Deckard School Road is unknown.
Michigan	Not available.
Minnesota	Minimum Minor ADT: 540 ADT (US 53 and CSAH 24, Cotton, MN) Maximum Minor ADT: 3,950 (US 169 and Dodd Street, Saint Peter, MN) Minimum Major ADT: 7,800 (US 53 and CSAH 24, Cotton, MN) Maximum Major ADT: 39,600 (MN 36 and Demontreville Trail, Lake Elmo, MN) Minimum Min/Maj: 3% (1,100 on Demontreville, 39,600 on MN 36) Maximum Min/Maj: 25% (2,875 on MN 284, 11,575 on US 212) AVERAGE Min/Maj: 1,798/ 17,778 = 10.1%
Mississippi	When giving consideration to the installation of an RCUT in a particular location, the Mississippi DOT utilizes the FHWA recommendation that minor roadway traffic volumes make up no more than 20-25% of total entering intersection volumes. In most cases, minor roadway volumes have been well below that recommended percentage. It should be noted that not all current RCUT locations adhere to that guidance; however, MDOT uses it currently when evaluating prospective new locations for the treatment.
Missouri	We do not have this information readily available, but we could pull this information if needed.
North Carolina	Varies widely.
Ohio	Major: OH-4 Bypass = 31,745 Minor: Symmes Rd West approach = 29,538 East approach = 23,609 Major: OH-4 Bypass = 31,745 Minor: Tylersville Rd West approach = 14,432 East approach = 7,522 Major: OH-4 Bypass = 31,745 Minor: Hamilton Mason Rd West approach = 7,747 East approach = 7,747
South Carolina	Berkeley County: US 52 and S-50: AADT Minor Volume/Total Volume = (660+2124)/(660+2,124+18,500+21,900)=0.06 Union County: US 176 and S-407: AADT Minor Volume/Total Volume = (1,380+1,380)/(1,380+1,380+8,500+8,300)=0.14 Horry County: SC 9 BYP and S-66: AADT Minor Volume/Total Volume = (950+950)/(950+950+8,500+8,500)=0.10
Texas	N/A
Wisconsin	No ratio is available. Minor road ADT estimates may be available upon request.

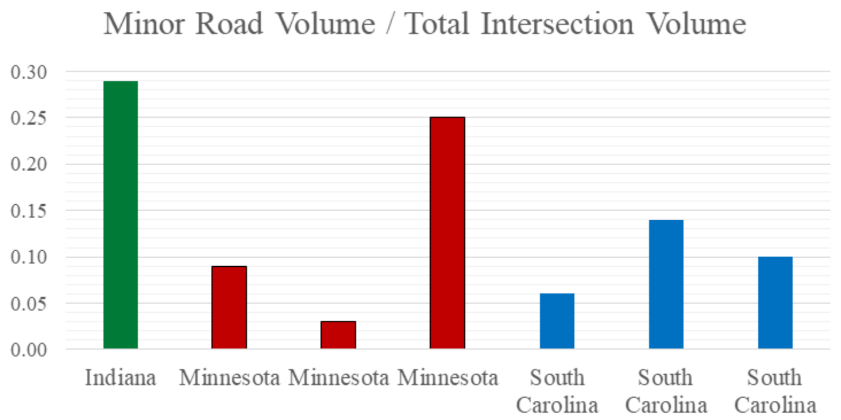


Figure 11. Ratio of minor road volume to total intersection volume

Q7. Have you performed a benefit-cost (BC) analysis for the RCUTs? If yes, what types of safety benefits have you assessed (crash frequency and severity reduction, etc.) What was the result of the before and after BC analysis?

Table 9, Table 10 and Figure 12 show the responses by the DOTs in detail.

Table 9 Safety benefits that were assesses based on benefit-cost (B/C) analysis (if available).

States	Comments
Alabama	Not available.
Georgia	GDOT's Safety Program will respond in the following week, with an answer to this question.
Indiana	The three sites have been in operation only a short time to this point (May 2017). Nonetheless, experience to this point at all of the sites has been positive relative to in-service performance; that is, the J-turns have been effective at addressing the traffic safety problems present in the prior intersection geometry/operation (conventional 2-way stop-controlled intersections).
Kentucky	Not specifically for Kentucky. For discussions, we have used analysis that other states have performed.
Michigan	Not available.
Minnesota	We did a back-of-the-envelope calculation on the 8 sites with the after data to 2015. The B/C to data (not considering future benefits) is already at about 1.2. We have used this to discuss that these sites have already payed for themselves and still have 15-30 years of life left! Severe Right Angle Crashes: 100% reduction Right Angle Crashes: 77% reduction Injury Crashes: 50% reduction Multi-Vehicle: 31% reduction (not statistically significant though).
Mississippi	A before and after crash reduction study of Mississippi's first RCUT – US 98 at Old Hwy 63 North – shows an overall crash reduction of 81%. Based on that reduction value and a construction cost of $1.52 million, the project will realize a benefit to cost ratio of 25.31 should it reach its conservatively estimated service life of 20 years. It should be noted that MDOT has no reason currently to assume that the service life will not continue beyond 20 years. Additionally, fatal and life threatening crashes, the crashes that drove the RCUT implementation, have been eliminated. Moderate injury crashes have also fallen by 92%.
Missouri	Not available.
North Carolina	We use CMFs for unsignalized superstreets based on our 2010 research: 0.54 for total crashes and 0.37 for fatal and injury crashes. B/C ratios are great based on those CMFs.
Ohio	We have done a planning stage B/C for an RCUT. Let me try and gather more of these data for you.
South Carolina	Benefit-Cost analysis is typically completed once a minimum 3 years of after crash data is available. These calculations are performed once the previous year's crash data is closed out (July 2017 using 2016 crash data). The Safety Office calculates changes in the severity and number of crashes as well as the changes in rate. The 5-yr B/C ratio for the Horry County SC 9 BYP and S-66 project is 48.83.
Texas	No
Wisconsin	Not available.

Table 10 States that have conducted B/C analysis for RCUTs

Benefit-Cost Analysis for RCUT Implementations / State	Alabama	Georgia	Indiana	Kentucky	Maryland	Michigan	Minnesota	Mississippi	Missouri	North Carolina	Ohio	South Carolina	Tennessee	Texas	Wisconsin
B/C Analysis	No	N/A	No	No	N/A	No	Yes	Yes	No	Yes	Yes	Yes	N/A	No	No

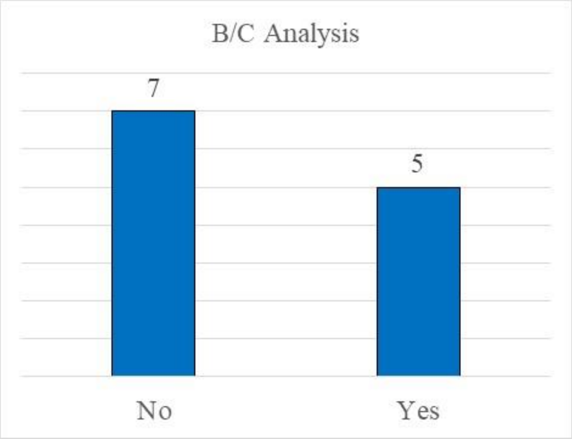


Figure 12. Number of states that did and did not conduct B/C Analysis

2.3.4. Traffic Safety and Operations

Q8. What are the types of crashes RCUTs have reduced? Are there any type of crashes that occurred more than before the implementation?

Table 11, Table 12 and Figure 13 show the responses by the DOTs in detail.

Table 11 Types of crashes which RCUTs have reduced or increased.

States	Comments
Alabama	Right-angle crashes, left-turns from side streets. Concern with U-turn angle crashes (particularly with larger trucks.)
Georgia	Of the RCUTs analyzed, angle crashes have seen the largest reduction after installation. No increase in other types of crashes has been observed from the data analyzed.
Indiana	Severe crashes (i.e., those resulting in fatal and serious injury to drivers or passengers). The bulk of that positive effect has been to high-speed, right-angle crashes involving a vehicle coming off the minor, stop-controlled approach colliding with either a through vehicle in the near-side approach or through vehicle in far-side approach in the 2nd stage of crossing. (For all 3 sites, the mainline is multilane.)
Kentucky	N/A
Michigan	N/A
Minnesota	Right Angle and Severe right angle have seen dramatic and statistically significant reductions. Injury crashes and multi-vehicle crashes have also been reduced. Not statistically significant increases were: rear-end (+71%), run-off-road (+267%), sideswipe (+100%)
Mississippi	Although the RCUT is still a fairly new countermeasure within the state of Mississippi, the results documented thus far have shown a substantial reduction of all crash types across the board at all installations. Where there have been crashes in the post-installation time frame, they have primarily been low speed, minor injury or property damage-only rear end crashes in the new minor road channelized right turn lane.
Missouri	Right Angle, Fatal Crashes, Total Crashes, Serious Injury Crashes
North Carolina	Angle and left-turn crashes largely disappear. We see a few more rear end, sideswipe, and run off road crashes.
Ohio	RCUTs have reduced high severity angle crashes that occur at rural, 4-lane divided intersections. By using an RCUT and closing the median opening, this eliminates this type of angle crash by making vehicles travel down the segment and make the U-turn.
South Carolina	Right angle crashes have been reduced
Texas	N/A
Wisconsin	We typically target right angle crashes that occurred on the far side of a divided highway. We have seen a reduction in these types of crashes after the RCUTs were installed.

Table 12 Summary of DOT responses to types of crashes which RCUTs have reduced or increased.

Crash Type / State	Alabama	Georgia	Illinois	Indiana	Kentucky	Louisiana	Maryland	Michigan	Minnesota	Mississippi	Missouri	North Carolina	Ohio	South Carolina	Tennessee	Texas	Wisconsin
Right Angle	✓	✓		✓					✓	✓	✓	✓	✓	✓			✓
Rear-End									X	✓		X					
Run-Off-Road									X	✓		X					
Side-Swipe									X	✓		X					
Left Turn from Minor Road	✓											✓					
U-turn	X																
Multi-Vehicle									✓								
High-Speed				✓													
Severe				✓					✓	✓	✓		✓				

Note: ✓ means reduction in crashes, X means increase in crashes.

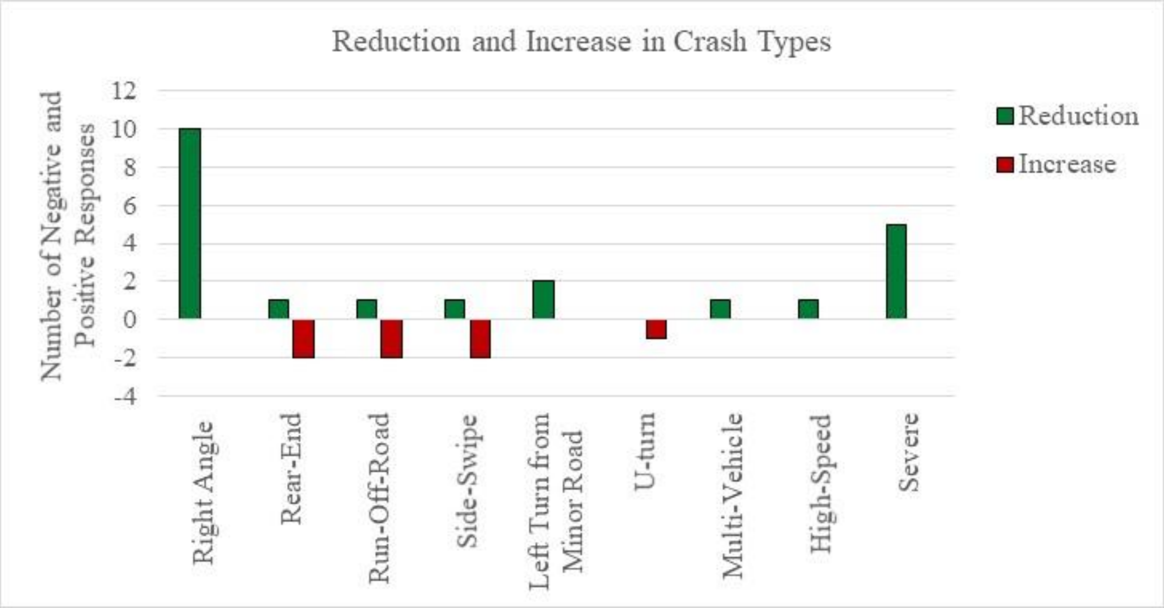


Figure 13. DOT response to types of crashes which RCUTs have reduced or increased.

Q9. How are pedestrians and bicyclists affected from the RCUT design based on your experience with the RCUTs in your state, in terms of traffic safety, signalization, operations and others?

Table 13 and Figure 14 show the responses by the DOTs in detail.

Table 13 Effects of RCUTs on the pedestrians and bicyclists.

States	Comments
Alabama	Improved safety, often handled through a two-stage crossing.
Georgia	All of the RCUT's currently installed in GA are unsignalized, and a high percentage of them have no pedestrian/bicycle facilities in place. Of the remaining, none have pedestrian/bicycle crossings across the mainline, only across the side-streets and there have been no reports of a decrease in safety (increase in pedestrian/bicycle accidents) or operation due to the presence of pedestrians/bicyclists.
Indiana	Not available.
Kentucky	Not available.
Michigan	Median available to reduce crossing time and for storage
Minnesota	No crash data to show increase or decrease yet. Most of these locations both before and after are not inviting or comfortable locations for bikes and pedestrians, and seem to not be used in this regard. However, discussions are continuing as these are used in more urban/pedestrian friendly areas and how to accommodate them.
Mississippi	Mississippi RCUT locations have exclusively been located in rural, high-speed locations where there is not consistent pedestrian or bicycle traffic.
Missouri	Mostly implemented in rural environments where there is little bicycle and pedestrian activity.
North Carolina	Pedestrians are great at RCUTs. See our 2013 research report on that topic. Bikes along the main street are better with an RCUT. Crossing bikes can be an issue if there is a moderate to high demand.
Ohio	For the three intersections on SR-4 Bypass, there are not any crosswalks or pedestrian signal heads. These intersections are along a main (6+ lane) corridor. For the proposed locations, they will be located on rural, 4-lane divided route intersections, so the pedestrian travel in these areas is minimal to none.
South Carolina	RCUTs have not been installed in areas with high pedestrian or bicycle volume
Texas	No change with bicycle usage. Pedestrian crossing are provided at signalized intersections.
Wisconsin	Pedestrians and bicyclists are accommodated as needed at RCUT sites in Wisconsin. Median curb opening with narrow paved path is typically provided.

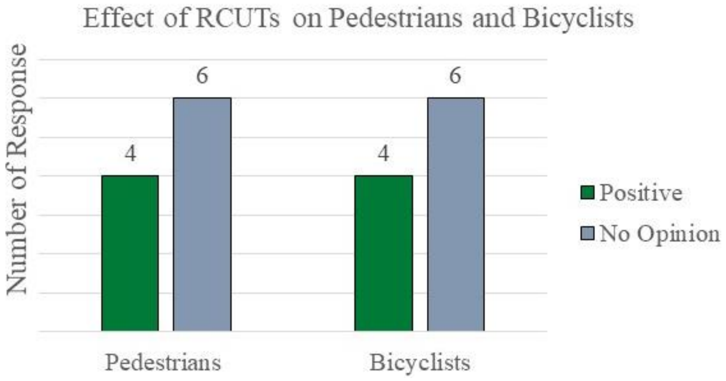


Figure 14. DOT responses related to the effect of RCUTs on the pedestrians and bicyclists

Q10. Have you utilized the micro-simulation models prior to the RCUT implementation (i.e., a micro-simulation model for the intersection that can identify the traffic conflict points)? If yes, which software and what significant results have you obtained?

Table 14 and Figure 15 show the responses by the DOTs in detail.

Table 14 Micro-simulation applications for RCUTs.

States	Comments
Alabama	Yes, but do not know which platforms were used.
Georgia	Yes, Vissim
Indiana	Yes, all 3 sites were micro-simulated prior to construction. SimTraffic and Vissim were used.
Kentucky	No
Michigan	No
Minnesota	Only in regards to how operations would be impacted. We can send these if interested in operations analysis.
Mississippi	No
Missouri	In some recent instances, we have used the VISSIM micro-simulation software to evaluate RCUTs. One of the main benefits of using this tool is its ability to create a 3D video image that can be used in public outreach efforts and help communicate the potential impact to a drivers travel route.
North Carolina	Of course. We use TransModeler. We have assembled hundreds of simulation models of superstreets
Ohio	No
South Carolina	Most SC installations have been at lower ADT intersections where micro-simulation was not needed. If needed, Synchro would be used to insure reasonable queue lengths and delay
Texas	Synchro and Corsim were used.
Wisconsin	WisDOT uses a spreadsheet to perform macroscopic operations analysis using the methodology included in the latest edition of the Highway Capacity Manual.

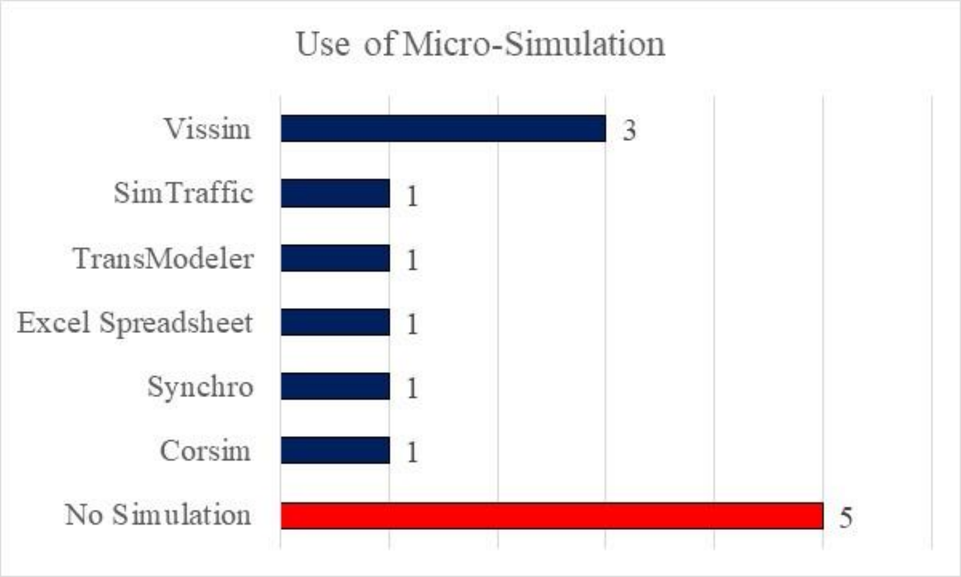


Figure 15. DOT responses to the micro-simulation usage

Q11. Are you relying on the CMFs (such as those listed in the FHWA CMF Clearinghouse) for the RCUTs? If yes, what do you think about the usability of the CMFs for your current RCUT intersections?

Table 15 and Figure 16 show the responses by the DOTs in detail.

Table 15 Reliance on CMFs for RCUTs.

States	**Comments**
Alabama	Yes, and they seem to be a fairly accurate compilation of multiple sites.
Georgia	GDOT's Safety Program will respond in the following week, with an answer to this question.
Indiana	Yes. We find the CMFs to be generally valid, a decent match to local experience/outcomes. If anything, high (meaning, to this point, our in-service performance would yield a lower CMF or higher CRF than what many/most publications suggest.
Kentucky	Yes – We are confident in using these values.
Michigan	No
Minnesota	We have used national CMF's when first starting these. Since then, we have started to use our own crash facts/data and calculated reductions to help promote this use. The national CMF's have done a good job to capture the magnitude of the reductions. It is helpful to state that other states/national performance has seen these XX types of reductions.
Mississippi	Yes, we are currently utilizing the CMFs for RCUTs in our benefit to cost analyses when determining if a location meets the standards to be eligible for HSIP funding. We have been very satisfied with the usability of the CMFs as they typically provide enough of a reduction in analysis to make the RCUT a viable alternative. While we believe the current CMF for the RCUT treatment is on the conservative end, we are able to tell our District and local officials that we routinely exceed the national reduction values as shown in the CMF Clearinghouse.
Missouri	No. We recognize the significant decrease in fatal and serious injury crashes when compared to typical at-grade crossings and have conveyed to our staff that RCUTs will be always be supported by our office as a safety alternative.
North Carolina	The CMFs for unsignalized superstreets are fine. The new FHWA research that supplied a CMF for signalized superstreets is a good step forward, but we need a larger database of those to refine that CMF.
Ohio	Yes. Any of the recent RCUT intersections that have gone through a preliminary Cost Benefit analysis have used the CMFs from the clearinghouse thus far. All of the ones mentioned on the clearinghouse have been studied for rural areas only. Typically when we use them, we shoot to have them be a 3 star rating or higher quality. We also look at the site type of the intersection and what the existing/proposed conditions are.
South Carolina	The Safety Office uses a CRF=0.4 for all crashes in the preliminary countermeasure selection for RCUTs. This ratio is consistent with the CMFs published in the CMF Clearinghouse.
Texas	No
Wisconsin	We are currently using the CMFs from the following report: http://www.cmfclearinghouse.org/study_detail.cfm?stid=249

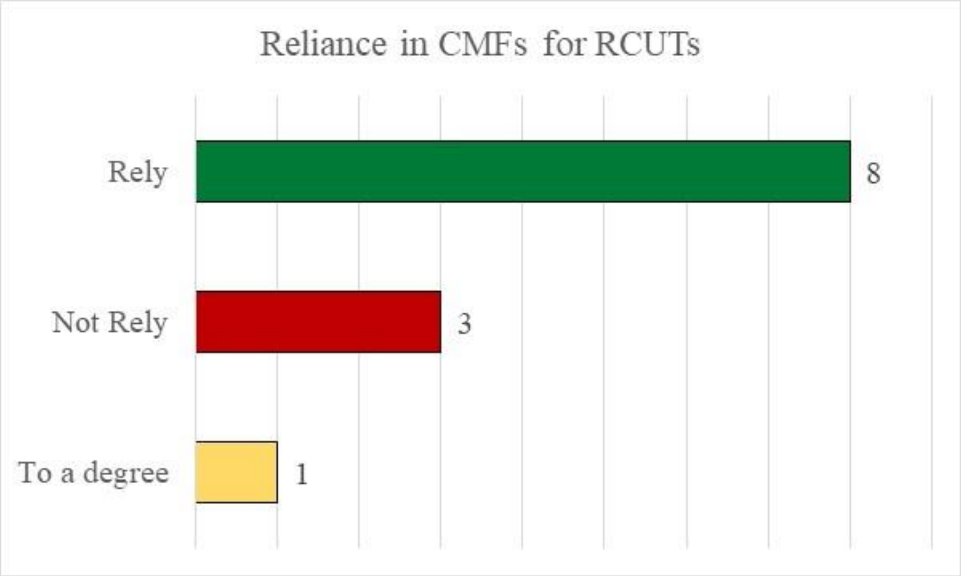


Figure 16. DOT responses to the reliance on the CMFs for RCUTs

Q12. Have you created regression equations (safety performance functions – SPFs) for state use only? Based on your experience, what should be the most important factors that should be used to create the SPFs for RCUTs?

Table 16 and Figure 17 show the responses by the DOTs in detail.

Table 16 State-specific SPFs for RCUTs and important variables.

States	Comments
Alabama	No strong opinion.
Georgia	GDOT's Safety Program will respond in the following week, with an answer to this question.
Indiana	No
Kentucky	No
Michigan	No
Minnesota	No, we have not. Factors: Minor and Major ADT (and cross product of these two), Skew of Intersection, Presence of Horizontal Curve (minor and major), Presence of Commercial Development in any quadrant, Previous Traffic Control Device
Mississippi	No
Missouri	Not available
North Carolina	No
Ohio	Not at this time. We only have a few operational in the state currently and only a few more planned.
South Carolina	No
Texas	No
Wisconsin	No, but we suspect the following factors might have an impact on safety. 1. Mainline and side road AADT, 2. Distance from main intersection to U-turn/J-turn, 3. Is there lighting at the main intersection or at the U-turn/J-turn locations? 4. Mainline posted speed limit, 5. Type of signing used to guide side road drivers to U-turn/J-turn, 6. Does U-turn/J-turn bay start at main intersection or some distance downstream of main intersection on the mainline?

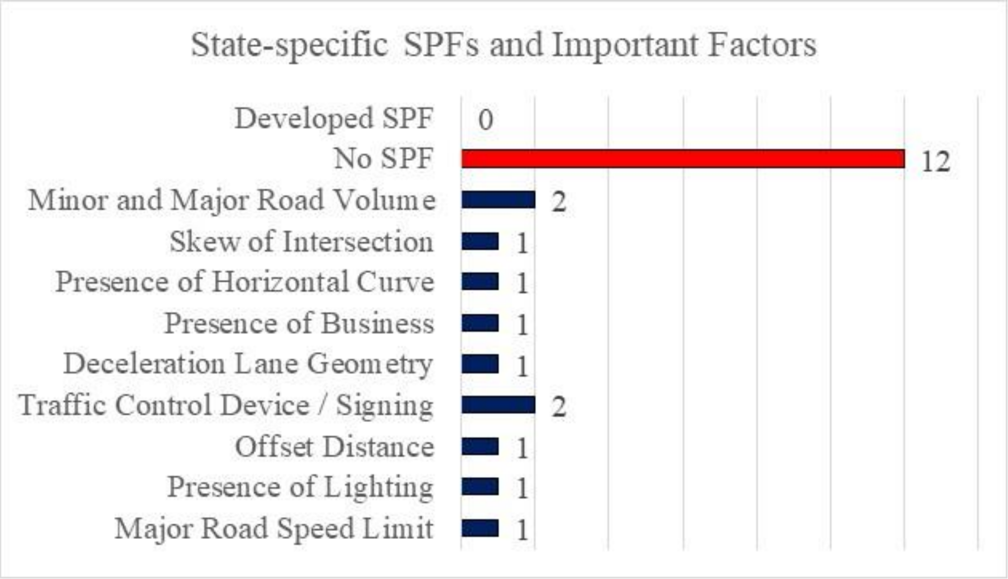


Figure 17. State-specific SPFs for RCUTs and important factors

Q13. How did the residents and businesses perceive the new RCUT design and operations? Please provide information on both negative and positive perceptions.

Table 17 and Figure 18 show the responses by the DOTs in detail.

Table 17 RCUTs from user perspective.

States	**Comments**
Alabama	If the business is directly affected by losing full access, then they are and remain opposed. Others generally are indifferent, but generally be are favorable once they see it in operation. Much like a roundabout, 80% oppose/20% support before, then 80% support/20% oppose after construction.
Georgia	There hasn't been a huge amount of feedback from the public on all the RCUTs currently operational in GA, but a few have received a lot of public praise. These include SR 20 @ Simpson Mill Rd in McDonough, SR 7/US 41 @ Grove St in Barnesville and the RCUTs installed in Griffin. Analysis of a few of the existing RCUTs have shown a significant reduction in crashes, so this could be contributing to a positive public image.
Indiana	In general, the initial public response prior to construction to this alternative intersection form (new to Indiana) was negative. That was expected, based on prior conversations with other states' experiences in introducing them to their states. Over time, as more and more are put into operation — and dozens more are planned — expectation is that natural public disapproval of things new will dissipate, as recognition becomes more apparent of traffic safety (and mobility) benefits.
Kentucky	Local officials were very open to the concept and have been complimentary of the idea during the design process.
Michigan	Not available.
Minnesota	Largely negative and extremely stiff resistance and acceptance from the public. Several had denied municipal consent, or passed resolutions opposing the intersection types. Many have gone to state representatives, senators, county commissioners, and even the governor to stop implementation. Some have understood and accepted the design quickly and approved of construction. After completion, most have said that they do not love the intersection, but it has been effective at stopping severe crashes, and the inconvenience is manageable.
Mississippi	Perception and reception of the RCUT countermeasure has ranged widely from location to location across the state. Overall, the general response has been a critical or negative reception of the idea pre-construction, and either no additional feedback or minimal positive feedback, post-construction. We have had locations, though, where even long after injury and fatal crashes have been completely eliminated, residents and politicians of the area still want to see the RCUT removed. To date, though, MDOT has not removed any RCUT location that were installed using HSIP funding.
Missouri	Not available.
North Carolina	Many stakeholders dislike a superstreet when proposed. NCDOT tries hard to build a positive public perception. After opening some of the negative feelings dissipate.
Ohio	I can ask our districts this question. They were more directly involved with the implementation.
South Carolina	One public meeting has been conducted. Met with resistance from adjoining landowners and City Council. Similar to other alternative intersection designs, these dissipate after construction. No post-construction complaints that I'm aware of.
Texas	Businesses were skeptical and adverse to the project at first. After the project was in operation, we asked TTI to see if the implementation of the project adversely impacted the businesses along the corridor. The pulled gross sales receipts for the year before construction began, then compared to a year of receipts after 1 year of the R-Cuts open and found an increase in 30% sales. They also noted new businesses and recorded plats along the corridor.
Wisconsin	Generally, the public supports the concept, as they understand the safety benefits but recognize they have a longer distance and added time on their trip. Public involvement meeting and public outreach are the best means to educate the public behind these safety improvements. Businesses such as convenience gas mart owners have expressed loss of business concerns. Agricultural roadway users also have a longer trip to cross a high-speed roadway and prefer to have the R-CUTs as close to the intersection as practicable.

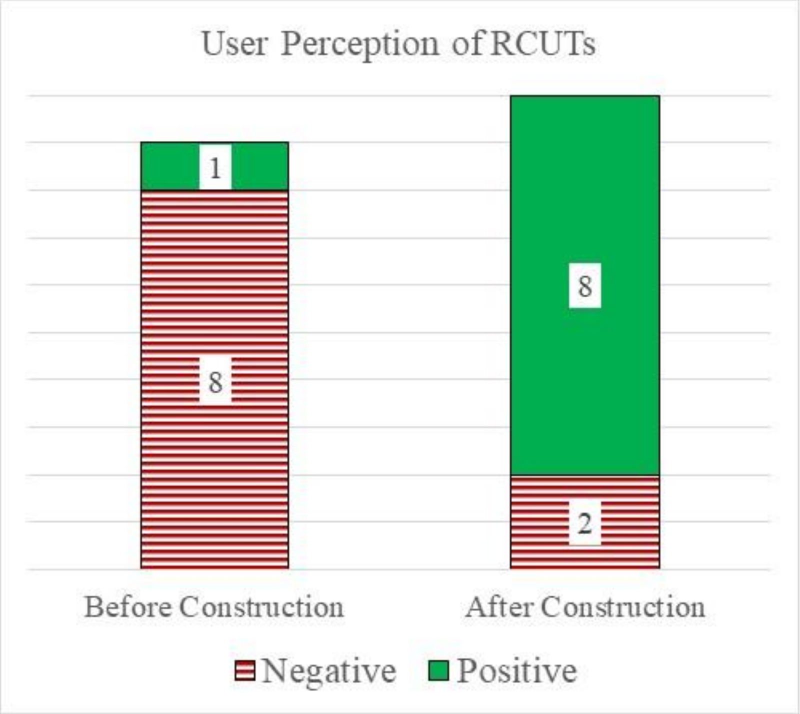


Figure 18. User perception of RCUTs before and after construction

2.3.5. Prospective RCUT Implementations in Your State

Q14. Do you have any ongoing or planned deployment of RCUTs in your state?

Table 18 and Figure 19 show the responses by the DOTs in detail.

Table 18 Ongoing or planned RCUT deployments.

States	Comments
Alabama	Yes. Many sites in Dothan, Montgomery, Huntsville, Gulf Shores/Orange Beach, etc.
Alaska	No
California	N/A
Georgia	Yes
Illinois	*Survey not filled.*
Indiana	Yes, Many more are being developed
Kansas	Yes, two are being planned, one in Goddard and one in Kansas City
Kentucky	Yes, Knox County - US 25E - Unsignalized
Louisiana	*Survey not filled.*
Maryland	*Survey not filled.*
Michigan	No
Minnesota	Yes, Nearly 30 locations are either, planned, programmed or are in discussion. All of these accept one are unsignalized. The first signalized location is anticipated for construction in 2018/2019, depending on funding. For the full list, please let me know if this is needed
Mississippi	Yes: US 278/SR 6 at SR 345, Pontotoc, Pontotoc County, Merge US 278/SR 6 at Rocky Ford Road, Pontotoc, Pontotoc County, Merge
Missouri	No
New York	No
North Carolina	Yes - Hundreds. It is NCDOTs default Aerial Design
Ohio	Yes, 4 planned RCUTs where listed in the survey
Oklahoma	There is at least one RCUT in planning in Oklahoma, although I do not think we have committed to it yet and it might conceivably wind up being a fully closed median.
Oregon	No
Pennsylvania	No
South Carolina	Yes
Tennessee	*Survey not filled.*
Texas	Yes, R-Cuts along SH 16 from LP 1604 to Triana Parkway in Bexar County
Utah	N/A
Virginia	Yes - Faith Hill Ave./Mary Washington Blvd., Fredericksburg, VA James Monroe Highway (US 29)/Mountain Run Lake Road, Culpeper, VA Route 17/Route 17 North Business, Fauquier County, VA Loudoun County Parkway/Center Street, Loudon County, VA
Wisconsin	Yes

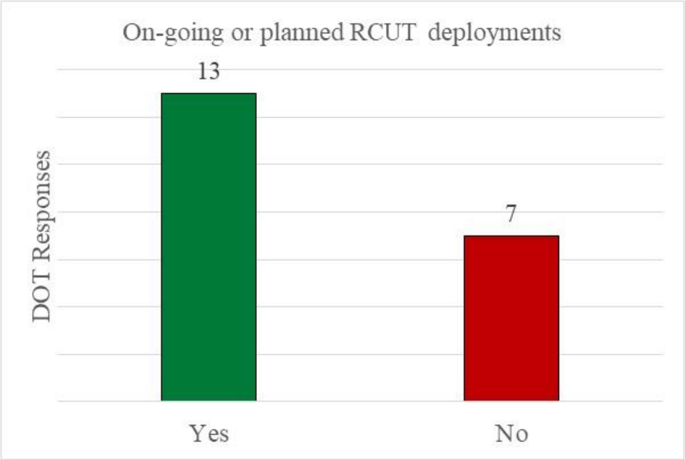


Figure 19. DOT responses for ongoing or planned RCUT deployments

Q15. In terms of planning and policy making, what is the reasoning behind the selection of RCUTs among other alternatives for future improvement?

Table 19, Table 20 and Figure 20 show the responses by the DOTs in detail.

Table 19 Reasoning behind selection of RCUTs among other alternatives.

States	**Comments**
Alabama	We see it as one of many alternative intersection/interchange forms, and chose the one that best functions and provides the desired safety benefits. We start with the CAP-X spreadsheet and move forward from there.
Alaska	No Response
California	Less cost & delay and better safety.
Georgia	RCUTs are considered among other intersection alternatives and in many chosen over them due to improved safety and operations in comparison to conventional intersections (signals and stop-controlled). RCUTs significantly reduce vehicle-to-vehicle conflict points, and reduce the number of and distance for crossing maneuvers which tend to produce the most frequent and severe crashes. They also provide more refuge space for pedestrians and bicycles. They also perform better operationally in many cases as vehicles on the side-streets are no longer waiting to cross multiple lanes of often high speed traffic.
Illinois	*Survey not filled.*
Indiana	A blend of traffic safety and mobility/operations. The former is more often the main driver in selection. In select cases the design allows us to remove an active traffic signal, or make unnecessary the installation of a new signal.
Kansas	Nothing else has worked and cheaper than building an interchange
Kentucky	Crash Types
Louisiana	*Survey not filled.*
Maryland	*Survey not filled.*
Michigan	Depends on the intersection, traffic volume, crash history, etc.
Minnesota	Two Main Reasons: They are starting to show that they are highly effective at stopping the safety problems at these existing locations. Limited funding prohibits more then 1-2 interchanges being built in the state in any given year. Other reasons: Signalized locations are showing greater capacity then standard at-grade intersections. Many intersections are reaching or are beyond capacity, and this could solve this issue. Once again this gets back to funding and limited interchange building availability.
Mississippi	The Mississippi DOT gives consideration to implementing RCUTs primarily at the intersection of rural four lane, divided highways and local two lane roadways where crash histories are mostly far side angle or “T-Bone” crashes. Additionally, the Department considers RCUTs at these rural, four lane divided locations where the minor roadway’s traffic volume entering the intersection is substantially less than that entering on the major roadway and unlikely to cause the intersection to meet any signal warrants, as listed in the MUTCD, in the foreseeable future.
Missouri	Safety
New York	No response
North Carolina	Safer, more efficient, great signal progression, great for pedestrians, saves money compared to interchanges or widening projects.
Ohio	RCUTs have been considered when we are looking to remove the median opening on 4-lane divided roadway where there has been a history of high severity crashes.
Oklahoma	That location was selected because of safety history. OK DoT does not maintain traffic signals and normally requires local governments to contribute to the cost of signals; there is no local entity willing to take over maintenance or contribute to cost. Otherwise the intersection would have been signalized.
Oregon	The design of many of our roads do not have the wide medians and so very much limit the options for providing for U-turns, but they continue to be considered as an option where they may be a good option

Table 19. Reasoning behind selection of RCUTs among other alternatives.

Pennsylvania	No response
South Carolina	RCUTs are one of the innovative design techniques the Traffic Safety Office uses to reduce the frequency and severity of crashes at intersections by limiting conflicts through geometric design and traffic control as identified in the SC Strategic Highway Safety Plan. RCUTs are considered when: · the median width of the roadway is 40' unless loons can be provided; · there is a heavy left-turn volume from the main line; · there is relatively low side street through and left-turn volumes; · the minor road volume is a small proportion of the total intersection volume
Tennessee	*Survey not filled.*
Texas	Reduced cost to implement. It was considered an intermediate improvement when going from a 4-lane divided highway to a controlled access freeway.
Utah	N/A
Virginia	Reallocation of existing median space (practicality of RCUT geometrics) Reduced conflict points (safety) Two-phase traffic signals (operational improvements)
Wisconsin	RCUTs are often considered when there is a right angle crash trend on the far side of the median on a divided highway. Various alternatives are investigated through our intersection control evaluation (ICE) process.

Table 20 DOT responses for reasoning behind selection of RCUTs among other alternatives

Reasoning Behind Selection of RCUT / State	Alabama	Alaska	California	Georgia	Illinois	Indiana	Kansas	Kentucky	Louisiana	Maryland	Michigan	Minnesota	Mississippi	Missouri	New York	North Carolina	Ohio	Oklahoma	Oregon	Pennsylvania	South Carolina	Tennessee	Texas	Utah	Virginia	Wisconsin
Safety Benefits	✓		✓	✓		✓		✓			✓	✓	✓	✓		✓	✓	✓			✓				✓	✓
Pedestrian/Bicyclist Mobility				✓		✓										✓										
Operation of Traffic				✓		✓					✓	✓	✓			✓							✓			
Signalization Benefits						✓										✓									✓	
Less Delay			✓																							
Less Cost than Interchange			✓				✓					✓				✓							✓			

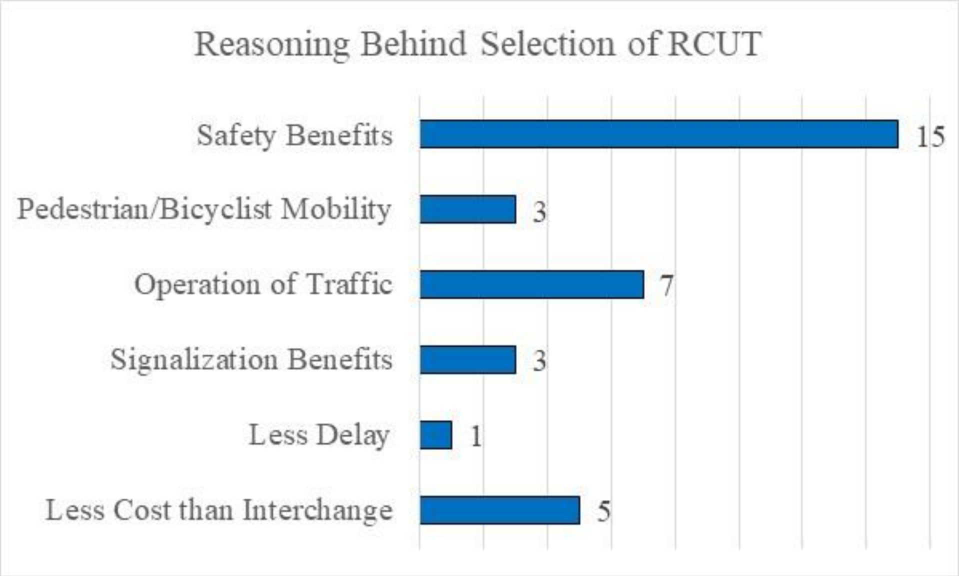


Figure 20. Summary of DOT responses for reasoning behind selection of RCUTs among other alternatives

Q16. Are there any other RCUT intersections in your state not under the jurisdiction of the Department of Transportation? If yes, can you provide the RCUT location and a contact person that can provide more information on that RCUT?

Table 21 shows the responses by the DOTs in detail.

Table 21 RCUTs which are not under jurisdiction of the DOT.

States	Comments
Alabama	The City of Huntsville has a few, but I am not sure of the other cities. Contact Dan Sanders, with the City of Huntsville Traffic Engineering Department.
Alaska	No Response
California	No Response
Georgia	We are not aware of any RCUT intersections that are not under the jurisdiction of the Department of Transportation.
Illinois	*Survey not filled.*
Indiana	No
Kansas	None
Kentucky	No
Louisiana	*Survey not filled.*
Maryland	*Survey not filled.*
Michigan	Yes, Michigan Ave @ Clippert St
Minnesota	We have several ¾ intersections across the state on local highways/streets. However, none have U-turn locations yet. None are known about for planning purposes at this time.
Mississippi	To my knowledge, there are not any other RCUT intersections on non-MDOT maintained roadways. There are likely to be directional medians installed at various locations across the state, but none that I am aware of that have the full complement of the directional median and median U-turns.
Missouri	Not that I'm (DOT Rep) aware of.
New York	No
North Carolina	No
Ohio	None to my knowledge. The only RCUT's that have been installed or planning to be installed fall under the jurisdiction of the DOT.
Oklahoma	No other locations that I'm aware of.
Oregon	No
Pennsylvania	N/A
South Carolina	There may be other RCUT installations in SC. This submittal includes only RCUT installations by the Traffic Safety Office.
Tennessee	*Survey not filled.*
Texas	Not that I am aware of.
Utah	N/A
Virginia	N/A
Wisconsin	Not that we're aware of.

Q17. Are there other experts (such as city, county or MPO officials) you think it would be helpful for us to send this survey?

Table 22 shows the responses by the DOTs in detail.

Table 22 Other RCUT experts known by the DOT.

States	Comments
Alabama	N/A
Alaska	No Response
California	*Survey not filled.*
Georgia	N/A
Illinois	*Survey not filled.*
Indiana	No
Kansas	No
Kentucky	No
Louisiana	*Survey not filled.*
Maryland	*Survey not filled.*
Michigan	N/A
Minnesota	Not at this time
Mississippi	No
Missouri	N/A
New York	N/A
North Carolina	Send it to the members of the TRB alternative intersection subcommittee.
Ohio	No
Oklahoma	N/A
Oregon	N/A
Pennsylvania	N/A
South Carolina	N/A
Tennessee	*Survey not filled.*
Texas	N/A
Utah	N/A
Virginia	No
Wisconsin	N/A

2.3.6. Summary of Findings

This section of the report presents the key findings, which were revealed as a result of the collected data analysis. The findings can be summarized as follows:

F1. The majority of state DOT offices that responded to the survey (a total of 24 state DOTs, or ≈75%) are either Safety (47%) or Traffic Operation (28%) offices (based on the responses to question Q2).

F2. Based on Q3, a total of 202 RCUTs were identified in 15 states. Among these RCUTs, the majority of them are stop controlled (174 locations, 86%), whereas 13 signalized and 15 merge-type locations were also reported. Based on DOT responses, we were unable to identify urban-rural classification of the majority of these RCUTs (only for 30 urban and 31 rural ones).

F3. State DOTs indicated that crash data were generally not public and should be requested from them. AADT information, on the other hand, was found to be publicly available in most cases. Geometric information, as an important part of the SPF development, can be acquired either through as-built drawings that will be provided by DOTs or using aerial imagery. The question on signalization of RCUTs was rarely answered since most of the locations were reported as stop controlled. The signalization data of few signalized locations was stated to be available upon request from DOTs. Construction cost of RCUTs was either given in the survey or stated to be unavailable.

F4. The majority of DOT offices indicated that the offset distance between minor road and U-turn location is the most important geometric design parameter of RCUTs. Besides offset distance, acceleration lane features, median width, signing and markings, and weaving distance between intersection center and beginning of U-turn deceleration lane were also noted as important parameters. Deceleration lane features, median opening size, U-turn radius, right turn lanes from major approach, concrete channelization to prohibit wrong-way movements, major road number of lanes and speed limit, driveways, and minor road volume were emphasized by the DOTs.

F5. Q6 of the survey was concerned with the ratio of minor approach volume to total intersection volume. The majority of the DOTs stated that they do not have information about this ratio. A few states, namely Indiana, Minnesota, and South Carolina, reported varying numbers ranging from 0.29 to 0.03. The mean and standard deviation of the ratio are equal to 0.14 and 0.10, respectively. These reported values show that RCUTs are operated under different volumes that experience a high variation.

F6. Among states which responded to Q7 (12 states), more than half of the state DOTs (7 states) indicated that they did not conducted a benefit-cost study (B/C) for their RCUTs. Five states, on the other hand, reported that they conducted B/C analysis which indicated that RCUTs are highly beneficial in terms of reducing the crash number and crash severities and, in turn, reducing the costs. State DOTs stated benefit-to-cost ratios up to 25.31.

F7. The RCUTs were generally preferred for the safety benefits. The experience of DOTs about the reduction and increase in the numbers of specific types of crash was assessed based on Q8. DOTs stated that the highest reduction was observed in right angle crashes in addition to the severe crashes (injury and fatality). Moreover, it was observed that high-speed, multi-vehicle, and left-turn from minor approach crashes were also reduced substantially. Rear-end, run-off-road, side-swipe, and U-turn crashes, on the other hand, were observed to not change or increase slightly. Nevertheless, significant reductions in right angle and severe crashes justifies the RCUTs as an alternative, despite slight increase in some type of crashes.

F8. The effect of RCUTs on pedestrians and bicyclists was asked to DOTs in Q9. DOTs generally stated that there is no or very limited traffic of pedestrians and bicyclists since most of the locations are rural, and hence they did not express their opinions. Nevertheless, the DOTs which experience non-motorist traffic at their RCUTs predicated positive effects of RCUTs on the pedestrians and bicyclists.

F9. The survey showed that most of the states did not prefer micro-simulation applications to simulate RCUTs deployments. However, a few DOTs stated that they used micro-simulation (VISSIM, SimTraffic, TransModeler, Synchro, Corsim and Excel spreadsheet) for their RCUTs.

F10. The CMFs available for RCUTs in FHWA clearinghouse were asked to DOTs to assess suitability of these CMFs from DOT perspective. The majority of the DOTs (8 states) indicate that they rely on the CMFs for RCUTs and use these CMFs in their analysis. A few DOTs (4 states), on the other hand, stated that they do not rely (or rely to a degree) on these CMFs and their findings show that analysis with CMFs did not result in accurate crash frequencies. It is worth to mention that the DOTs which do not rely on the CMFs and are cautious about use of these CMFs, are the states which have the highest number of RCUTs and study the RCUTs most (North Carolina, Missouri, and Michigan).

F11. DOTs stated that they have not developed any regression models or SPFs for RCUTs. However, a few DOTs indicated that the following variables might be important for an accurate SPF: 1) minor and major road volume, 2) skew of intersection, 3) presence of horizontal curve, 3) presence of business, 4) deceleration lane geometry, 5) traffic control device/signing, 6) offset distance, 7) presence of lighting, 8) major road speed limit.

F12. Users' perspective of RCUTs were found to vary before and after implementation of RCUTs. Before construction, DOTs stated that generally there is a negative perception of RCUTs due to increased travel distance and reduced accessibility for the businesses. After construction, on the other hand, the user perception turned to positive possibly due to enhanced safety with minimum inconvenience in terms of longer travel distances.

F13. As for future RCUT deployments, majority of DOTs (13 states, 65%) stated that they will keep investing in the RCUTs, whereas some states (most of them do not have any implemented RCUTs) stated that they do not consider future implementations.

F14. The reasoning behind selection of RCUTs among other alternatives was asked to DOTs in Q15. The DOT responses predicate the most common reason behind selection of RCUT, which is the safety benefits. The other reasons from the most ubiquitous to least are listed as follows: 1) safety benefits (15 DOTs), 2) operation of traffic (7 DOTs), 3) less cost than an interchange (5 DOTs), 4) signalization benefits (3 DOTs), 5) pedestrian and bicyclists mobility (3 DOTs), 6) less delay (1 DOT).

3. TASK 2: COLLECT AND ANALYZE GEOMETRIC, TRAFFIC, AND CRASH DATA

In Task 2, working collaboratively with the Project Manager, all the RCUT intersections in the U.S. were identified and targeted for data collection purposes by the PIs and their graduate students. In 2014, FHWA released a report (Hummer et al., 2014) which showed a total of 51 RCUTs that could be utilized in determining SPFs. On the other hand, Task 2 of this project revealed that a total of 240 RCUTs exist or have been implemented since the FHWA study was completed. All known to exist RCUTs were targeted for data collection in this task, and states were asked to provide data on other RCUT locations, which were not known before. For each RCUT intersection, geometric, traffic and crash data were collected. When possible, the crash data covered 3 to 5 years before and 3 to 5 years after the construction of the RCUTs. All pertinent data was requested from federal, state, and municipal agencies. In addition, databases such as Ohio's Transportation Information Mapping System – Crash Analysis Tool (TIMS – GCAT), Tennessee's Enhanced Tennessee Roadway Information Management System (E-TRIMS), Georgia's Electronic Accident Reporting System (GEARS), Maryland's Open Data Portal, Texas' Crash Records Information System (CRIS) GIS files, roadway inventory files, and online resources such as Google maps and aerial photographs were also utilized in acquiring and verifying information. From the collected geometric and traffic data, all independent variables likely to influence traffic crashes were extracted – including intersection area type (urban, suburban, rural), roadway functional classification (arterial, collector, distributor), segment lengths, median offset lengths, number of lanes and legs, shoulder widths, presence of a median, geographical location and AADT. From several states, construction cost data as well as signalization and timing data and/or plans were also collected. Where applicable, crash data collected not only included for vehicle-to-vehicle crashes, but it also included vehicle-to-pedestrian and vehicle-to-bicycle crashes. A site visit to North Carolina also occurred in order to visually inspect the existing RCUTs. A drone exercise was also conducted to capture an aerial (bird eye view) drone video of three signalized consecutive RCUT intersections in North Carolina. The goal of this exercise was to record the turning movements of a high-volume (near capacity) signalized RCUT/RCUT corridor, if possible, to share with the FDOT Districts, and have it available for public outreach in Florida.

3.1. DATA COLLECTION AND AVAILABLE DATA

A comprehensive search has been performed in order to identify the Restricted Crossing U-Turn (RCUT) implementations under jurisdiction of several transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies). This was supported by the compilation of all existing documentation through the online resources (books, databases, journals) as well as online resources (search engines, TRIS). Consequently, a final comprehensive list of RCUTs was compiled and the data related to these RCUTs (crash, traffic, geometry, construction costs, and signalization/timing data) was gathered.

3.1.1. Identified RCUTs in the U.S.

Data collection started with the identification of existing RCUTs. For this purpose, we reviewed the relevant state and federal reports as well as research articles covering a time period of 1999-2017. The pioneering work of the Federal Highway Administration, namely "Restricted Crossing U-turn Informational Guide" presents a total of 51 RCUTs in several states (Hummer, Ray, et al., 2014). A summary of the RCUTs presented in this report is shown in Table 23, and the full list of these RCUTs is provided in Appendix C.

Table 23 Number of RCUTs as given by Federal Highway Administration in 2014

States	Number of RCUTs	Signalized	Unsignalized
Alabama	*5*	*2*	*3*
Louisiana	*4*	*0*	*4*
Maryland	*2*	*0*	*2*
Michigan	*2*	*0*	*2*
Minnesota	*11*	*0*	*11*
Missouri	*5*	*0*	*5*
North Carolina	*14*	*12*	*2*
Ohio	*3*	*3*	*0*
Texas	*5*	*5*	*0*
Total	***51***	***22***	***29***

Reference: Hummer, J.E., Ray, B., Daleiden, A., Jenior, P., Knudsen, J., 2014. Restricted Crossing U-turn Informational Guide, (Hummer, Ray, et al., 2014).

Following the literature review to identify the existing RCUTs, a survey was conducted in Task 1 to compile a comprehensive list of RCUTs as well as to acquire experience and knowledge of states which has been working on RCUTs. For this purpose, the research team developed a detailed survey as part of the project. 26 state DOTs have been identified as important contributors to this project in order to gather the information on the RCUT implementations (also referred to as J-Turns, superstreets, reduced conflict intersections, and synchronized street intersections) in different states. As such, state officials have been asked to provide information on the RCUT implementations in their states as well as to provide availability and access of geometric, traffic and crash data for these RCUT intersections.

The information obtained from literature reviews, investigation of existing documentation, and surveys was compiled to constitute a final comprehensive list of RCUTs in the United States. As a result of this effort, the research team has discovered a total of 240 RCUTs (42 signalized and 198 unsignalized), which is substantially higher compared to the number of 51 given in the FHWA's "Restricted Crossing U-turn Informational Guide" report. A summary table, showing the types and locations of these RCUTs, has been provided in Table 24, and a full list of these RCUTs is given in Appendix D. Furthermore, the geographical distribution of RCUTs is illustrated in Figure 21 as well as Figure 22a (all RCUTs), Figure 22b (unsignalized RCUTs), and Figure 22c (signalized RCUTs). Moreover, the charts of Figure 23 also illustrate the number of signalized and unsignalized RCUTs in different states.

Consequently, the research team discovered that several other states, which were not listed to have RCUTs in the FHWA's "Restricted Crossing U-turn Informational Guide" report, have also implemented RCUT intersections. These states include Georgia, Illinois, Indiana, Mississippi, South Carolina, Tennessee, and Wisconsin, which have 50 more RCUTs (all unsignalized) in total. The research team also identified other RCUT implementations in the states that were known to have RCUTs in the FHWA report. Table 24 clearly shows that North

Carolina is the leading state in RCUT implementations by far in terms of both signalized and unsignalized RCUTs. That is why North Carolina was chosen to be a candidate state for the site visit. In addition, there are other states such as Georgia, Maryland, Minnesota, and Missouri, which also have considerable number of RCUTs.

Table 24 Total, signalized, and unsignalized number of RCUTs in states

States	**Number of RCUTs**	**Signalized**	**Unsignalized**
Alabama	*11*	*6*	*5*
Georgia	*23*	*0*	*23*
Illinois	*1*	*0*	*1*
Indiana	*3*	*0*	*3*
Louisiana	*5*	*0*	*5*
Maryland	*14*	*1*	*13*
Michigan	*3*	*2*	*1*
Minnesota	*12*	*0*	*12*
Mississippi	*8*	*0*	*8*
Missouri	*19*	*0*	*19*
North Carolina	*118*	*25*	*93*
Ohio	*3*	*3*	*0*
South Carolina	*3*	*0*	*3*
Tennessee	*4*	*0*	*4*
Texas	*5*	*5*	*0*
Wisconsin	*8*	*0*	*8*
Total	***240***	***42***	***198***

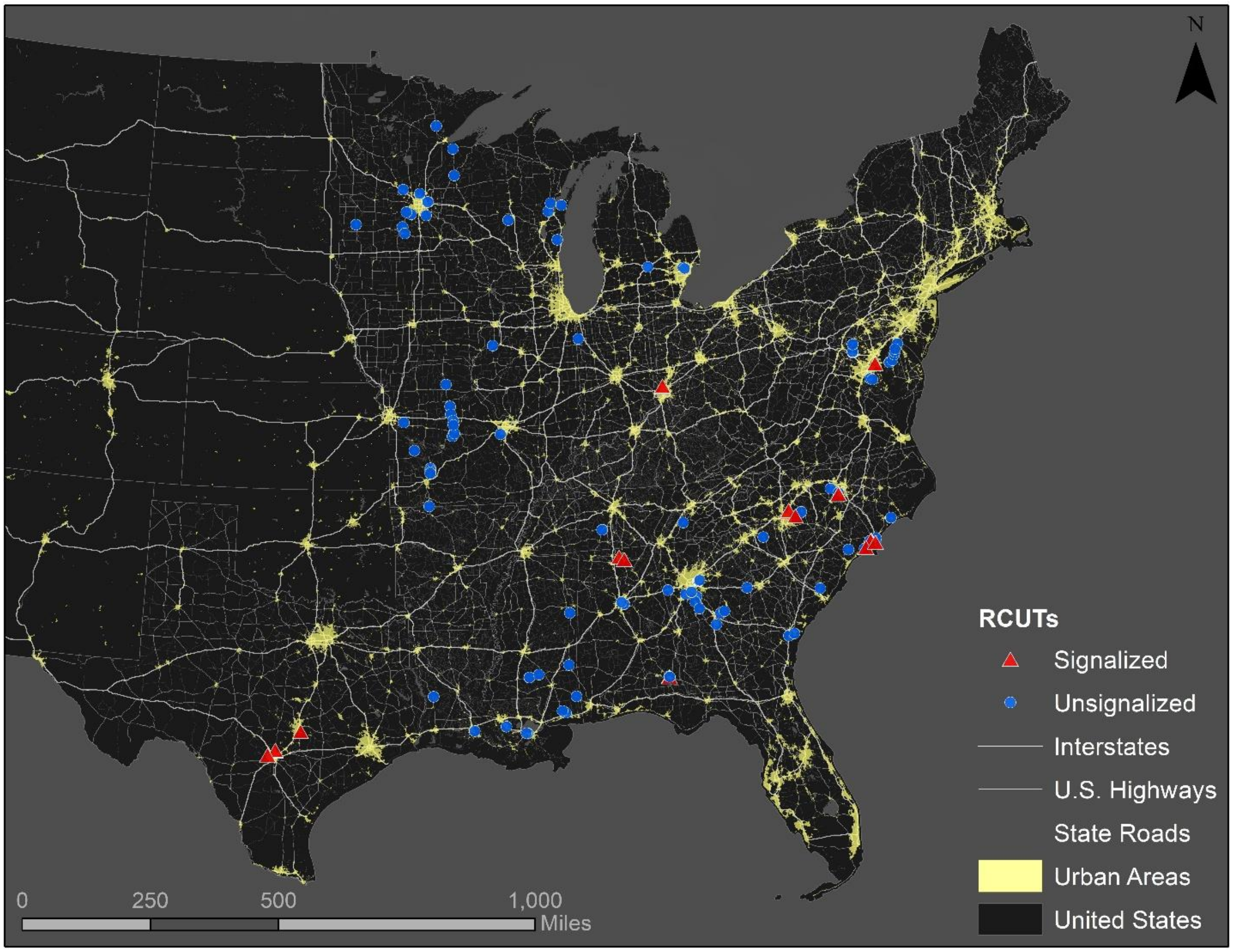
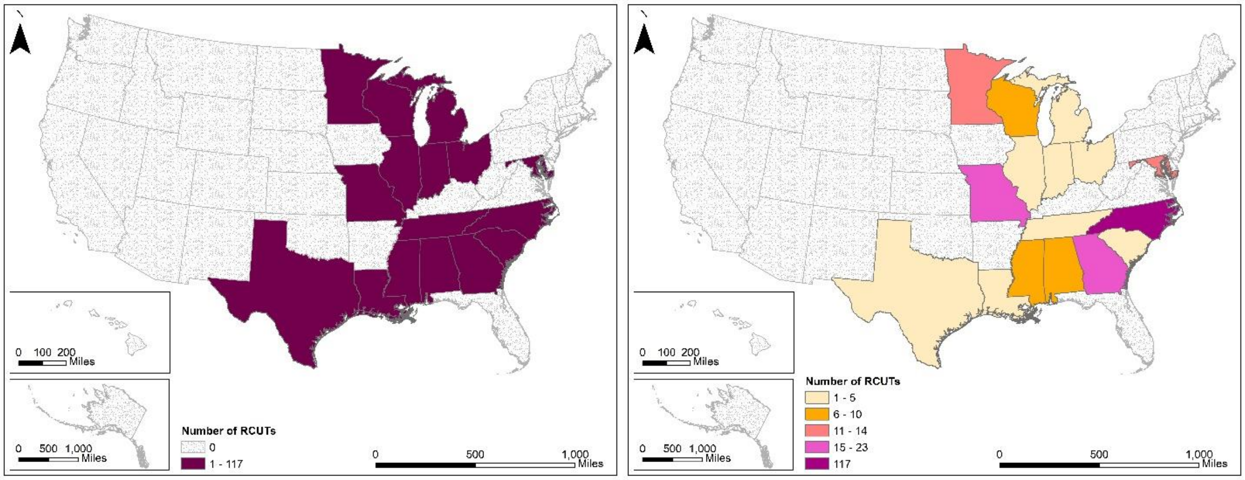
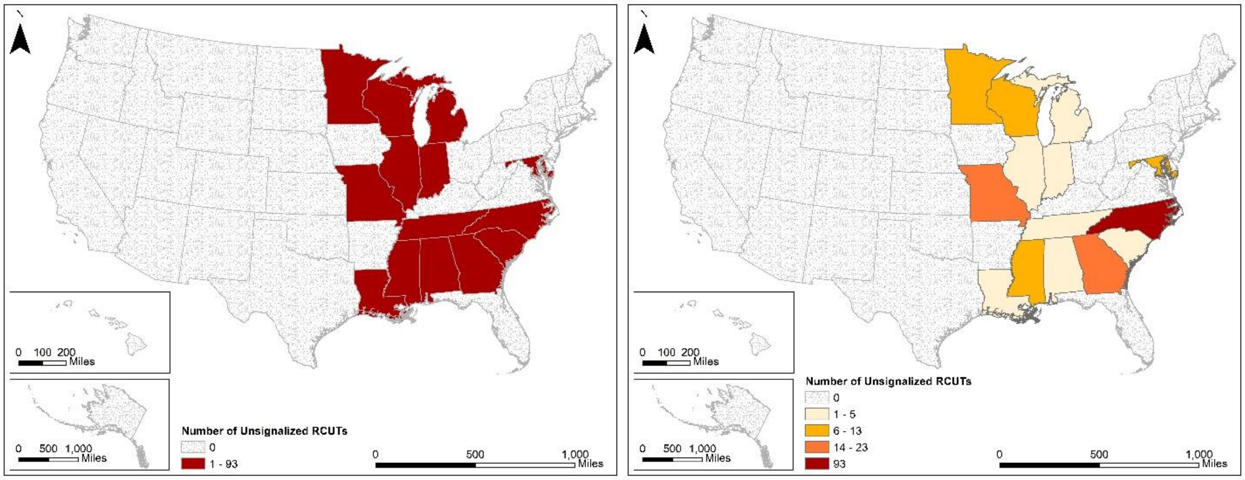


Figure 21. Distribution of RCUTs among the states

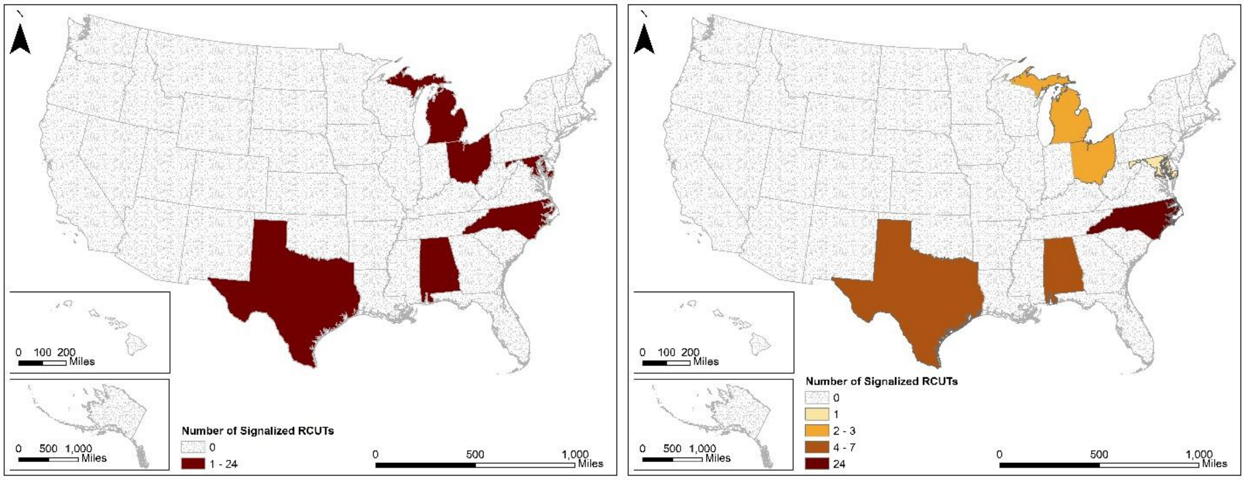


(a)

Figure 22. Distribution of RCUTs: (a) Total number of RCUTs in the U.S., (b) Number of unsignalized RCUTs in the U.S., (c) Number of signalized RCUTs in in the U.S.



(b)



(c)

Figure 22. Distribution of RCUTs: (a) Total number of RCUTs in the U.S., (b) Number of unsignalized RCUTs in the U.S., (c) Number of signalized RCUTs in in the U.S.

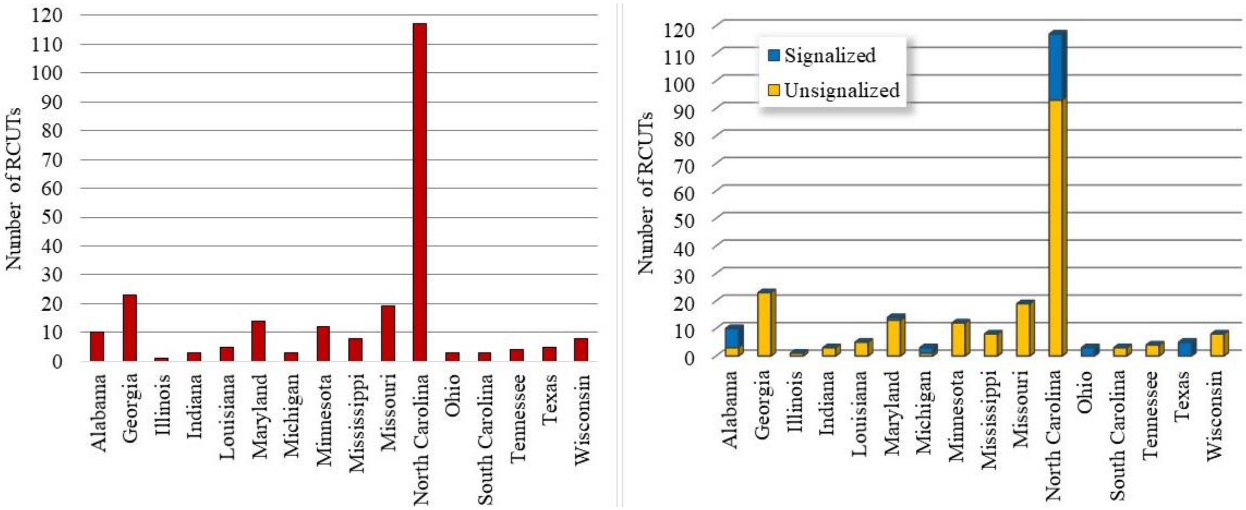


Figure 23. Types and distributions of RCUTs in states

3.1.2. Data Collection

An important task for developing SPFs is data collection, which was found to be burdensome and was defined as labor intensive (Findley et al., 2012). In order to develop SPFs, CFs, and CMFs, geometry- and traffic-related variables are needed along with the crash data. To start with, collection, processing, and classification are critical to successfully assess the safety on roadway facilities. States usually amass the crash data from crash reports of the police and provide these data in terms of spreadsheets, shapefiles, or crash reports. Appendix J shows the contact information for the state officials who provided the relevant data. During the data collection process, the research team obtained crash data in several different formats and through different procedures. For instance, some states provided their crash data by directly sending the necessary files (spreadsheets or PDFs) to the team while some other states granted access to their databases, following the signing of a confidentiality agreement. Furthermore, the State of Maryland has already established an open data policy, which allowed the research team to directly download data without any permission needed from the state officials. The traffic and geometry data were provided by the responsible branches of departments of transportation in the format of shapefiles or PDFs or as-built drawings in the case of geometry. Note that traffic data were usually very accessible through the DOT and/or non-DOT websites, and it is publicly available. However, it is very difficult to obtain the geometry data in terms of as-built drawings, especially for the older facilities. In these situations, as well as for quality assurance, the research team found it practical and accurate enough to use satellite imagery provided by Google Earth® or other companies (Donnell et al., 2016; Savolainen et al., 2015; Wang et al., 2014). Several states also advised the research team to use such methods to obtain the geometric data. In addition to crash, traffic, and geometry data, several states provided their construction cost, signalization, and timing data. Data collection status is shown in Table 25 and summarized in Table 26 and Figure 24. A detailed explanation of the states for which data were not received is provided in Table 27, and data sources for RCUTs in different states are given in Table 28.

Table 25 Data collection status

States	Number of RCUTs	Crash	Traffic	Geometry
Alabama	*11*	*Partially received*	✓	✓
Georgia	*23*	✓	✓	✓
Illinois	*1*	*Not received*	✓	✓
Indiana	*3*	*Not received*	✓	✓
Louisiana	*5*	✓	✓	✓
Maryland	*14*	✓	✓	✓
Michigan	*3*	✓	✓	✓
Minnesota	*12*	✓	✓	✓
Mississippi	*8*	✓	✓	✓
Missouri	*19*	✓	✓	✓
North Carolina	*118*	✓	✓	✓
Ohio	*3*	✓	✓	✓
South Carolina	*3*	✓	✓	✓
Tennessee	*4*	✓	✓	✓
Texas	*5*	✓	✓	✓
Wisconsin	*8*	✓	✓	✓

Table 26 Summary table for the data collection status

Status	**Signalized**	**Unsignalized**	**Total**
Full Data	*36*	*189*	*225*
Partial Data	*2*	*3*	*5*
Pending	*4*	*6*	*10*
Total	*42*	*198*	*240*

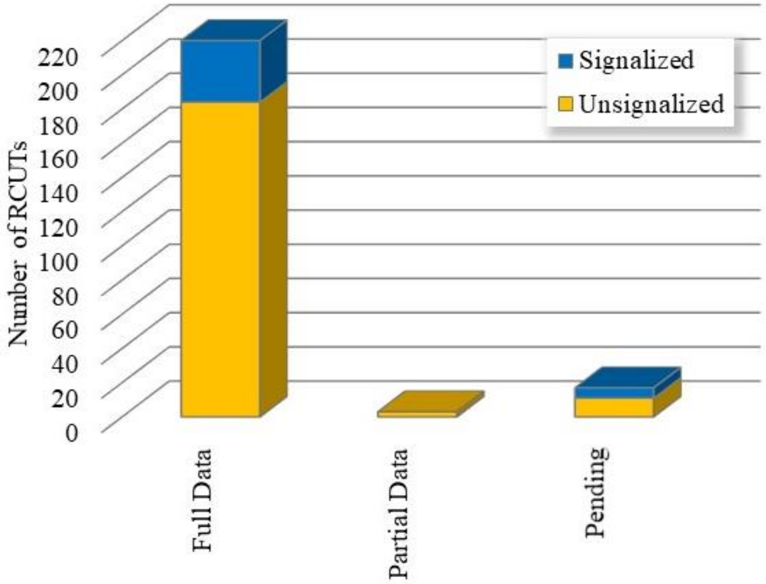


Figure 24. Data collection status

Table 27 Information for those states for which data was not received

States	**Status**
Illinois	*We contacted Filiberto Sotelo (State Safety Engineer, IDOT) several times, however, we could not get a response from him in terms of crash data access. Yet, this is only one location.*
Indiana	*Brad Steckler (Director of Traffic Engineering, INDOT) sent the traffic and geometry data. He informed us that he is preparing the crash data, and will send the data when it is ready.*

Table 28 Data sources for different states

States	**Number of RCUTs**	**Crash**	**Traffic**	**Geometry**
Alabama	*11*	*Requested*	*Online*	*Requested/Google Earth*
Georgia	*23*	*Online*	*Online*	*Google Earth*
Illinois	*1*	*Requested*	*Online*	*Requested/Google Earth*
Indiana	*3*	*Requested*	*Online*	*Drawings/Google Earth*
Louisiana	*5*	*Spreadsheet*	*Online*	*Google Earth*
Maryland	*14*	*Online*	*Online*	*Google Earth*
Michigan	*3*	*Spreadsheet*	*Online*	*Google Earth*
Minnesota	*12*	*Spreadsheet*	*Shapefile/Online*	*Google Earth*
Mississippi	*8*	*Spreadsheet*	*Spreadsheet/Online*	*Google Earth*
Missouri	*19*	*Spreadsheet*	*Online*	*Google Earth*
North Carolina	*118*	*Spreadsheet*	*Shapefile/Online*	*Google Earth*
Ohio	*3*	*Online*	*Survey/Online*	*Google Earth*
South Carolina	*3*	*Spreadsheet*	*Spreadsheet*	*Drawings/Google Earth*
Tennessee	*4*	*Online*	*Online*	*Google Earth*
Texas	*5*	*Online*	*Shapefile/Online*	*Google Earth*
Wisconsin	*8*	*Spreadsheet*	*Online*	*Drawings/Google Earth*

3.1.2.1. Crash Data

The main advantage of the RCUTs, compared to conventional intersections, is the safety improvement brought about by implementation of these innovative designs. Besides the benefits associated with operations and traffic flow of intersections, RCUTs are known to improve the safety of problematic intersections substantially by reducing not only the crash rate and frequency but also the number of severe injuries and fatalities (Bared, 2009; Hummer et al., 2010). Edara et al. (2013) and Edara et al. (2015) showed that total and fatal crash frequencies were reduced by 31% and 64%, respectively, following the unsignalized RCUT implementations in Missouri intersections. Similarly, Inman et al. (2013) found that RCUTs considerably reduce the total number of crashes (44%) as well as those with injuries and fatalities (9%). It is obvious that RCUTs have tremendous benefits in terms of safety; however, to quantify safety improvement of RCUTs more comprehensively and to develop SPFs specific to RCUTs, there was a need to collect crash data from all the states that have implemented RCUTs. The crash data sources for the RCUTs in different states are shown in Table 29. Following Table 29, a summary of the data collection process is provided for each state individually.

Table 29 Crash data sources for different states

States	Number of RCUTs	Crash Data Sources
Alabama	*11*	*Data for two locations was received (please see Table 27).*
Georgia	*23*	*We signed a confidentiality agreement to gain access to GEARS database (https://www.gearsportal.com/Pages/Public/Home.aspx) which provides crash data for the State of Georgia. We acquired access granted and downloaded crash data.*
Illinois	*1*	*Not received (please see Table 27).*
Indiana	*3*	*Not received (please see Table 27).*
Louisiana	*5*	*Spreadsheet - We tried to contact Hadi Shirazi (Manager at Traffic Engineering Management, LA DOTD) several times, who has filled out the survey previously, but could not get a response so far. However, we investigated the LACRASH website (Louisiana crash system - http://lacrash.lsu.edu/) and contacted Dan Magri (Deputy Assistant Secretary, Office of Planning, LADOT), who notified the responsible officials to provide the requested data. As a result, we obtained the crash data.*
Maryland	*14*	*Maryland adopts an open data policy, hence we were able to download the crash data through the database website. (https://data.maryland.gov/browse?q=crash&sortBy=relevance&page=1)*
Michigan	*3*	*Spreadsheet - We sent a data request letter to Jeremy Russo (Crash Specialist at Michigan State Police) explaining the type and extend of data we need. We received the crash data from Amanda Heinze (Crash Specialist at Michigan State Police).*
Minnesota	*12*	*Spreadsheet - Derek Leuer (Traffic Safety Engineer, MnDOT) has sent the crash data for the RCUTs in spreadsheets.*
Mississippi	*8*	*Spreadsheet - Mark Thomas (Traffic Engineering Division - Safety Section, MDOT) has sent summary crash spreadsheets for each RCUT in the State of Mississippi.*
Missouri	*19*	*Spreadsheet - Debbie Call-Engle (Traffic Safety Specialist, MoDOT) has sent the crash data for the RCUTs in spreadsheets.*
North Carolina	*118*	*Spreadsheet - Carrie L. Simpson (Traffic Safety Project Engineer - Transportation Mobility & Safety Division, NCDOT) has sent the crash data for the RCUTs in spreadsheets.*
Ohio	*3*	*We requested to gain access to Ohio crash database TIMS – GCAT (https://gis.dot.state.oh.us/tims/CrashAnalytics/Login). The access has been granted, and we were able to download crash data.*
South Carolina	*3*	*Spreadsheet - Jana Potvin (Safety Project Engineer, CSDOT) has sent the crash data for the RCUTs in spreadsheets.*
Tennessee	*4*	*We signed a confidentiality agreement to gain access to Tennessee's Enhanced Tennessee Roadway Information Management System (https://e-trims.tdot.tn.gov/), which provides the crash data. We acquired the access grant to download the crash data.*
Texas	*5*	*We signed a confidentiality agreement to gain access to CRIS database (https://cris.dot.state.tx.us). CRIS database provides the crash data of the State of the Texas. We acquired the access grant and downloaded the data.*
Wisconsin	*8*	*Spreadsheet - Brian Porter (State Traffic Safety Engineer - Bureau of Traffic Operations, WisDOT) has sent the crash data for the RCUTs in spreadsheets.*

Alabama: The Alabama survey was completed by Timothy E. Barnett (State Traffic and Safety Operations Engineer); however Mr. Barnett directed us to Waymon Benifield (Safety Administrator, ALDOT) for data collection purposes. Mr. Benifield requested a notarized confidentiality agreement to provide the requested data. Therefore, we have prepared required documents, and have sent the signed and notarized confidentiality agreement. Partial data for two locations has been received.

Georgia: The State of Georgia uses a crash database namely *Georgia Electronic Accident Reporting System (GEARS)* to share their crash data. To be able to access these data, it is required to submit an application to a company called *LexisNexis Risk Solutions*, which provides the database services. Subsequently, the application is approved by E. David Adams (Safety Program Manager), and then access is granted to the research team. In order to have this access, we signed a confidentiality agreement required to gain the access to GEARS database (https://www.gearsportal.com/Pages/Public/Home.aspx). Consequently, we acquired the access grant and downloaded the crash data.

Illinois: Illinois correspondent during this project is Filiberto Sotelo (State Safety Engineer), who also filled out the survey on behalf of the State of Illinois. Therefore, we contacted with Mr. Sotelo several times; however, we could not get a response from him in terms of the crash data access until the time this report was written. Note that Illinois only has one unsignalized RCUT location.

Indiana: Brad Steckler (Director of Traffic Engineering, INDOT), who also filled and sent the project survey, has been the State of Indiana correspondent during the project. Mr. Steckler has sent the traffic and geometry data as part of our data request. At that time, he informed as that he is preparing, and will send the crash data when it is ready. However, we have not received the crash data until the time this report was written.

Louisiana: For the State of Louisiana, we were able to get the project survey from Hadi Shirazi (Manager at Traffic Engineering Management), and hence we decided to proceed directly with the data request with him. For this purpose, we tried to contact with Mr. Shirazi several times but could not get a response. However, we investigated the *Louisiana crash system (LACRASH)* (http://lacrash.lsu.edu/) and contacted Dan Magri (Deputy Assistant Secretary, Office of Planning), who notified the responsible officials to provide the requested data. As a result, we received the data in spreadsheet format.

Maryland: Maryland was one of the two states which did not agree to submit survey (as in the case of Tennessee). However, Maryland adopts an open data policy, hence we were able to download the crash data through the database called *Open Data Portal* (https://data.maryland.gov/browse?q=crash&sortBy=relevance&page=1).

Michigan: After several correspondences, we have been informed that we can obtain the crash data from Jeremy Russo (Crash Specialist at Michigan State Police). Therefore, we sent a data request letter to Mr. Russo, explaining the type and extend of the data we need. We received the data, which was prepared and sent to us by Amanda Heinze (Crash Specialist at Michigan State Police).

Minnesota: Derek Leuer (Traffic Safety Engineer, MnDOT), who also filled the project survey, has sent the crash data for the RCUTs in spreadsheets.

Mississippi: Mark Thomas (Traffic Engineering Division - Safety Section, MDOT), who also filled the project survey, has sent summary crash spreadsheets for each RCUT in the State of Mississippi.

Missouri: Initially, we received the project survey from Ray Shank (Traffic Safety Engineer). However, crash data for the RCUTs has been sent by Debbie Call-Engle (Traffic Safety Specialist, MoDOT) in the format of spreadsheets.

North Carolina: North Carolina crash data took a long time to be prepared due to the substantial number of RCUT implementations in this state. Carrie L. Simpson (Traffic Safety Project Engineer - Transportation Mobility & Safety Division, NCDOT) took the responsibility of preparing the data, and she compiled the necessary information in three months. Crash data was received in two parts. First part mostly consist of the data for unsignalized RCUTs. During the research team's site visit to North Carolina, we discussed the possibility to obtain data for signalized intersections and later on, Mrs. Simpson has sent the remaining crash data for the signalized RCUTs along with their safety reports.

Ohio: Ohio is one of the states which uses a web-based database to provide crash data. Therefore, we requested to gain access to Ohio crash database which is called *Transportation Information Mapping System – Crash Analysis Tool (TIMS – GCAT)* (https://gis.dot.state.oh.us/tims/CrashAnalytics/Login). Consequently, the access has been granted to us, and we were able to download crash data.

South Carolina: Initially, we received the project survey form Joey Riddle (Safety Program Engineer). However, Jana Potvin (Safety Project Engineer) has sent the crash data for the RCUTs in spreadsheets.

Tennessee: Even though we could not get the project survey filled by Tennessee, we found out that Tennessee has a database to store crash data, namely *Tennessee's Enhanced Tennessee Roadway Information Management System (E-TRIMS)* (https://e-trims.tdot.tn.gov/). We signed a confidentiality agreement to gain access to this database. Consequently, we acquired the access grant to download crash data.

Texas: The State of Texas also maintains a database to store its' crash data, namely *Crash Records Information System (CRIS)* (https://cris.dot.state.tx.us). Therefore, we signed a confidentiality agreement to gain access to the CRIS database. We acquired the access grant and downloaded the crash data.

Wisconsin: Brian Porter (State Traffic Safety Engineer - Bureau of Traffic Operations, WisDOT), who also filled the project survey, has sent the crash data for the RCUTs in spreadsheets.

3.1.2.2. Traffic Data

One of the most important factors in developing safety performance functions (SPF) is the traffic volume, and in the case of intersections, volumes of both major and minor approaches. Note that RCUTs are alternative intersection types generally implemented at locations where high volume major approach traffic intersects with low volume minor approach traffic. Therefore, obtaining traffic volumes for both major and minor approaches is particularly critical for RCUT SPFs, due to these uneven traffic volumes at different approaches. In order to obtain AADT data, the research team investigated DOT websites and survey responses of DOT officials, and found that traffic counts and AADT information are generally available through websites in different formats such as shapefiles, spreadsheets, and/or pdf files. Moreover, several states also provide AADT information via interactive webpages. Table 30 shows the traffic data sources obtained for the states that have implemented RCUTs.

Table 30 Traffic data sources for different states

States	**Number of RCUTs**	**Traffic Data Sources**
Alabama	*11*	*https://aldotgis.dot.state.al.us/atd/*
Georgia	*23*	*http://geocounts.com/gdot/*
Illinois	*1*	*https://www.gettingaroundillinois.com/gai.htm?mt=aadt*
Indiana	*3*	*http://indot.ms2soft.com/tcds/tsearch.asp?loc=Indot&mod* .
Louisiana	*5*	*http://wwwapps.dotd.la.gov/engineering/tatv/*
Maryland	*14*	*https://data.maryland.gov/browse?q=aadt&sortBy=relevance&anonymous=true*
Michigan	*3*	*http://www.michigan.gov/documents/mdot/2015_07_16_I-94_Traffic_Data_v2_494918_7.pdf* *http://gis-mdot.opendata.arcgis.com/datasets?q=traffic&sort_by=name*
Minnesota	*12*	*http://www.dot.state.mn.us/traffic/data/data-products.html* *Shapefiles*
Mississippi	*8*	*http://mdot.ms.gov/applications/trafficcounters/* *Spreadsheet*
Missouri	*19*	*http://www.modot.org/safety/trafficvolumemaps.htm*
North Carolina	*118*	*https://connect.ncdot.gov/resources/State-Mapping/Documents/NCDOT2016InterstateFreewayReport.pdf* *Shapefiles*
Ohio	*3*	*http://odot.ms2soft.com/tcds/tsearch.asp?loc=Odot&mod=*
South Carolina	*3*	*Spreadsheet*
Tennessee	*4*	*https://www.tdot.tn.gov/APPLICATIONS/traffichistory*
Texas	*5*	*http://txdot.ms2soft.com/tcds/tsearch.asp?loc=Txdot&mod=TCDS* *http://gis-txdot.opendata.arcgis.com/datasets* *Shapefiles*
Wisconsin	*8*	*https://trust.dot.state.wi.us/roadrunner/*

3.1.2.3. Geometry Data

RCUT is an alternative intersection design that has a one-way median opening for left-turn movements from the major approach exclusively, and it restricts through and left-turn movements from the minor approach. Minor through and minor left-turn traffic have to make a right turn and then a U-turn from a designated downstream location to complete the desired movement. Moreover, pedestrian crossings at RCUTs are different than the conventional designs due to the particular geometry of these intersections. Therefore, it is very critical to obtain sufficiently precise geometric data to develop accurate safety performance functions. The research team found that design drawings for RCUTs are quite difficult to obtain; however, satellite imagery provided by Google Earth® or other companies are fairly reliable sources to gather geometric information of RCUTs (Donnell et al., 2016; Savolainen et al., 2015; Wang et al., 2014). Hence, the research team mostly relies on the satellite imagery to compile the design properties and geometry data. Several states also advised the research team to use such methods to obtain the geometric data. Nevertheless, we obtained design drawings of RCUTs for the following states: Indiana, South Carolina, and Wisconsin. Table 31 provides the geometry data sources for different states.

Table 31 Geometry data sources for different states

States	Number of RCUTs	Geometry Data Sources
Alabama	*11*	*Requested/Google Earth*
Georgia	*23*	*Google Earth*
Illinois	*1*	*Requested/Google Earth*
Indiana	*3*	*Drawings/Google Earth*
Louisiana	*5*	*Google Earth*
Maryland	*14*	*Google Earth*
Michigan	*3*	*Requested/Google Earth*
Minnesota	*12*	*Google Earth*
Mississippi	*8*	*Google Earth*
Missouri	*19*	*Google Earth*
North Carolina	*118*	*Google Earth*
Ohio	*3*	*Google Earth*
South Carolina	*3*	*Drawings/Google Earth*
Tennessee	*4*	*Google Earth*
Texas	*5*	*Google Earth*
Wisconsin	*8*	*Drawings/Google Earth*

3.1.2.4. Construction Cost Data

Construction cost of RCUTs have also been investigated as part of the project. The research team could only acquire this information from the following five states: Indiana, Mississippi, Missouri, North Carolina, and South Carolina. Nevertheless, note that these states have 151 RCUTs out of 240 identified RCUTs (63%) indicating that information given in Table 32 can provide a valuable estimation on the construction costs of RCUTs. According to the information provided by state DOTs, construction cost of an RCUT span from $200,000 to $1,300,000. This high variation is due to the fact that, while some of the RCUTs are completely new, some of them were converted from conventional intersections to RCUTs, which may considerably cut construction costs. In addition, traffic control type of intersection also affects the total construction cost since signalization costs also contribute to the total cost at signalized RCUT locations.

Table 32 Construction cost data for different states

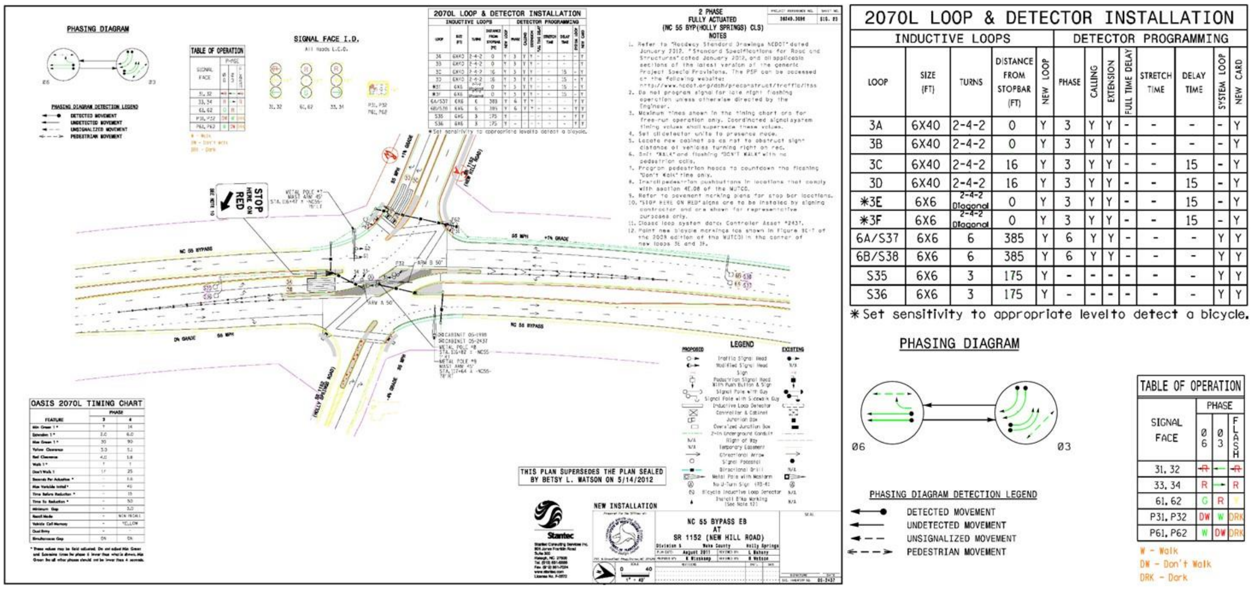
States	Number of RCUTs	Cost Estimate / RCUT
Alabama	*11*	-
Georgia	*23*	-
Illinois	*1*	-
Indiana	*3*	*$400,000 (1 site) & $1,200,000 (other 2 site each)*
Louisiana	*5*	-
Maryland	*14*	-
Michigan	*3*	-
Minnesota	*12*	-
Mississippi	*8*	*~ $1,870,000 (on average)*
Missouri	*19*	*~ $650,000 to $700,000*
North Carolina	*118*	*~ $200,000 to $1,300,000*
Ohio	*3*	-
South Carolina	*3*	*$750,000, $810,000, $325,000*
Tennessee	*4*	-
Texas	*5*	-
Wisconsin	*8*	-

3.1.2.5. Signalization Data

Design and geometry of RCUTs allow independent operations of two directions of traffic, which also permits an arrangement of signal phasing to satisfy different demands from opposite directions independently (Bared, 2009; Hummer and Reid, 2000). Therefore, it is important to benefit from other states' experience and expertise on the signal phasing and timing. For this purpose, the research team has requested signalization timing and signal phasing plans of the states that has signalized RCUTs. Consequently, the research team obtained signalization plans of all RCUTs in the State of North Carolina, which has the highest number of signalized RCUTs (25 signalized RCUTs). An example of these plans is shown in Figure 25. The research team has also requested similar signalization data from Alabama and Texas, but were not able to collect their signalization plans yet. Three states, on the other hand, informed the research team that signalization plans for their RCUTs are not available.

Table 33 Signalization data availability

States	Signalized RCUTs	Signalization data available
Alabama	*6*	*Requested.*
Maryland	*1*	*Not available.*
Michigan	*2*	*Not available.*
North Carolina	*25*	*Available.*
Ohio	*3*	*Not available.*
Texas	*5*	*Requested.*



2070L LOOP & DETECTOR INSTALLATION

INDUCTIVE LOOPS					DETECTOR PROGRAMMING							
LOOP	SIZE (FT)	TURNS	DISTANCE FROM STOPBAR (FT)	NEW LOOP	PHASE	CALLING	EXTENSION	FULL TIME DELAY	STRETCH TIME	DELAY TIME	SYSTEM LOOP	NEW CARD
3A	6X40	2-4-2	0	Y	3	Y	Y	-	-	-	-	Y
3B	6X40	2-4-2	0	Y	3	Y	Y	-	-	-	-	Y
3C	6X40	2-4-2	16	Y	3	Y	Y	-	-	15	-	Y
3D	6X40	2-4-2	16	Y	3	Y	Y	-	-	15	-	Y
✱3E	6X6	2-4-2 Diagonal	0	Y	3	Y	Y	-	-	15	-	Y
✱3F	6X6	2-4-2 Diagonal	0	Y	3	Y	Y	-	-	15	-	Y
6A/S37	6X6	6	385	Y	6	Y	Y	-	-	-	Y	Y
6B/S38	6X6	6	385	Y	6	Y	Y	-	-	-	Y	Y
S35	6X6	3	175	Y	-	-	-	-	-	-	Y	Y
S36	6X6	3	175	Y	-	-	-	-	-	-	Y	Y

✱ Set sensitivity to appropriate level to detect a bicycle.

PHASING DIAGRAM

TABLE OF OPERATION

SIGNAL FACE	PHASE		
	Ø6	Ø3	FLASH
31, 32	←R	←	←R
33, 34	R	→	R
61, 62	G	R	Y
P31, P32	DW	W	DRK
P61, P62	W	DW	DRK

W - Walk
DW - Don't Walk
DRK - Dark

Figure 25. Example signalization plan obtained from North Carolina

3.1.3. Data Collection Difficulties and Issues

Throughout the data collection process, the FAMU-FSU research team encountered a number of difficulties/issues, including the following:

3.1.3.1. Identification of the appropriate DOT representative

Initially, the research team contacted the DOT representatives by phone, which is provided by the Federal Highway Administration. In several states, the research team also had to determine an alternative DOT representative with sufficient knowledge to provide the necessary data.

3.1.3.2. Workload of DOT representatives

Some State DOT representatives mentioned that they were not able to provide the data in a short span of time due to their workload, and asked for more time to compile the data. In many cases, DOT representatives preferred to grant access to their databases, so that the research team could download and process the data.

3.1.3.3. Missing participations

As reported before, States of Tennessee and Maryland have not agreed on participating the survey due to a variety of reasons including their workload. Regardless, the research team stayed constantly in contact with the Tennessee and Maryland DOTs to obtain the RCUT related data needed to develop SPFs. Consequently, the research team has been granted access to databases of both states through: a) a confidentiality agreement for Tennessee, b) an open access portal for Maryland.

3.1.3.4. Data formats

The research team discovered that every state has it is own format for the data. This creates a challenge to compile the data and bring all different types of formats together. Moreover, in many cases, the research team had to download data for the whole state and identify those crashes related to RCUTs. In order to perform this identification, the research team geo-located the crashes on the roadway networks of those states, and then identified the ones related to the RCUTs.

3.1.4. Summary

At the end of the data collection process, the research team was able to collect full data for 225 RCUTs (189 Unsignalized, 36 Signalized). The team was still waiting to receive data for the remaining 15 RCUTs (9 Unsignalized, 6 Signalized). Following the data collection effort, all data was going to be processed and compiled to create a uniform dataset (see Task 4). This dataset was planned to be used to analyze the data and develop safety performance functions.

3.2. SITE VISITS

Regarding FDOT's and the research team's interest in learning more about other states' experience with RCUTS, the research team has successfully contacted a closer state such as North Carolina in order to set up and schedule the site visits.

3.2.1. Actual Site Visits

3.2.1.1. North Carolina

North Carolina DOT (NCDOT) officials kindly informed the research team that they were available for the RCUT site visits in the last week of August, 2017. Therefore, the research team coordinated the site visit during a 3-day period from August 28th to August 30th. Meetings with the NCDOT personnel and visits to selected RCUT locations occurred from August 28th to August 30th. This site visit engaged project PI Eren Erman Ozguven, student team leader for the project Mehmet Baran Ulak, the FDOT project manager Alan El-Urfali and an FDOT official, Humberto Castillero, as well as IEC consultant of FDOT in North Carolina, Bastian Schroeder, from Kittelson & Associates. The visit covered two sites, namely US 17 and NC 55 corridors. The team met with Bastian Schroeder on the US 17 site on the 28th of August, and he provided information regarding the US 17 corridor in the Leland area. On 29th of August, the team met with James Dunlop on the NC 55 site, and he provided information regarding the NC55 corridor in the Raleigh area. Later on the same day, the team also met with Joseph Hummer, State Traffic Manager of NCDOT, James Dunlop, Congestion Management Director of NCDOT, Carrie L. Simpson, Traffic Safety Project Engineer, and Michael Reese at the main NCDOT office and had a fruitful discussion regarding their experience with RCUTs and the project and data needs. NCDOT officials provided substantial information and data regarding RCUTS and showed the implemented RCUT locations in the State of North Carolina.

Site visits were conducted in an open and collaborative manner, with participants identifying and discussing issues related to the RCUT implementations. Visual information on traffic operations was obtained at selected RCUT locations through taking pictures and videos. A detailed summary was compiled after each site visit, including (a) RCUT implementation experience of the DOT, (b) recent and planned RCUT projects, (c) signalization and cost, (d) traffic safety- and operations-related perspectives, and (e) a summary of next steps and action items.

The team obtained a huge data set of the aerial images and locations of all RCUTs as well as the signalization and construction cost data regarding the RCUTS in North Carolina. Carrie Simpson from NCDOT separately sent the crash data for the signalized and unsignalized RCUT locations. The site visit revealed that there were more RCUT locations in North Carolina than expected and known by USDOT, both signalized and unsignalized. The research team has also taken pictures and videos of this visit to NC 55 and US 17 locations.

The research team hopes that FDOT can use these site visit summaries as a guide to inform and prioritize infrastructure improvements that can involve contemporary intersection designs such as RCUTs in order to improve traffic safety and operations at problematic locations in the State of Florida.

3.2.2. Drone Exercise

As part of the project a drone exercise was conducted in the State of North Carolina. This drone exercise took place on September 25, 2017 between 5 PM and 6 PM on the NC 55 Corridor. Drone exercise captured aerial (bird eye view) drone videos of three signalized “Restricted Crossing U-Turn” (RCUT) intersections. The goal of this exercise was to record the turning movements of a high-volume (near capacity) signalized RCUT/RCUT corridor, if possible, to share with FDOT Districts, and have it available for public outreach in Florida. Vehicle-level volume/class data was not collected during the exercise, but only video of the intersection operations was recorded. The vendor ensured to comply with all the FAA and State of North Carolina certification regulations, satisfy the public safety requirements, and protect the privacy of vehicles and drivers as part of the contractual conditions for procuring the drone services.

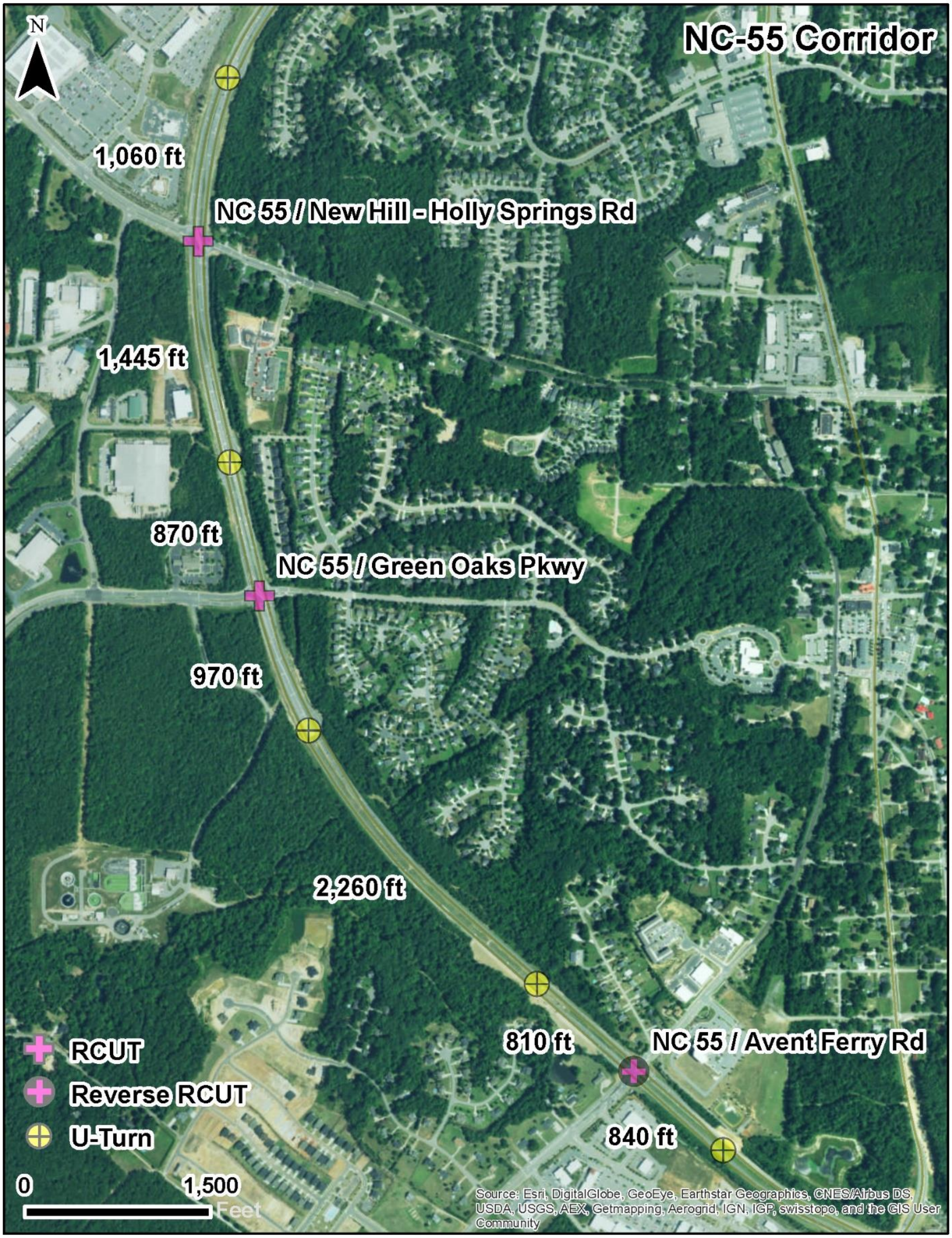
As a result, seven 5-minutes HD quality video footages on the three intersections on the NC55 corridor (Figure 26) were recorded. For each location, there is one video for the whole RCUT corridor including the U-turn locations, and six videos for minor and major approaches.

The first footage included the NC 55 and Green Oaks Parkway intersection. This footage included (a) the bird eye view of the U-turns and the actual intersection, (b) videos of each approach (the intersection itself, not the U-turns: 2 major and 2 minor approaches, this video footage clearly showed the turning movements and signalization), (c) signalization timing while a RUBY Drones personnel is crossing the roadway shown in Figure 27 and the turning movements during that cross were included in the video (see example snapshot in Figure 30).

The second video included the NC 55 and New Hill Road intersection (Figure 28). This footage (a) showed the bird eye view of the U-turns and the actual intersection, (b) consist of videos of each approach (the intersection itself, not the U-turns: 2 major and 2 minor approaches, this video footage clearly showed the turning movements and signalization), (c) signalization timing while a RUBY Drones personnel is crossing the roadway shown in Figure 27 and the turning movements during that cross were included in the video (see example snapshot in Figure 31).

The third video included the NC 55 and Avent Ferry Road intersection (Figure 29). This footage included (a) the bird eye view of the U-turns and the actual intersection, (b) videos of each approach (the intersection itself, not the U-turns: 2 major and 2 minor approaches, this video footage clearly showed the turning movements and signalization), (c) signalization timing while a RUBY Drones personnel is crossing the roadway shown in Figure 27 and the turning movements during that cross were included in the video (see example snapshot in Figure 32).

All the supplementary data files including the site visit and drone exercise videos have been delivered to the FDOT.



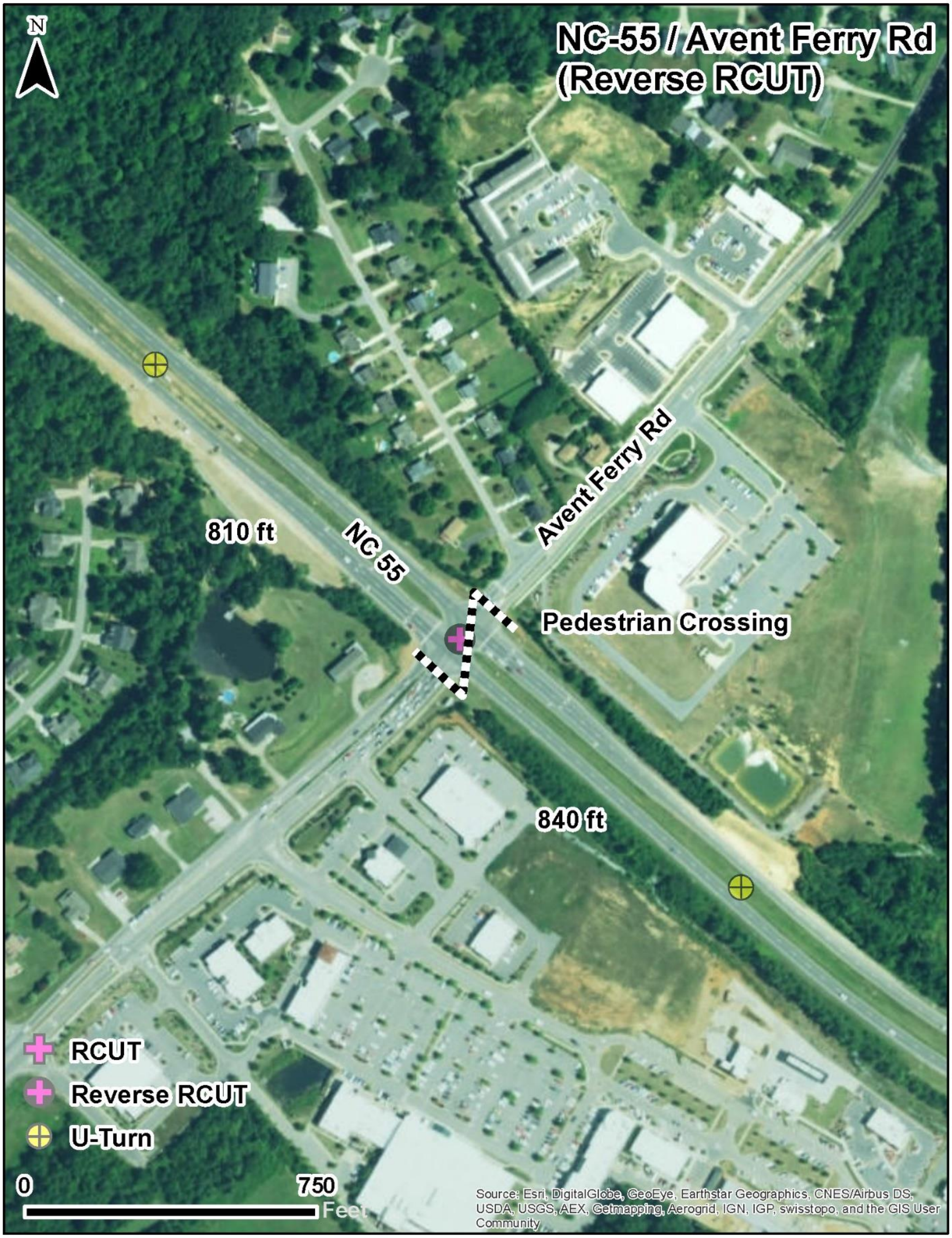
Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 26. NC 55 RCUT corridor

Figure 27. NC 55 & Green Oaks Parkway intersection

Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 28. NC 55 & New Hill Road intersection



Source: Esri, DigitalGlobe, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AEX, Getmapping, Aerogrid, IGN, IGP, swisstopo, and the GIS User Community

Figure 29. NC 55 &Avent Ferry Road intersection (Reverse RCUT)

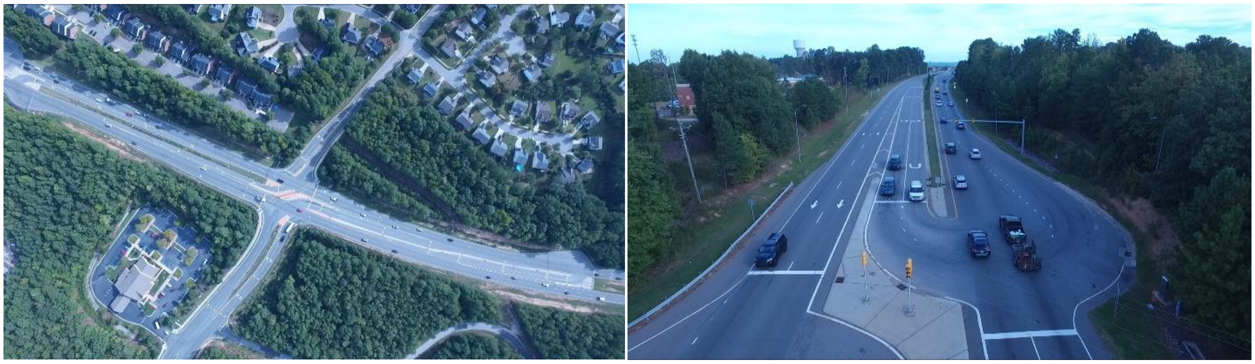


Figure 30. NC 55 & Green Oaks Parkway intersection example footage

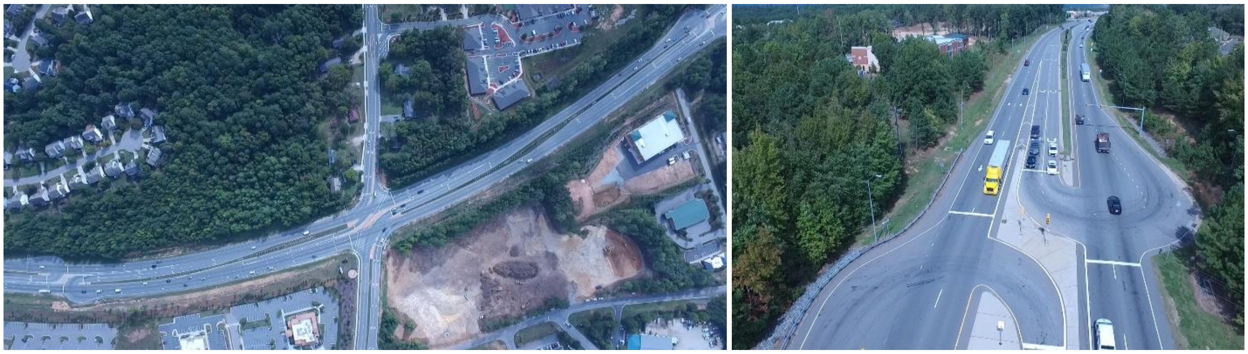


Figure 31. NC 55 & New Hill Road intersection example footage

Figure 32. NC 55 & Avent Ferry Road intersection (Reverse RCUT) example footage

4. TASK 3: DEVELOPMENT OF SAFETY PERFORMANCE FUNCTIONS

In Task 3, working collaboratively with the Project Manager, all the RCUT intersections in the U.S. were utilized to develop the SPFs by the PIs and their graduate students. In 2014, FHWA released a report (Hummer et al., 2014) which shows a total of 51 RCUTs that could be utilized in determining SPFs. On the other hand, Task 2 of this project revealed that a total of 240 RCUTs exist or have been implemented since the FHWA study was completed. All known to exist RCUTs were targeted for data collection in this task, and states were asked to provide data on other RCUT locations, which were not known before. For each RCUT intersection, geometric, traffic and crash data were collected. When possible, the crash data covered 3 to 5 years before and 3 to 5 years after the construction of the RCUTs. All pertinent data was requested from federal, state, and municipal agencies. In addition, databases such as Ohio's Transportation Information Mapping System – Crash Analysis Tool (TIMS – GCAT), Tennessee's Enhanced Tennessee Roadway Information Management System (E-TRIMS), Georgia's Electronic Accident Reporting System (GEARS), Maryland's Open Data Portal, Texas' Crash Records Information System (CRIS) GIS files, roadway inventory files, and online resources such as Google maps and aerial photographs were also used in acquiring and verifying information. From the collected geometric and traffic data, all independent variables likely to influence traffic crashes were extracted – including intersection area type (urban, suburban, rural), roadway functional classification (arterial, collector, distributor), segment lengths, median offset lengths, number of lanes and legs, shoulder widths, presence of a median, geographical location, AADT and posted speed limit. From several states, construction cost data as well as signalization and timing data and/or plans were also collected. These variables were used to create the SPFs for both signalized and unsignalized intersections, where several models have been developed. These SPFs can be successfully used by transportation agencies to evaluate and justify the installation of innovative intersection designs that will drastically improve intersection safety and operations. Results of this task will be used with the new Intersection Control Evaluation (ICE) Policy and Procedure, and RCUT Safety Performance Function (SPF) will be incorporated into the SPICE Tool. Based on the extensive evaluation of these models, recommendations have been presented, which can serve as guidelines for transportation agencies in decision making for RCUT implementations.

A comprehensive analysis has been performed in order to develop Safety Performance Functions (SPFs) for the Restricted Crossing U-Turn (RCUT) intersections, which may be under the jurisdiction of a variety of transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies). In order to conduct this analysis, the impact of traffic-, geometric design- and environment-related variables on the crashes occurred at RCUTs has been investigated. Consequently, a final comprehensive list of proposed SPF models was presented for signalized and unsignalized RCUTs.

The main advantage of the RCUTs, compared to conventional intersections, is the safety improvement brought about by implementation of their innovative design. Besides the benefits associated with efficient traffic flow, RCUTs improve the safety of problematic intersections substantially by reducing not only the crash rate and frequency but also the number of severe injuries and fatalities (Bared, 2009; Edara et al., 2015, 2013; Hummer et al., 2010). One of the reasons for this reduction is the lower number of conflict points generated by RCUTs compared to those generated by conventional intersections (Bared, 2009). That is, RCUTs have 18 conflict points whereas conventional intersections have 32 conflict points, which implies a higher crash risk. Furthermore, RCUTs alter the types of crashes that occur at intersections, which also helps to reduce the severe crashes (i.e., severe injuries and fatalities). To clarify, angle-type crashes, which are considered as the most serious type of crashes in the literature, are substantially reduced by the implementation of RCUTs (Inman et al., 2013). Moreover, there is a significant reduction in the number of all types of crashes (e.g., angle, right-turn, left-turn etc.) except side-swipe and rear-end crashes at RCUT locations (Hummer, Ray, et al., 2014). That is, this report states that, after RCUT implementations at different locations, the rate of reduction of crashes was reduced and there was even a slight increase in side-swipe and rear-end crashes.

Crash models are crucial in terms of traffic safety in order to understand the factors affecting the crash rates, frequencies, and severities. The following geometry-, operation-, and traffic-related information were useful for the crash analysis (Savolainen et al., 2015): (a) number of intersection legs, (b) type of traffic control, (c) AADT for the major and minor roadways, (d) number of approaches with left-turn lanes, (e) number of approaches with right-turn lanes, (f) presence of lighting, (g) presence of one-way or two-way traffic, (h) intersection sight distance, (i) intersection skew angle, (j) presence/type of left-turn phasing, (k) pedestrian volumes, (l) presence of bus stops, (m) presence of on-street parking, and (n) presence of median. Nevertheless, SPFs are intended to be simple and easily implementable mathematical equations. Therefore, complex models or a high number of variables are not favored due to practical and computational reasons. This is because SPFs are crash frequency models commonly used by practitioners who may or may not have statistical expertise. As such, complex and hard-to-apply models are not favored. The number of variables, on the other hand, are also kept limited in order to ease the data collection process. For practical purposes, agencies usually prefer simpler and user-friendly SPFs. Major and minor approach traffic volumes should also be introduced separately into the models in order to enhance the accuracy, and minor approach volume is sometimes more important than major approach volume (Maze et al., 2010).

Crash data are usually divided with the time period that data covers in order to obtain annual crash frequencies. In addition to the total crash frequency, it is very common to disaggregate the data according to severity levels and types of crashes. For example, Edara et al. (2015) divided the crash data into the following four severity levels for unsignalized RCUTs: property damage only, minor (possible, non-incapacitating) injury, disabling (incapacitating) injury, and fatality.

For different types of intersections, there are different SPF models developed in different studies and states. The common features for all these SPFs, whether being developed for segments or intersections, is the simplicity and low number of predictive variables in the equations used to model crash frequencies. The roadway segment SPFs generally include AADT and segment length, whereas a few models also introduce speed limit, lane widths, and shoulder widths into the SPFs. Intersection SPFs, on the other hand, generally employ major and minor AADTs. Srinivasan and Carter (2011) also used the number of legs in order to model crash frequencies. The logarithmic transformation (natural logarithm) is a commonly used approach to introduce AADT (major and/or minor) and segment length into SPFs, whereas no transformation was preferred in some models. The effects of these variables on the crash frequency are determined based on the sign of variable coefficients. That is, a positive sign indicates an increase in the crash frequency, whereas a negative sign shows a reduction. The goodness-of-fit of the fitted models is usually determined based on several indicators such as likelihood ratio test, Akaike Information Criterion, Bayesian Information Criterion, or Pearson's chi-squared test. For the roadway crash prediction analysis, generally, the statistical significance of the model coefficients are controlled by p values reported in the conducted analyses. In these analyses, it is customary to assume a coefficient with a significance level lower than 0.05 as a significance coefficient (based on the 95% confidence level). However, it was reported that, if the sample size is limited, the variable coefficients may be found not statistically significant, therefore, it may be acceptable to assume significance coefficients up to 0.20 depending on the conditions (80% confidence level) (Kweon and Lim, 2014).

There are different statistical models implemented for the analysis of crashes. An exhaustive review of these models can be found in Lord and Mannering (2010). These methods vary from simple multiple linear regression models to complex statistical models. Among others, the most common and convenient approach, which is also recommended by the Highway Safety Manual (HSM) and Safety Analyst (AASHTO, 2010; Exelis Inc, 2013; Kweon and Lim, 2014), is the negative binomial regression. Negative binomial regression is an extension or generalization of Poisson regression; however, different than Poisson regression, it can account for the overdispersion issue, which is commonly experienced with the crash data. That is, the crash data usually has a larger variability (overdispersion) than what a Poisson regression can handle. Note that mean and variance is equal to each other for a Poisson distribution, and therefore, Poisson regression models result in biased estimates. This larger variability can be introduced into the negative binomial model using an overdispersion parameter, which increases the accuracy of estimates. This overdispersion parameter constitutes the basis of before and after crash analysis conducted using the empirical Bayes approach (Hauer, 2001). The overdispersion parameter is estimated in the model along with the coefficients of variables (e.g., AADT, length) employed in order to create the model itself. The negative binomial regression distribution is a generalization of Poisson distribution by including a gamma noise variable, which introduces an extra variance due to the over-dispersion of crash data. The negative binomial distribution can be defined as follows:

$$\Pr(Y = y_i|\mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})}\left(\frac{\alpha^{-1}}{\alpha^{-1} + \mu_i}\right)\left(\frac{\mu_i}{\alpha^{-1} + \mu_i}\right)^{y_i}$$

where μ is the mean incident rate of y. In the case of crashes, μ is usually the number of crashes per year at a roadway segment or an intersection. $\alpha = 1/\nu$, where ν is the scale parameter of gamma distributed noise. The mean incident rate μ can be modeled as follows:

$$\mu_i = \exp(\beta_0 + \boldsymbol{X\beta})$$

where β_0 is the intercept term, $\boldsymbol{X}$ is the matrix of predictors, and $\boldsymbol{\beta}$ is the vector of coefficients. The estimation of coefficients of predictors can be succeeded by maximum likelihood estimation (MLE), which maximizes the likelihood function to find an optimal solution (coefficients maximizing the likelihood function). Likelihood function can be written as follows:

$$\mathcal{L} = \prod_{i=1}^{n} \Pr(Y = y_i | \mu_i, \alpha)$$

where *i=1,2, …, n*, indicate the observations, and *n* is the total sample size. The negative binomial regression analysis was conducted using the "glm.nb" function of "glmnet" package of the R programming software.

4.1. SIGNALIZED RCUTs

The SPF development process started with the identification of existing types of signalized RCUTs. For this purpose, we reviewed different types of RCUT implementations in the entire U.S., and discovered that there are mainly five types of signalized RCUTs as follows: 1) 4-legged RCUTs with 2 U-turns, 2) 4-legged RCUTs with 1 U-turn, 3) 3-legged RCUTs with 2 U-turns, 4) 3-legged RCUTs with 1 U-turns, and 5) 3- or 4-legged RCUT without a U-turn. The list of these types along with the number of RCUTs that belong to each type is given in Table 34, and the full list of these RCUTs including the states they are implemented in is provided in Appendix E. To develop the SPF models, RCUTs which have U-turns were utilized whereas RCUTs without U-turns were excluded from the analysis.

Table 34 Number of different types of signalized RCUTs

Type	Number of RCUTs
4-legged RCUT with 2 U-turns	*20*
4-legged RCUT with 1 U-turns	*3*
3-legged RCUT with 2 U-turns	*2*
3-legged RCUT with 1 U-turns	*8*
4- or 3-legged RCUT without U-turn	*3*
Total	***36***

Along with the identification of signalized RCUT types, traffic, geometric design, and environmental characteristics as well as crashes that occurred in these RCUTs were obtained as part of this task. For this purpose, the following variables were identified and documented (please see Appendix F for the full list of these variables):

1. Crashes: Total number of crashes, number of possible injury crashes, number of non-incapacitating injury crashes, number of incapacitating injury crashes, and number of fatality crashes.

2. Traffic: Major roadway AADT in the first direction, major roadway AADT in the second direction, minor roadway AADT in the first direction, minor roadway AADT in the second direction, major roadway speed limit, and minor roadway speed limit.

3. Geometric design: Number of legs, number of U-turns, number of lanes on major roadway first direction, number of lanes on major roadway second direction, number of lanes on minor roadway first direction, number of lanes on minor roadway second direction, lane width of major roadway, shoulder type of major roadway, shoulder

width of major roadway, offset distance of major roadway first direction, offset distance of major roadway second direction, presence of acceleration lane on major roadway first direction, presence of acceleration lane on major roadway second direction, acceleration lane length on major roadway first direction, acceleration lane length on major roadway second direction, presence of deceleration lane on major roadway first direction, presence of deceleration lane on major roadway second direction, deceleration lane length on major roadway first direction, deceleration lane length on major roadway second direction, weaving length on major roadway first direction, weaving length on major roadway second direction, median width of major roadway first direction, median width of major roadway second direction, number of U-turn lanes on first U-turn, number of U-turn lanes on second U-turn, median width of first U-turn, median width of second U-turn, number of right turn lanes on major roadway first direction, number of right turn lanes on major roadway second direction, number of left-turn lanes on major roadway first direction, number of left-turn lanes on major roadway second direction, and presence of concrete channelization.

4. Environment: Urbanization, presence of lighting, number of driveways, presence of business, presence of residence, presence of pedestrian crossing.

Following the documentation of these traffic-, geometric design-, and environment-related characteristics, the variables that could be used in safety performance functions were determined. Table 35 presents these candidate variables and their descriptions whereas Table 36 provides the descriptive statistics of these variables. These candidate variables were chosen based on their potential strong relationship with the crashes that have occurred at RCUTs as well as considering the practical applications of developed SPFs. That is, for example, the AADTs of major approaches were aggregated into one value, and only the maximum AADT values at major approaches were used. This is due to the fact that it may not be easy and most of the time impossible for agencies to obtain two different AADTs for each direction of the major approach. Moreover, environment-related variables were avoided in the models as much as possible since they are usually qualitative, and they depend on the personal assessment of SPF user (e.g., urbanization, presence of business/residence). Furthermore, base conditions were identified for all RCUTs, and therefore, they were excluded from the SPF analysis. These base conditions include the following variables: Shoulder Type (Paved), Lane Width (12 feet), Presence of Acceleration Lane (No Acceleration Lane), Acceleration Lane Length (0 feet).

Table 35 Candidate variables for signalized RCUT SPFs

Variables	**Description**
Maximum Major Road AADT	*The maximum of the major approach AADTs entering to the intersection*
Maximum Minor Road AADT	*The maximum of the minor approach AADTs entering to the intersection*
Major Road Speed Limit	*Major approach speed limit*
Minor Road Speed Limit	*Minor approach speed limit*
Urbanization	*A categorical variable indicating the level of urbanization around the RCUT. This is a qualitative variable estimated by the observation of research team. There are four categories assigned to each RCUT: Very low, low, moderate, and high urbanization.*
Number of Legs	*Number of legs of the RCUT intersection, either 3 or 4.*
Number of U-turns	*Number of U-turns of the RCUT intersection, either 1 or 2 (RCUTs which do not have U-turns were excluded from analysis).*
Number of Major Road Lanes	*Number of lanes on the major approach of the RCUT. The highest number in both approach was chosen (e.g., if one approach has 2 lanes and the other one has 3, then 3 is chosen as number of lanes).*
Number of Minor Road Lanes	*Number of lanes on the minor approach of the RCUT. The highest number in both approach was chosen (e.g., if one approach has 1 lanes and the other one has 2, then 2 is chosen as number of lanes).*
Presence of Lighting	*An environmental variable indicating whether the intersection is illuminated or not.*
Maximum Offset Distance	*The maximum distance between the center of intersection and the U-turn locations (e.g., if one approach has 800 ft. offset and the other one has 600 ft., then 800 ft. is chosen as maximum offset distance).*
Total Offset Distance	*The total distance between the center of intersection and the U-turn locations (e.g., if one approach has 800 ft. offset and the other one has 600 ft., then total offset distance is 1400 ft.).*
Maximum Deceleration Lane Length	*The maximum length of the deceleration lanes before U-turn locations (e.g., if one approach has 400 ft. deceleration lane and the other one has 250 ft., then 400 ft. is chosen as maximum deceleration lane length).*
Total Deceleration Lane Length	*The total length of the deceleration lanes before U-turn locations (e.g., if one approach has 400 ft. deceleration lane and the other one has 250 ft., then total deceleration lane length is 650 ft.).*
Maximum Median Width	*The maximum median width of the major approaches (e.g., if one approach has 40 ft. median and the other one has 25 ft., then 40 ft. is chosen as maximum median width).*
Total Median Width	*The total median width of the major approaches (e.g., if one approach has 40 ft. median and the other one has 25 ft., then total median width is 65 ft.).*
Maximum U-turn Median Width	*The maximum U-turn median width of the U-turns (e.g., if one U-turn has 20 ft. median and the other one has 25 ft., then 25 ft. is chosen as maximum U-turn median width).*
Total U-turn Median Width	*The total U-turn median width of the U-turns (e.g., if one U-turn has 20 ft. median and the other one has 25 ft., then total U-turn median width is 25 ft.).*
Maximum Weaving Length	*The maximum weaving length between right turn lanes of minor road and beginning of deceleration lanes (e.g., if one approach has 400 ft. weaving length and the other one has 250 ft., then 400 ft. is chosen as maximum weaving length).*
Total Weaving Length	*The total weaving length between right turn lanes of minor road and beginning of deceleration lanes (e.g., if one approach has 400 ft. weaving length and the other one has 250 ft., then total weaving length is 650 ft.).*
Number of Right Turn Lanes from Major Road	*The maximum number of right turn lanes from major approach to minor approach*
Number of Left-Turn Lanes from Major Road	*The maximum number of left-turn lanes from major approach to minor approach*
Number of Driveways	*The number of driveways within the whole footprint (including intersection center, U-turns, and segment between intersection center and U-turns) of the RCUT intersection.*

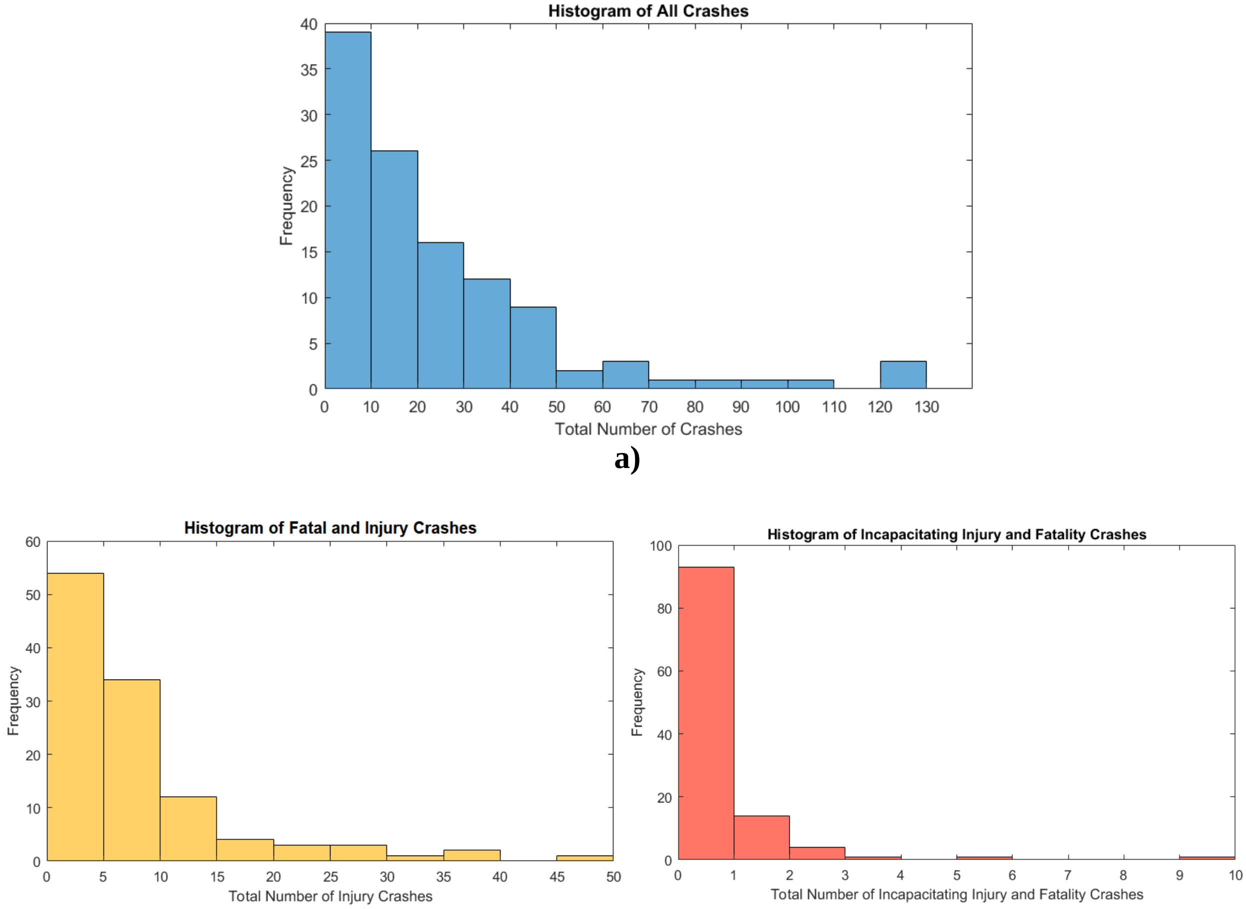
Table 36 Descriptive statistics of signalized RCUT candidate variables

Variables	**Min.**	**Max.**	**Mean**	**St. D.**	**Med.**	**25th%**	**75th%**	**95th%**
Maximum Major Road AADT	9,700	100,467	38,138	17,778	32,456	27,500	50,279	64,804
Maximum Minor Road AADT	1,000	18,218	6,828	4,699	6,676	3,000	9,000	15,266
Major Road Speed Limit	35	70	52.37	9.20	50	45	55	69
Minor Road Speed Limit	0	55	36.49	8.62	35	35	40	50
Urbanization	1	4	2.44	0.99	2	2	3	4
Number of Legs	3	4	3.76	0.43	4	4	4	4
Number of U-turns	1	2	1.70	0.46	2	1	2	2
Number of Major Road Lanes	2	3	2.40	0.49	2	2	3	3
Number of Minor Road Lanes	1	3	2.12	0.63	2	2	3	3
Presence of Lighting	0	1	0.59	0.49	1	0	1	1
Maximum Offset Distance	600	1,650	977	276	900	800	1,150	1,500
Total Offset Distance	650	2,675	1,533	511	1,575	1,025	1,900	2,400
Maximum Deceleration Lane Length	300	1,300	525	222	450	400	600	1,140
Total Deceleration Lane Length	300	2,300	820	421	688	450	1,025	1,600
Maximum Median Width	0	85	26	16	25	15	35	50
Total Median Width	0	145	38	26	35	20	53	75
Maximum U-turn Median Width	5	275	31	44	20	15	30	70
Total U-turn Median Width	10	275	44	47	28	18	60	90
Maximum Weaving Length	250	1,150	611	234	575	425	715	1,100
Total Weaving Length	250	2,000	943	396	900	650	1,250	1,400
Number of Right Turn Lanes from Major Road	0	2	1.04	0.36	1	1	1	2
Number of Left-Turn Lanes from Major Road	1	3	1.40	0.53	1	1	2	2
Number of Driveways	0	10	3.21	2.95	3	1	5	10
Abbreviations	Min: minimum, Max: maximum, St. D.: standard deviation, Med: Median, 25th%: 25th percentile, 75th%: 75th percentile, 95th%: 95th percentile,							

In addition to traffic-, geometric design-, and environment-related variables, crashes along with their severities were documented. Table 37 presents the descriptive statistics for these crashes while Figure 33 shows the crash histograms. Moreover, Figure 34 presents the combined histograms of crashes based on severity levels. Figure 35, on the other hand, shows the histogram of the ratio between major approach AADT and minor approach AADT at signalized RCUTs. Furthermore, Figure 36 presents the relationship between the ratio of Major AADT with Minor AADT and number of crashes at signalized RCUTs. Note that for signalized RCUTs, all crashes occurred on the whole footprint of a RCUT were included (Please refer to Appendix I for a full list of crashes and AADT values of RCUTs). That is, all crashes occurred at the intersection center (250 ft. upstream from minor approaches), U-turns (including 250 ft. upstreams approaching to U-turns), and segment between the intersection center and U-turns were collected as those crashes effecting the whole RCUT. Crashes were investigated in three categories: 1) "all crashes" including all severities, 2) "fatal and injury crashes" including all crashes involving some level of injury (i.e., PDO crashes excluded), and 3) "fatal and severe injury crashes" including incapacitating injuries and fatalities.

Table 37 Descriptive statistics of signalized RCUT crashes

Crashes	**Total**	**Min.**	**Max.**	**Mean**	**St. D.**	**Med.**	**25th%**	**75th%**	**95th%**
All Crashes	2805	0	125	24.75	25.94	14.50	7	35	81
Fatal and Injury Crashes	843	0	49	7.48	8.69	5	2	9	26
Fatal and Severe Injury Crashes	37	0	9	0.34	1.08	0	0	0	2
Abbreviations	Min: minimum, Max: maximum, St. D.: standard deviation, Med: Median, 25th%: 25th percentile, 75th%: 75th percentile, 95th%: 95th percentile,								



a)

b) **c)**

Figure 33. Histograms of signalized RCUT crashes: (a) all crashes, (b) fatal and injury crashes, and (c) fatal and severe injury crashes

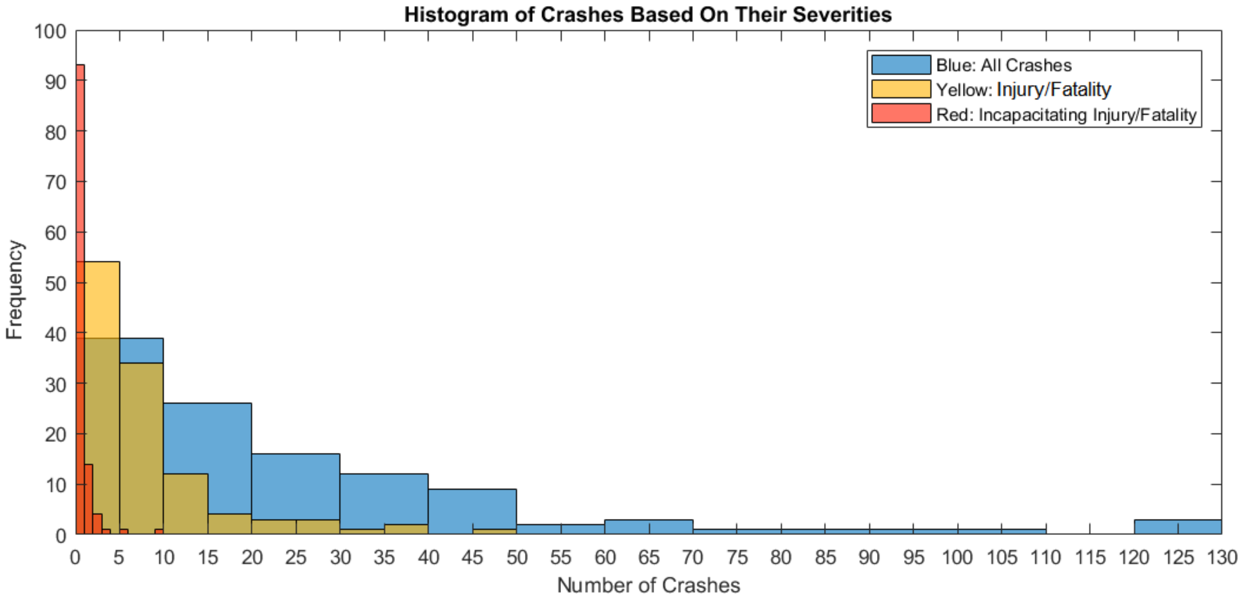


Figure 34. Combined Histograms of signalized RCUT crashes with different severities

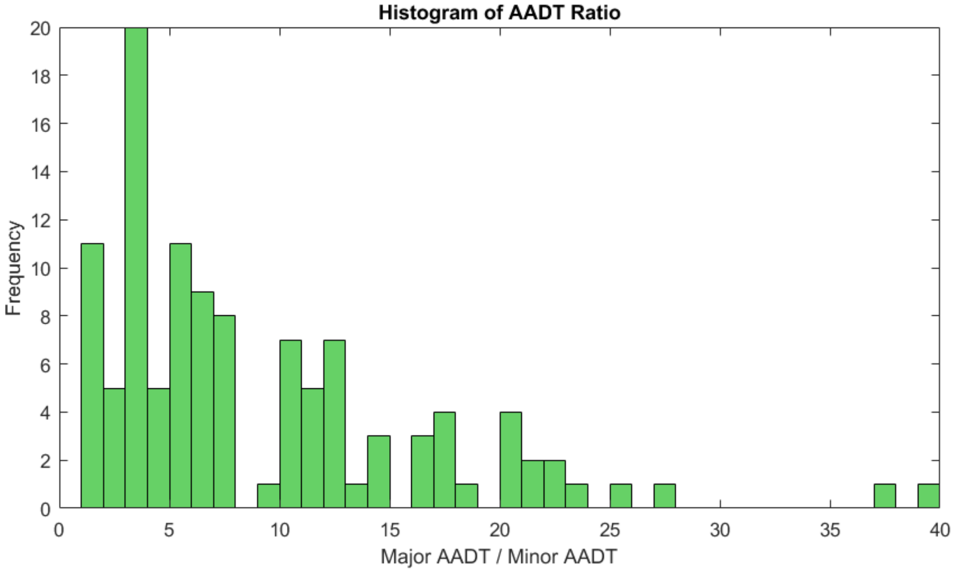
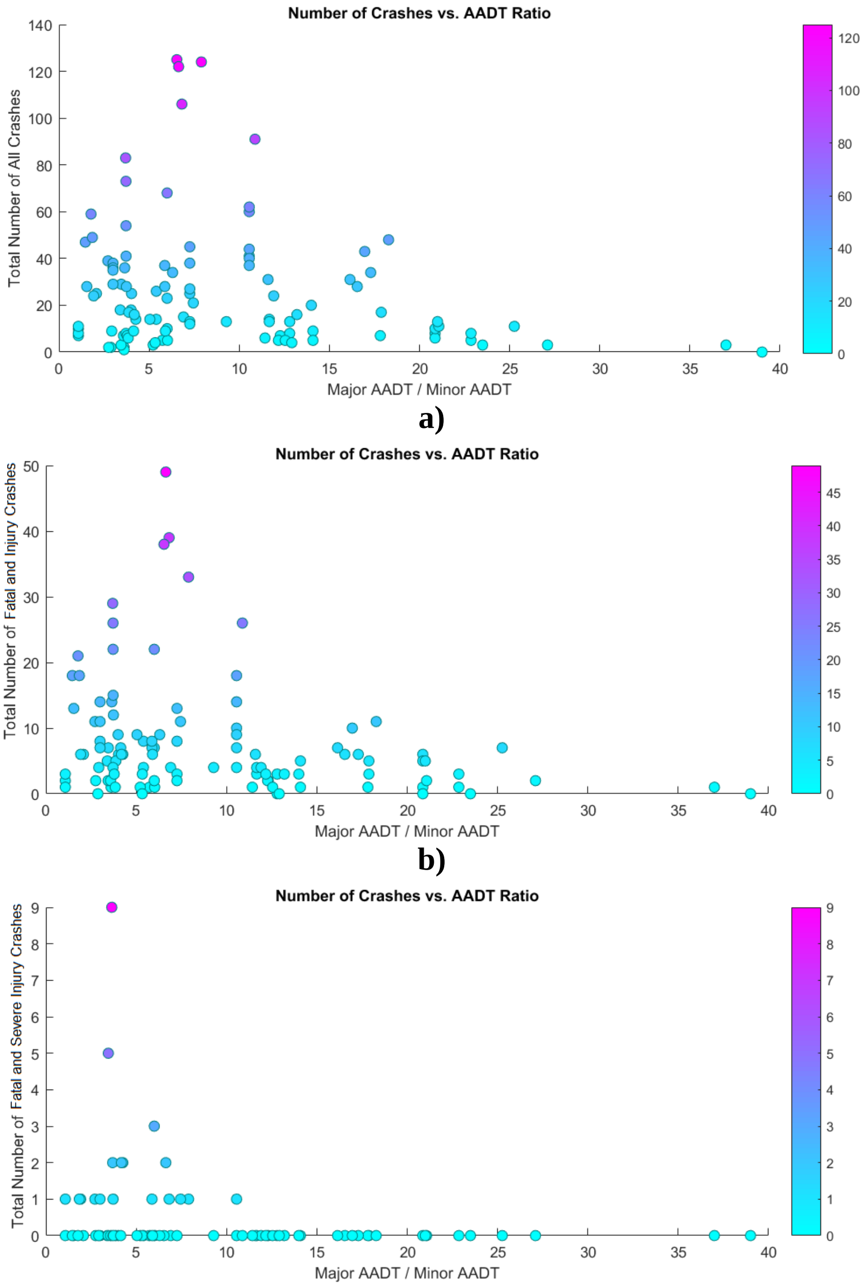


Figure 35. Histogram of ratio of major AADT to minor AADT at signalized RCUTs



a)

b)

c)

Figure 36. Relationship between the ratio of major AADT with minor AADT and number of crashes at signalized RCUTs: (a) total number of all crashes, (b) total number of fatal and injury crashes, and (c) total number of fatal and severe injury crashes

The relationship between crashes and the candidate variables was also investigated. To understand these relationships, 2-D histograms were plotted as shown in Figure 37 (All Crashes), Figure 38 (Fatal and Injury Crashes), and Figure 39 (Fatal and Severe Injury Crashes). These plots work as traditional histograms but at a two dimensional space. That is, color of the each hexagon in the 2-D histogram reflects how many data points (counts) are within that hexagon boundary. For instance, the dark red hexagon in the first 2-D histogram in Figure 37 (Total

Number of Crashes vs. Maximum Major AADT) indicates that there are 12 data points (observations) that have total number of crashes between 5 to 10 crashes while the major approach AADT of these data points is approximately 30,000. Blue/purple hexagons, on the other hand, indicate that there is only one observation within the boundary of those hexagons.

2-D histograms show that there is a clear trend between major approach AADTs and total number of all crashes as well as total number of fatal and injury crashes. A similar observation can also be made for the minor approach AADTs and number of crashes even though the trend is not as clear as the trend observed for the major approach AADT. The relationships between other candidate variables and total number of crashes are more obscure than the relationships between AADTs and number of crashes. Nevertheless, it is still possible to claim that 2-D histograms of number of legs, number of U-turns, offset distance, weaving distance, median width, number of lanes, and number of driveways have relatively strong correlations with the number of crashes.

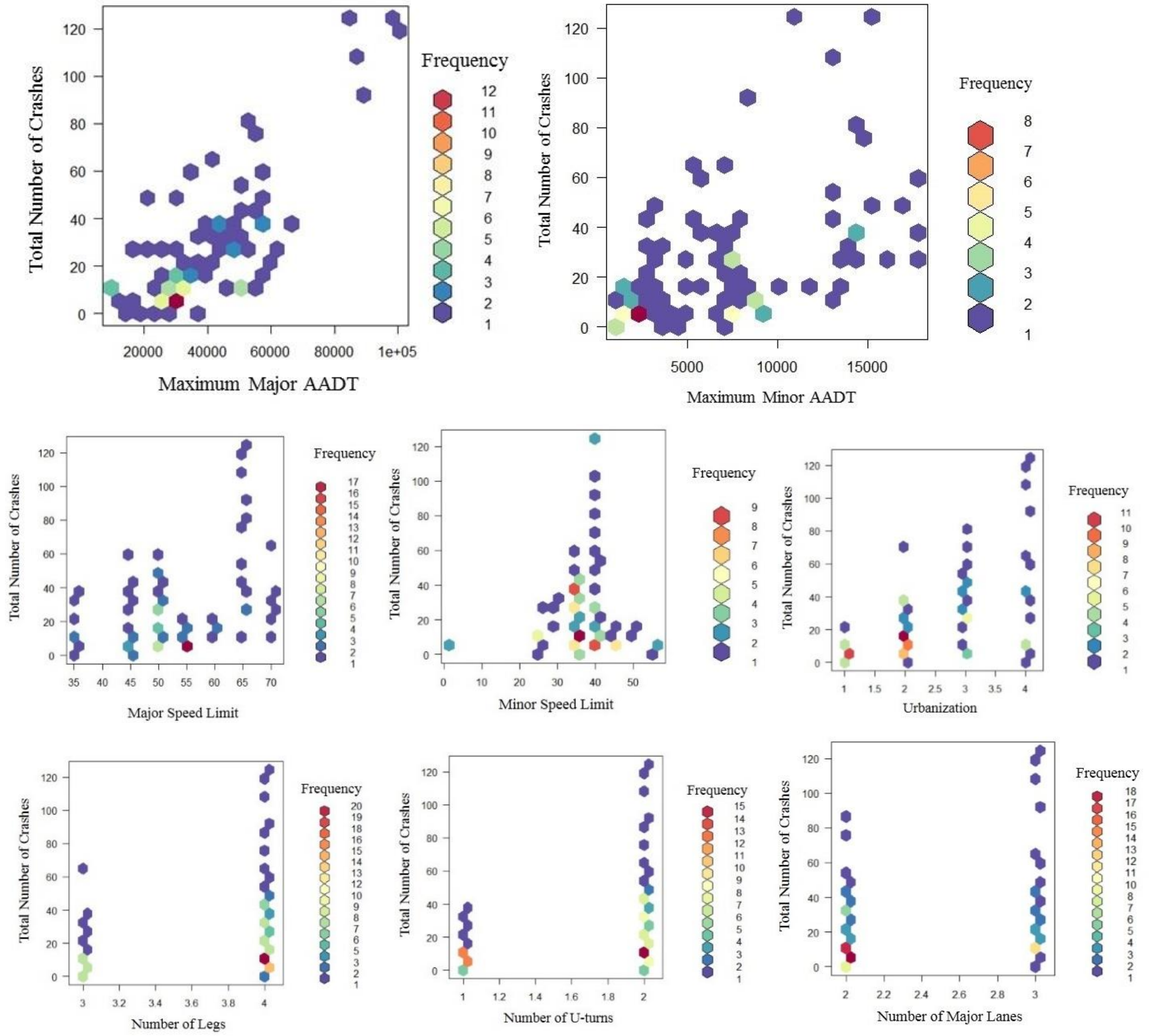


Figure 37. 2-D Histograms of the relationship between signalized RCUT "all crashes" and candidate analysis variables

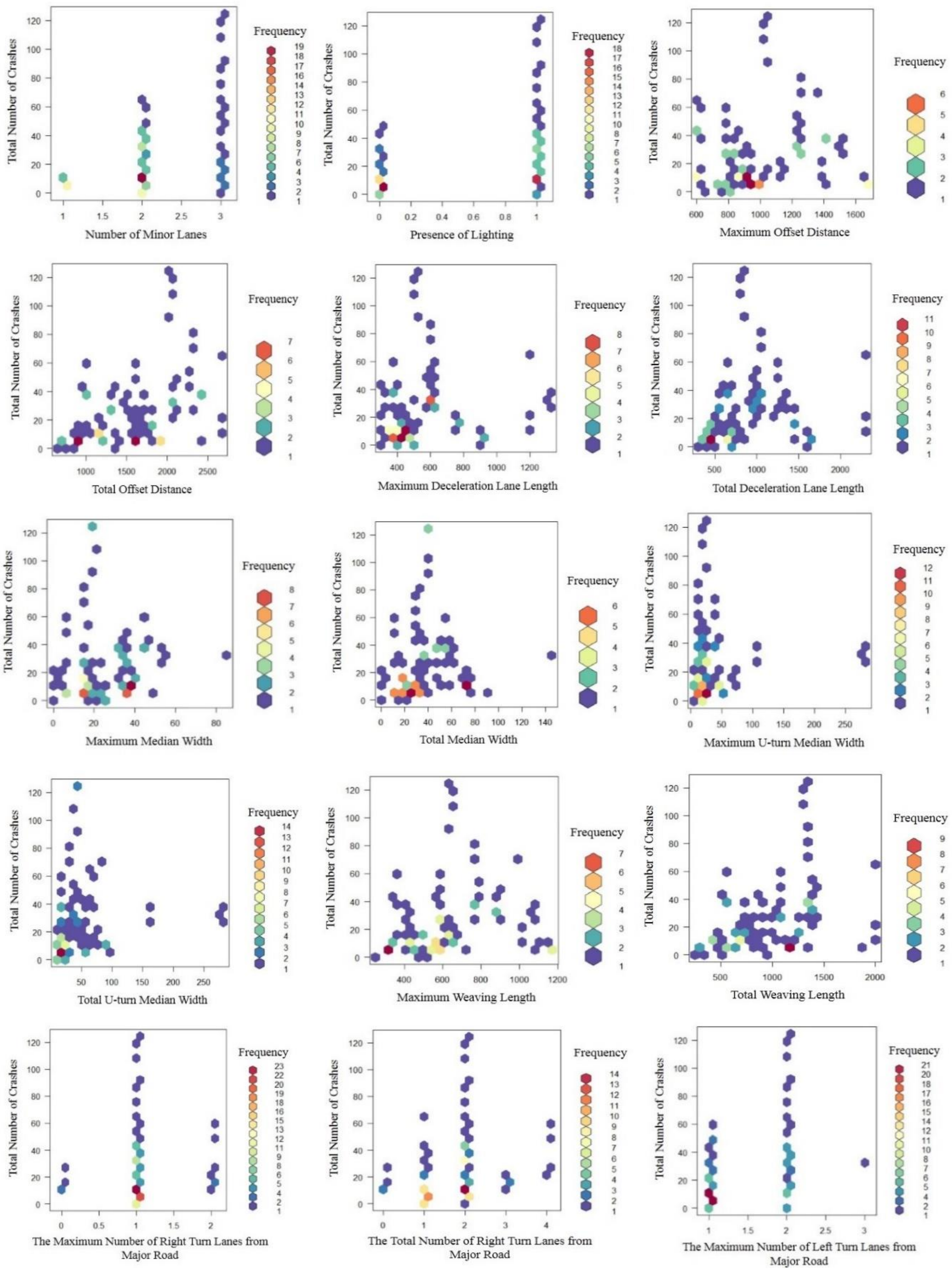


Figure 37. 2-D Histograms of the relationship between signalized RCUT "all crashes" and candidate analysis variables

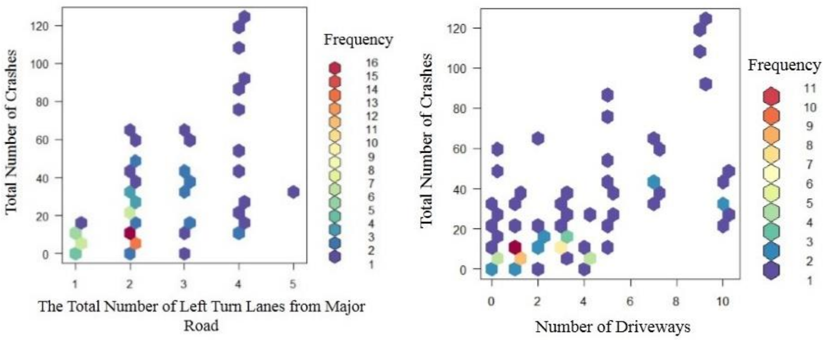


Figure 37. 2-D Histograms of the relationship between signalized RCUT "all crashes" and candidate analysis variables

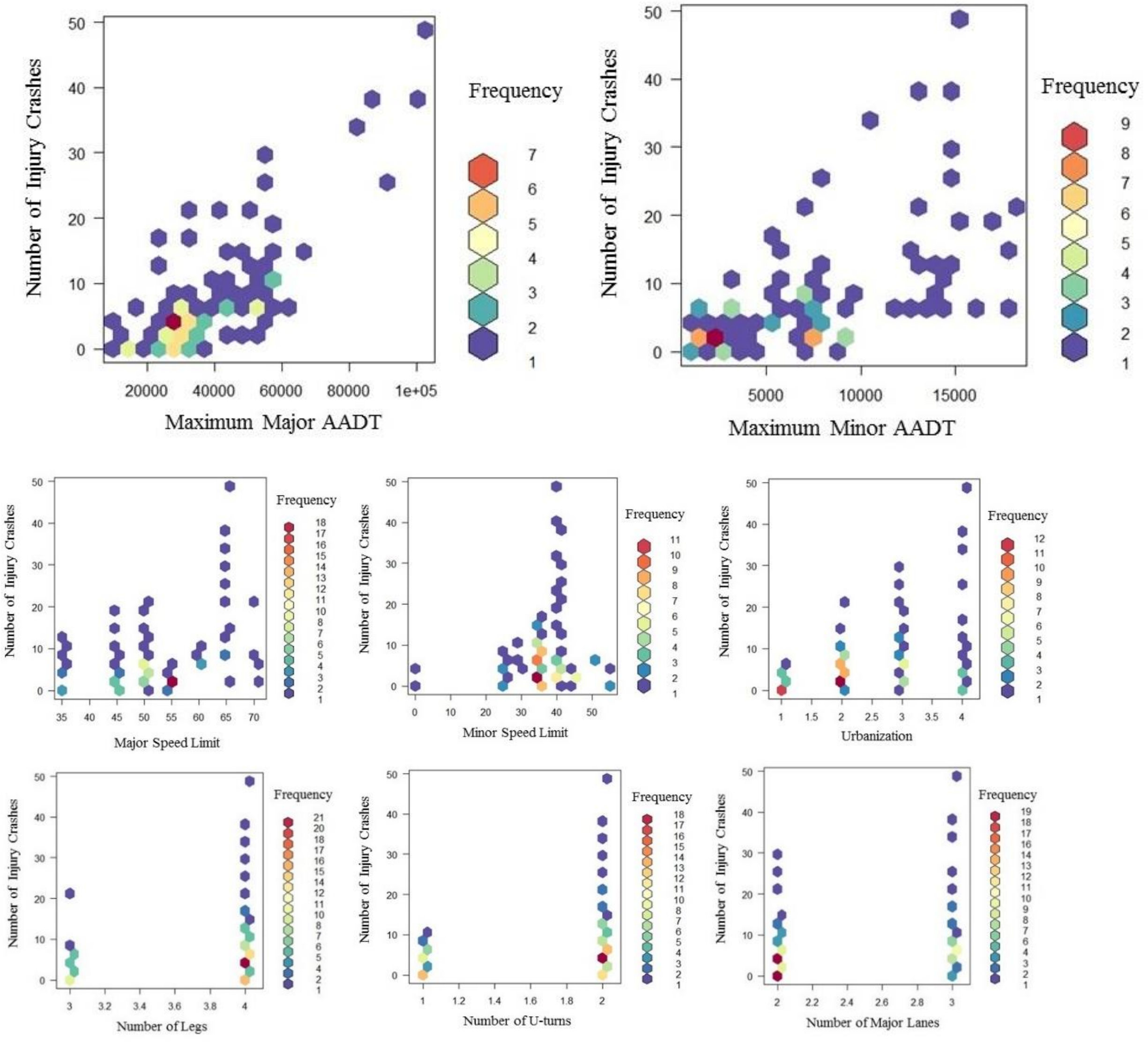


Figure 38. 2-D Histograms of the relationship between signalized RCUT "fatal and injury crashes" and candidate analysis variables

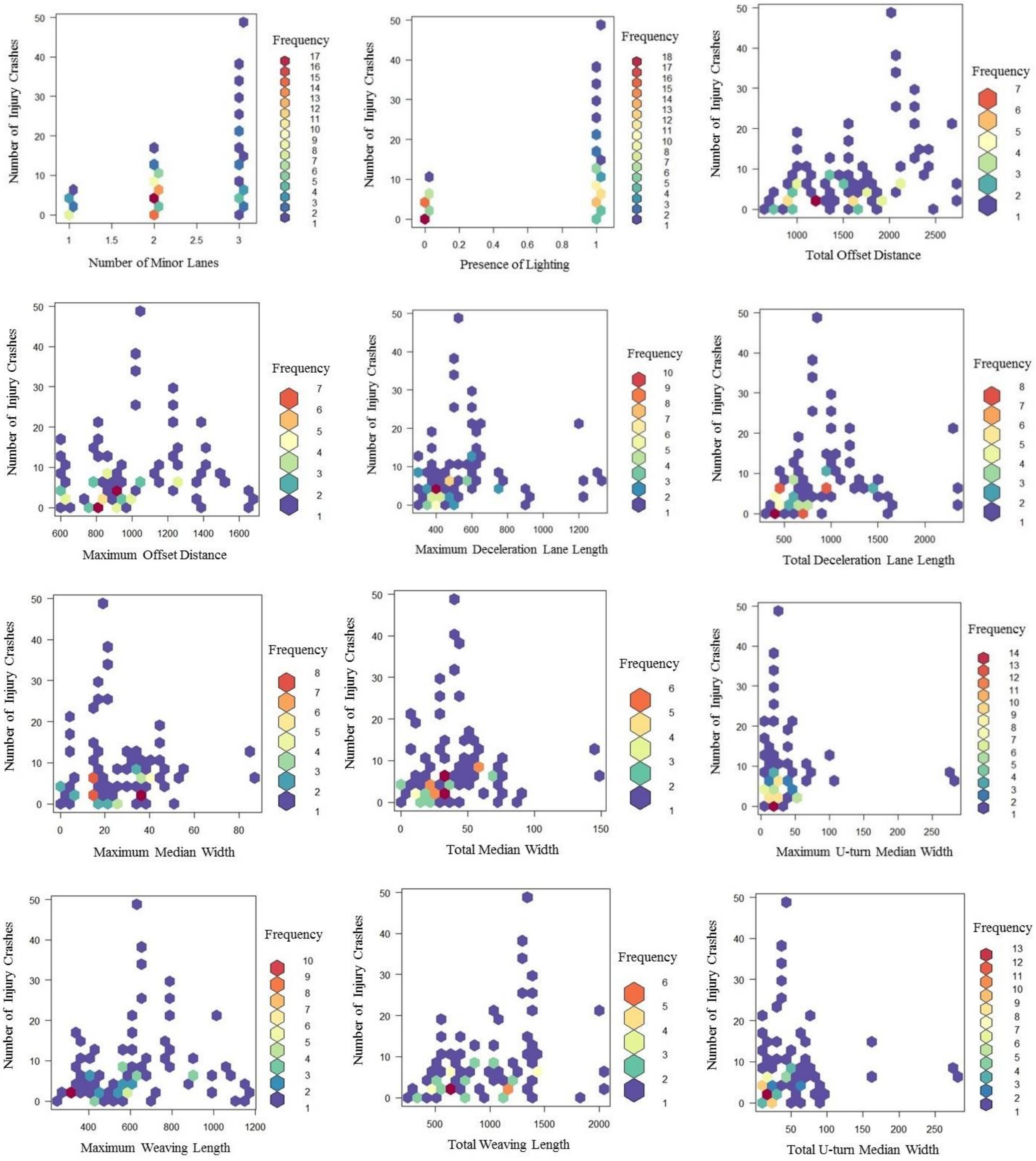


Figure 38. 2-D Histograms of the relationship between signalized RCUT "fatal and injury crashes" and candidate analysis variables

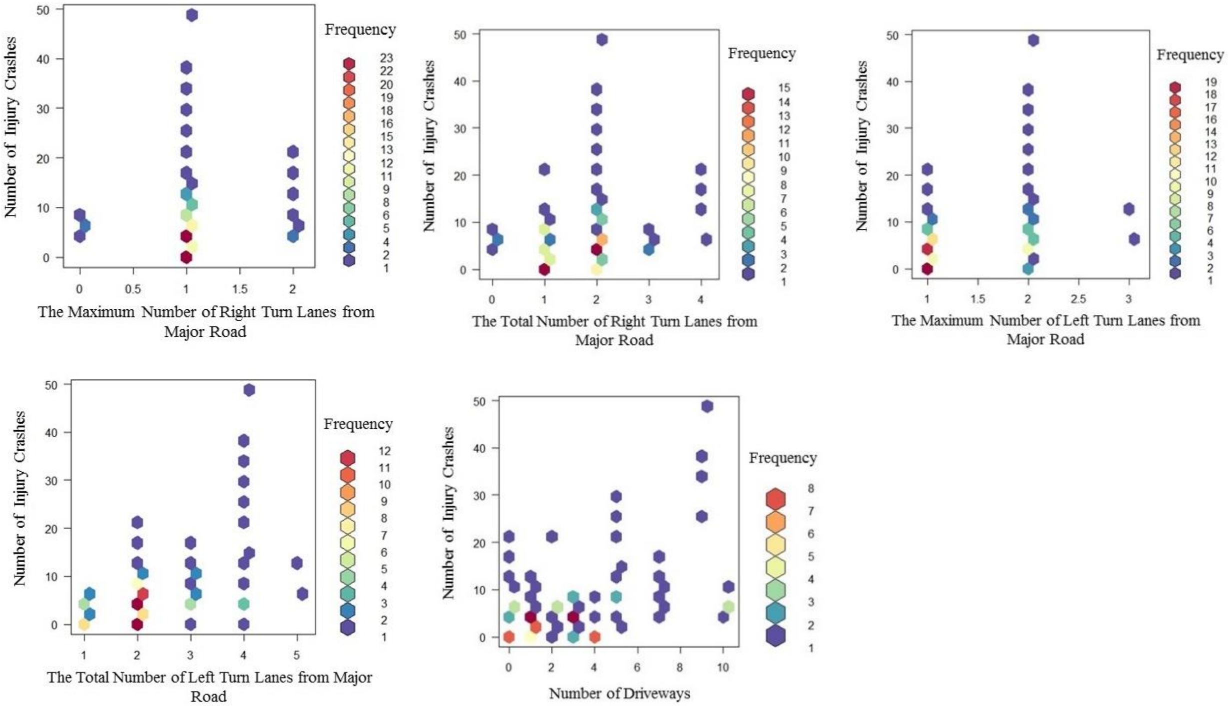


Figure 38. 2-D Histograms of the relationship between signalized RCUT "fatal and injury crashes" and candidate analysis variables

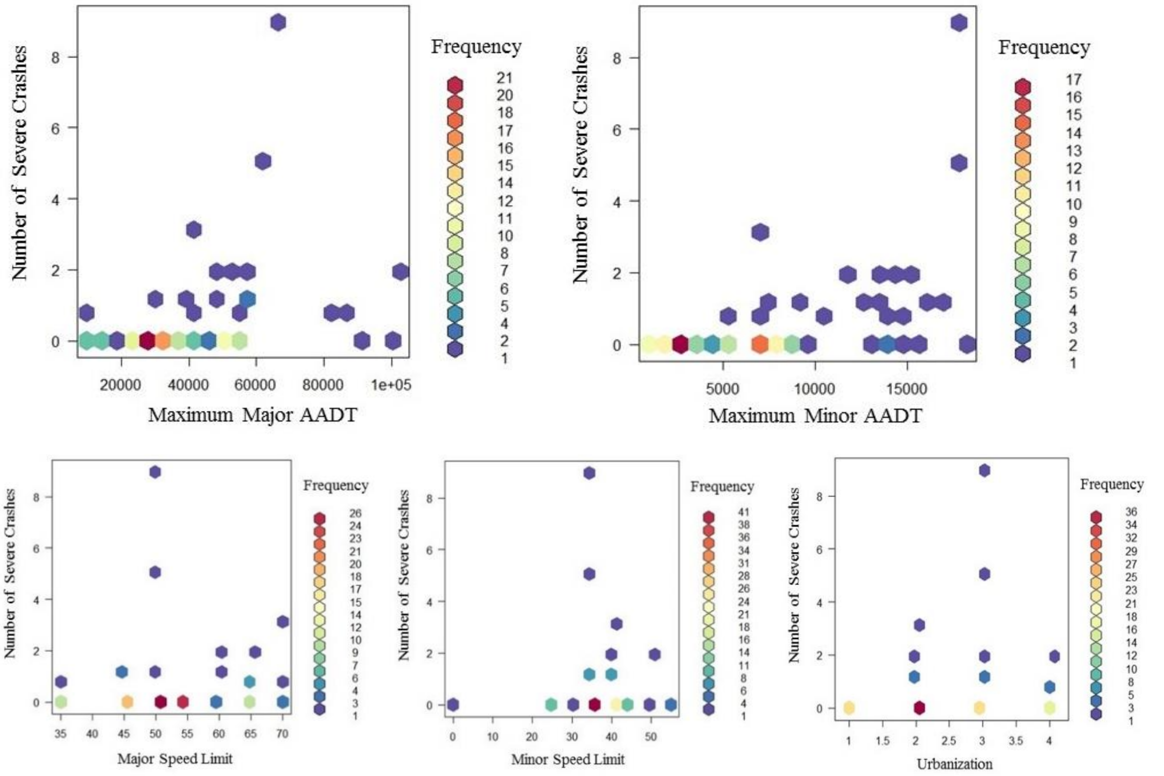


Figure 39. 2-D Histograms of the relationship between signalized RCUT "fatal and severe injury crashes" and candidate analysis variables

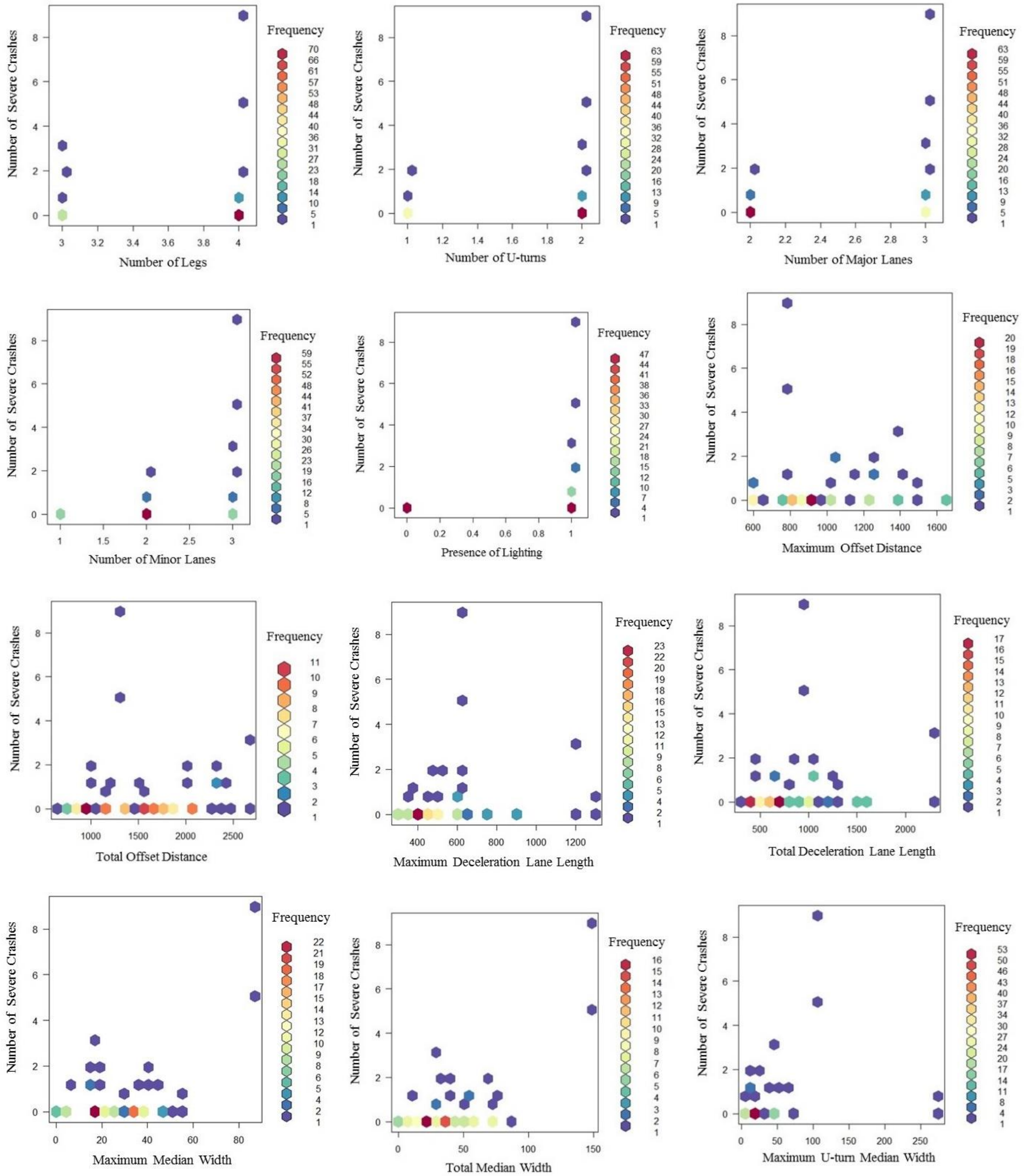


Figure 39. 2-D Histograms of the relationship between signalized RCUT "fatal and severe injury crashes" and candidate analysis variables

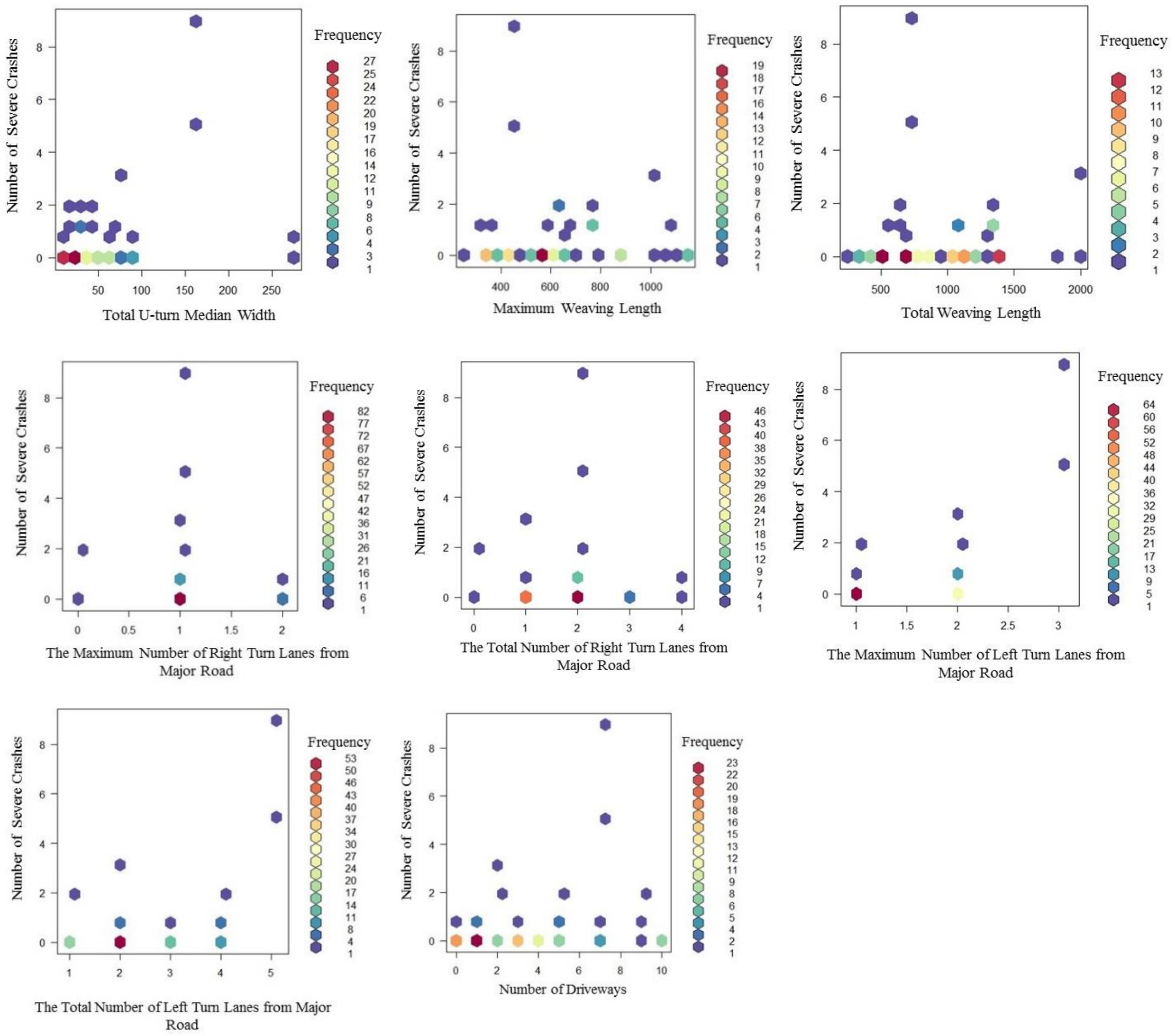


Figure 39. 2-D Histograms of the relationship between signalized RCUT "fatal and severe injury crashes" and candidate analysis variables

The exploratory analysis of the data indicates that the most critical variables for signalized RCUTs are as follows: major approach AADT, minor approach AADT, and number of U-turns. These variables also constitute the final SPF model of both all crashes and fatal and injury crashes (Model 6 of all crash SPFs and Model 3 of fatal and injury crash SPFs – Please see the next section). Therefore, Figure 40, Figure 41, and Figure 42 were plotted to illustrate the relationship between these variables and the number of crashes. These figures show that there is a strong increasing trend in number of crashes with the increase in the major AADT and/or minor AADT values. Moreover, it is clear that the number of crashes at RCUTs with 2 U-turns are significantly higher than the crash numbers at those with 1 U-turn.

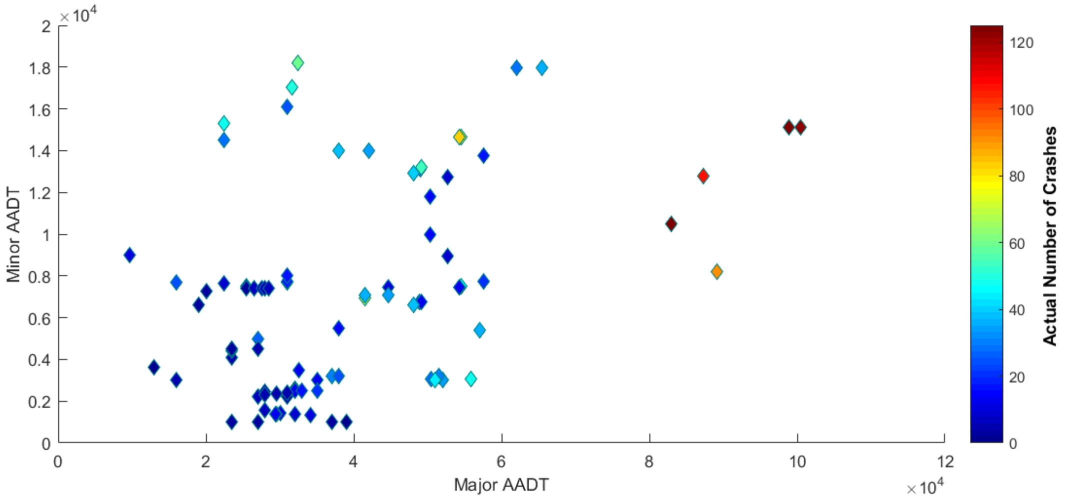
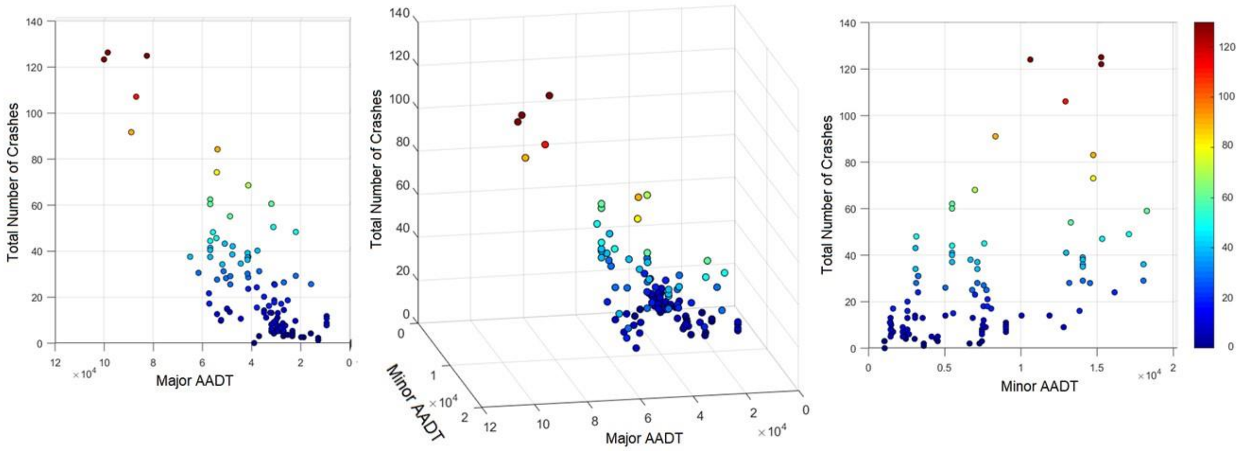


Figure 40. Relationship between minor and major approach AADTs with color-scaled signalized RCUT crash numbers



(a) **(b)** **(c)**

Figure 41. Relationship between total number of crashes and AADTs of major and minor approaches with a color-scaled signalized RCUT crash numbers: (a) total number of crashes vs. major AADT, (b) 3-D plot showing relationship of these three variables, and (c) total number of crashes vs. minor AADT,

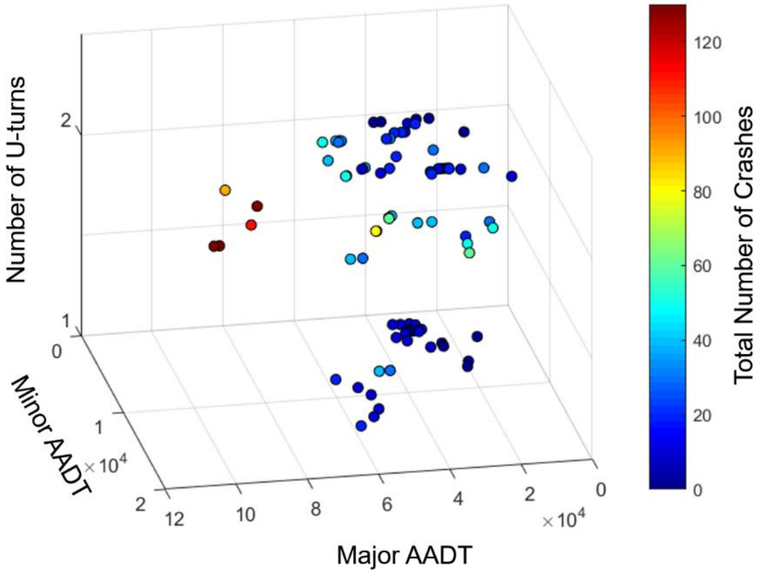


Figure 42. 3-D plot showing relationship of major AADT, minor AADT, and number of U-turns with total number of signalized RCUT crashes (color-scaled crash numbers)

4.1.1. Signalized RCUT SPF Models

After the extensive pre-analysis of crash data and candidate variables, Safety Performance Functions (SPFs) were developed for signalized RCUT intersections. All candidate variables were considered for SPFs; however, final sets of variables were determined based on the following criteria: (a) variable has a statistically significant effect on number of crashes, (b) variable data is convenient and easy to collect and obtain, and (c) is it practical to implement from a transportation agency perspective. Several models were developed for “all crashes” (six models) and “fatal and injury crashes” (three models) to provide flexibility in choosing the most appropriate model for local agencies and departments of transportation. Note that it was not possible to develop SPF models for fatal and severe injury crashes due to the scarcity of severe crashes (incapacitating injury and fatality). This lack of severe crashes clearly shows the power of RCUTs in reducing or eliminating severe injuries and advocates in the favor of RCUT implementations.

In this report, the U-turns are defined as shown in Figure 5: the U-turn locations at the right and left side of the intersection center. To be specific, the U-turns are crossovers just for the RCUT; however, not the main intersection of an adjacent RCUT. “Standalone RCUTs” were utilized to develop SPFs. That is, the system of RCUTs was not used where the main intersection of one RCUT is a U-turn for another. The number of major approach lanes includes only the through lanes but not the right turn lanes. To determine the number of driveways, publicly maintained roadways within the footprint were also counted. All driveways and side streets that connect within (including main road and crossovers) the footprint of the RCUT to identify this value. The deceleration lane “starts” where taper ends (deceleration lane reaches the full width) and “ends” where the U-turn curve starts. Even when there are dual U-turn lanes, it does not influence the length of the deceleration lane since the curved part of the U-turn location is not measured. The median width was measured from edge of pavement to edge of pavement. Note that the maximum gap was measured to identify the median width on each side of the RCUT.

4.1.1.1. Signalized RCUT SPF Models for All Crashes

This section presents the developed models for all crashes that occurred at signalized RCUTs. A total of six models with different variable sets were developed to provide alternative models with different complexities, which span from complex models to relatively simple and easily implementable models. This can aid in creating a flexibility for safety agencies or officials that can prefer more complex models when sufficient data are available, while it is also possible to implement more practical and simpler models when sufficient data are not available. Analysis results are presented in five tables that summarize the model findings, whereas Appendix G presents a more detailed analysis of the results. Table 38 presents the variable sets of six developed models. Note that Model 1 represents the full model and the following models are based on subsets of Model 1 variables. In each model, while moving from Model 1 to Model 6, the least significant variable was excluded from the predecessor model, and hence the successor model was formed. Furthermore, for the sake of simplicity, abbreviations will be used for variable names as presented in Table 39, and model functions are written using these abbreviations as shown in Table 40. Moreover, the variable coefficients of these models are given in Table 41. The model parameters such as over-dispersion parameter as well as model quality measures such as log-likelihood and AIC (Akaike's Information Criterion) are provided in Table 42. Furthermore, Figure 43 shows crash prediction planes of the Model 6. These figures were created to illustrate the variation of number of predicted crashes with respect major and minor AADTs as well as number of U-turns.

Table 38 Signalized RCUT SPF models for all crashes

Model	**Variables**
Model 1	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns, Number of Major Lanes, Number of Minor Lanes, Total Median Width, Maximum Offset Distance, Number of Driveways*
Model 2	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns, Number of Major Lanes, Number of Minor Lanes, Total Median Width, Maximum Offset Distance*
Model 3	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns, Number of Major Lanes, Number of Minor Lanes, Total Median Width*
Model 4	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns, Number of Major Lanes, Maximum Offset Distance*
Model 5	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns, Number of Major Lanes*
Model 6	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns*

Table 39 Signalized RCUT SPF model variable abbreviations for all crashes

Variables	**Abbreviation**
Maximum Major AADT	$AADT_{major}$
Maximum Minor AADT	$AADT_{minor}$
Number of U-turns	UT
Number of Major Lanes	$MaLa$
Number of Minor Lanes	$MiLa$
Total Median Width	$TMeW$
Maximum Offset Distance	MOD
Number of Driveways	NDW

Table 40 Signalized RCUT SPF model functions for all crashes

Model	**Functions**
Model 1	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT + MaLa + MiLa + TMeW + MOD + NDW\right)$
Model 2	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT + MaLa + MiLa + TMeW + MOD\right)$
Model 3	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT + MaLa + MiLa + TMeW\right)$
Model 4	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT + MaLa + MOD\right)$
Model 5	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT + MaLa\right)$
Model 6	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT\right)$

N_p*: Number of Predicted Crashes*

Table 41 Signalized RCUT SPF model coefficients for all crashes

Model	*Intercept*	$ln\left(AADT_{major}\right)$	$ln(AADT_{minor})$	UT	$MaLa$	$MiLa$	$TMeW$	MOD	NDW
Model 1	-13.50	0.986	0.503	0.705	0.364	-0.279	-5.08e-3	3.54e-4	0.042
Model 2	-15.00	1.145	0.468	0.831	0.392	-0.305	-4.09e-3	3.67e-4	-
Model 3	-15.14	1.213	0.470	0.738	0.324	-0.261	-3.62e-3	-	-
Model 4	-13.60	1.089	0.359	0.651	0.272	-	-	2.84e-4	-
Model 5	-13.88	1.149	0.374	0.596	0.229	-	-	-	-
Model 6	-13.96	1.152	0.443	0.600	-	-	-	-	-
Model 6*	-14.54	1.186	0.478	0.572					

* Model result after outlier data points (2 observations) excluded from analysis, please refer to Appendix G.

Table 42 Signalized RCUT SPF model parameters and model quality measures for all crashes

Model	*# of Variables*	# of Observations	θ	*Log-likelihood*	*AIC*
Model 1	8	114	6.03	-797.5	817.5
Model 2	7	114	5.58	-801.4	819.4
Model 3	6	114	5.28	-804.9	820.9
Model 4	5	114	5.14	-806.7	820.7
Model 5	4	114	4.99	-808.8	820.8
Model 6	3	114	4.77	-813.0	823.0
Model 6*	3	111	5.05	-785.4	795.4

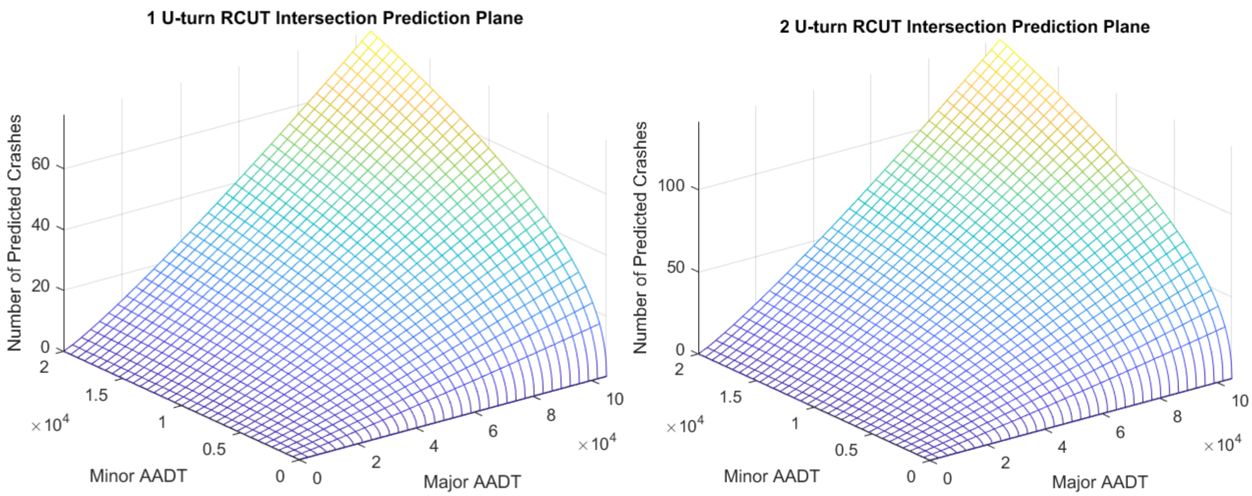


Figure 43. Signalized RCUT crash prediction planes for "all crash" Model-6 SPF

4.1.1.2. Signalized RCUT SPF Models for Fatal and Injury Crashes

This section presents the developed models for crashes with injuries that have occurred at signalized RCUTs. A total of 3 models with different variable sets were developed to provide alternative models with different complexities, which span from complex models to relatively simple and easily implementable models. This can aid in creating a flexibility for safety agencies/officials that can prefer more complex models in the case of available data while it is also possible to implement more practical/simpler models if less number of variables are available. The analysis results are presented in 5 tables that summarize the model findings whereas Appendix G present a detailed analysis of the results. Table 43 presents the variable sets of three developed models. Note that Model 1 represents the full model and following models are composed of subsets of Model 1 variables. In each model, moving from Model 1 to Model 3, the least significant variable was excluded from the predecessor model, and hence successor model was formed. Furthermore, or the sake of simplicity, abbreviations will be used for variable names as presented in Table 44, and model functions are written using these abbreviations as shown in Table 45. Moreover, the variable coefficients of these models are given in Table 46. The model parameters such as over-dispersion parameter as well as model quality measures such as log-likelihood and AIC (Akaike's Information Criterion) are provided in Table 47. Furthermore, Figure 44 shows crash prediction planes of the Model 3. These figures were created to illustrate the variation of number of predicted crashes with respect major and minor AADTs as well as number of U-turns.

Table 43 Signalized RCUT SPF models for fatal and injury crashes

Model	**Variables**
Model 1	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns, Number of Major Lanes, Total Median Width, Maximum Offset Distance*
Model 2	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns, Number of Major Lanes*
Model 3	*Maximum Major AADT, Maximum Minor AADT, Number of U-turns*

Table 44 Signalized RCUT SPF model variable abbreviations for fatal and injury crashes

Variables	**Abbreviation**
Maximum Major AADT	$AADT_{major}$
Maximum Minor AADT	$AADT_{minor}$
Number of U-turns	UT
Number of Major Lanes	$MaLa$
Total Median Width	*TMeW*
Maximum Offset Distance	*MOD*

Table 45 Signalized RCUT SPF model functions for fatal and injury crashes

Model	**Functions**
Model 1	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT + MaLa + TMeW + \ln(MOD)\right)$
Model 2	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT + MaLa\right)$
Model 3	$N_p = \exp\left(Intercept + ln\left(AADT_{major}\right) + ln(AADT_{minor}) + UT\right)$

N_p: *Number of Predicted Crashes*

Table 46 Signalized RCUT SPF model coefficients for fatal and injury crashes

Model	*Intercept*	$\boldsymbol{ln\left(AADT_{major}\right)}$	$\boldsymbol{ln(AADT_{minor})}$	$\boldsymbol{UT}$	$\boldsymbol{MaLa}$	$\boldsymbol{TMeW}$	$\mathbf{ln}(\boldsymbol{MOD})$
Model 1	-18.30	1.154	0.547	0.357	0.311	-5.55e-3	0.300
Model 2	-16.09	1.142	0.555	0.341	0.202	-	-
Model 3	-16.21	1.160	0.604	0.336	-	-	-
Model 3*	-16.93	1.197	0.652	0.299	-	-	-

* Model result after outlier data points (2 observations) excluded from analysis

Table 47 Signalized RCUT SPF model parameters and model quality measures for fatal and injury crashes

Model	*# of Variables*	# of Observations	$\boldsymbol{\theta}$	*Log-likelihood*	*AIC*
Model 1	6	114	9.46	-555.9	571.9
Model 2	4	114	6.60	-563.8	575.8
Model 3	3	114	6.26	-566.6	576.6
Model 3*	3	111	7.61	-543.9	553.9

* Model result after outlier data points (2 observations) excluded from analysis, please refer to Appendix G.

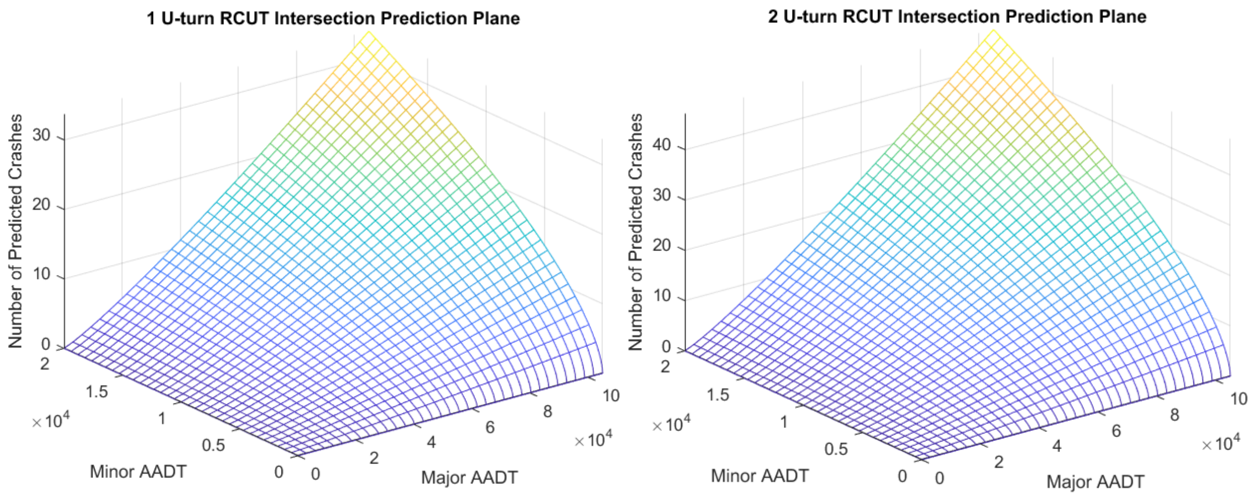


Figure 44. Signalized RCUT crash prediction planes of Model-3 SPF for fatal and injury crashes

4.1.2. Criteria for Implementation of Signalized RCUT SPFs

The RCUTs are known to be successful when minor approach AADT is not very high compared to the major approach AADT. Accordingly, RCUT implementations used in this study were found to comply with this general rule of thumb. Figure 45 shows the major approach to minor approach AADT ratio with respect to the major approach AADT for the studied signalized RCUTs in the U.S. The AADT ratio limit shown on this figure was shown as the limit to implement the signalized RCUT SPFs developed in this report. This limit may also be assessed as the feasible limit to implement signalized RCUTs at a potential location. Figure 46, on the other hand, illustrates this limit for SPF-predicted crash numbers (using model 6 for all crashes and model 3 for fatal and injury crashes) based on alternative minor to major approach AADT ratios (alpha). Note that the major approach AADT should not be higher than 100,000 whereas minor approach AADT can be identified using the following empiric equation for a given major approach AADT:

$$Ratio\ Function = 1.211 * \exp\left(-2.73 * 10^{-5} * AADT_{major}\right)$$

$$AADT_{minor}(limit) = AADT_{major} * Ratio\ Function$$

Major AADT	Ratio Factor	Minor AADT Limit
5,000	1.056	5,280
15,000	0.804	12,000
25,000	0.612	15,300
35,000	0.466	16,300
45,000	0.354	15,950
55,000	0.270	14,800
65,000	0.205	13,350
75,000	0.156	11,700
85,000	0.119	10,100
95,000	0.091	8,600

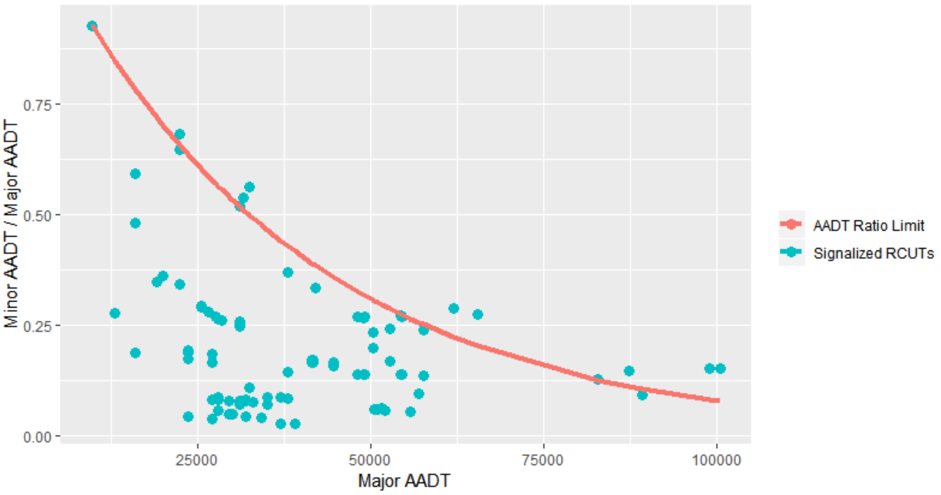
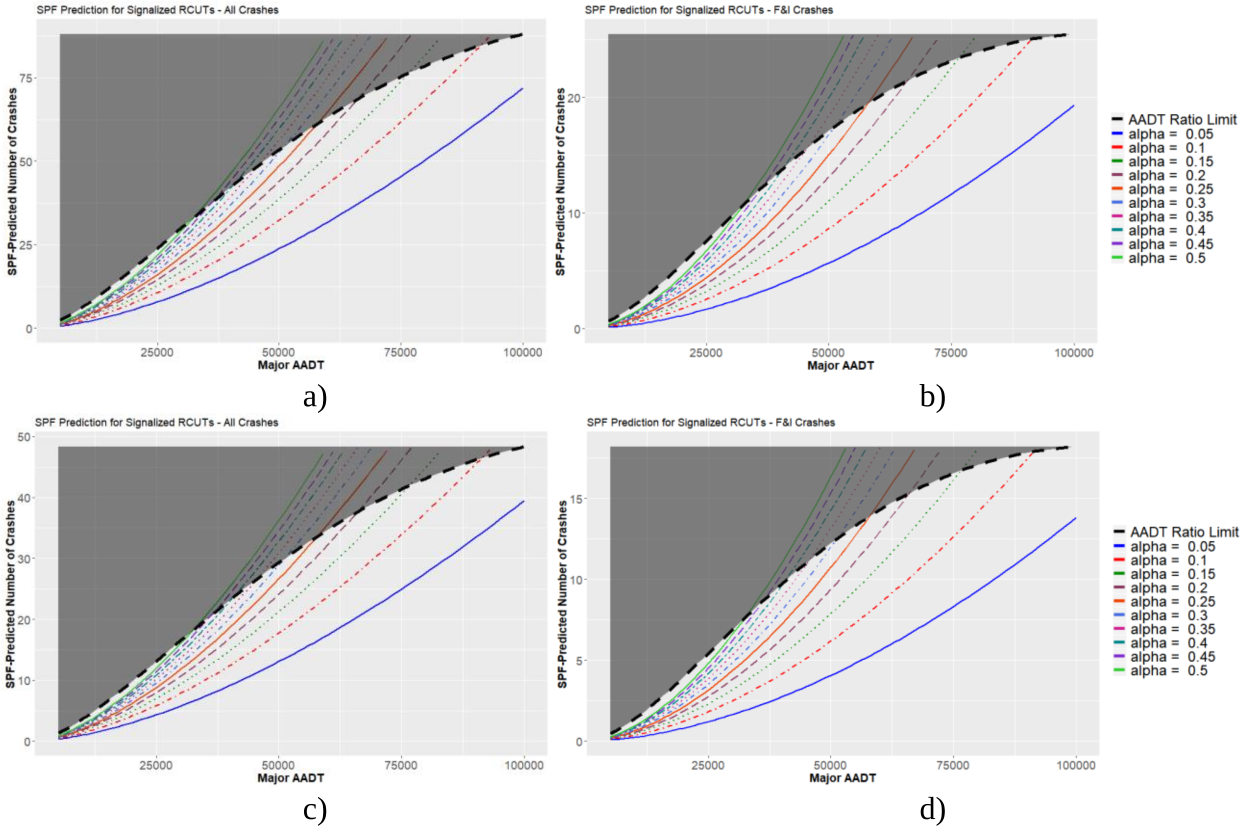


Figure 45. Major and minor approach ratios of signalized RCUTs in the U.S. and the proposed AADT ratio limit



a)

b)

c)

d)

Figure 46. Limit for SPF-predicted crash numbers based on the minor to major approach AADT ratio (alpha): a) 2 U-turn – All crashes; b) 2 U-turn – F&I crashes; c) 1 U-turn – All crashes; d) 1 U-turn – F&I crashes. Shaded zone is out of the proposed limit

4.1.3. Discussion and Recommendations for Signalized RCUTs

The comprehensive analysis of signalized RCUT crashes and developed SPFs provided important insights and recommendations for transportation agencies related to the implementation of this alternative intersection type. To begin with, analysis findings show that the possible location for a future RCUT implementation should be chosen with extreme care because traffic volumes of major and minor approaches as well as their ratios play a critical role in the efficient and successful RCUT implementations. Figure 41 shows that the higher the major and minor AADTs, the higher the total number of crashes. More importantly, when the ratio of major AADT to minor AADT is small due to high minor approach traffic, there is a considerable increase in the number of crashes compared to RCUTs which have larger major AADT to minor AADT ratios (Figure 36). Therefore, transportation agencies should avoid implementing RCUTs at locations where high minor traffic volume is being experienced.

Another insight obtained through the investigation of RCUT crashes is that RCUTs appear to be more suitable for suburban and less urbanized areas because very high crash numbers are observed for intersections located at highly urbanized areas (Figure 37). Figure 37 also shows that shorter deceleration lanes might be associated with higher number of crashes. However, this variable was not found to be statistically significant in predicting the total crash number. Another geometric variable, namely offset distance, was used in modeling total crash numbers and was adopted as one of the SPF variables. However, it was found that offset distance slightly increased the total number of crashes. This is due to the fact that all crashes occurred along the footprint of an RCUT intersection were included in the analysis, and the longer the offset, the more the number of crashes observed between the intersection center and U-turns. However, this does not necessarily mean that offset distance should be kept to a minimum. Indeed, number of fatal and severe injury crashes are observed to decrease with longer offset distance even though the total number of all crashes seems to increase. Further research is necessary to determine the optimal offset distance in terms of its effect on reducing crashes (Figure 37 and Figure 39).

There are 6 SPF models developed for all crashes and 3 SPF models for fatal and injury crashes. Furthermore, the 6th SPF for “all crashes” and 3rd SPF for “fatal and injury crashes” were also modified after outlier observations (2 observations) were excluded. These different models were developed to provide a flexibility to agencies and safety officials on the selection of proper SPF model for RCUTs. As such, the research team proposes the adoption of 5th or 6th SPF models for “all crashes”, and 3rd SPF for “fatal and injury crashes” due to their simplicity. These models are practical to implement from an agency perspective and especially when there is data scarcity regarding the geometric design features. Moreover, statistically speaking, the quality of these simpler models is close to the more complex models as evidenced by their respective AIC values (Table 42 and Table 47). Nevertheless, all developed SPF models are suitable for accurately predicting crashes of RCUTs.

4.2. UNSIGNALIZED RCUTs

The SPF development process started with the identification of existing types of unsignalized RCUTs. For this purpose, we reviewed different types of RCUT implementations in the entire U.S., and discovered that there are mainly five types of unsignalized RCUTs as follows: 1) 4-legged RCUTs with 2 U-turns, 2) 4-legged RCUTs with 1 U-turn, 3) 3-legged RCUTs with 2 U-turns, 4) 3-legged RCUTs with 1 U-turns, and 5) 3- or 4-legged RCUT without a U-turn. The list of these types along with the number of RCUTs that belong to each type is given in Table 48, and the full list of these RCUTs with the states they are implemented in is provided in Appendix E. To develop the SPF models, RCUTs which have U-turns were utilized whereas RCUTs without U-turns were excluded from the analysis.

Table 48 Number of different types of unsignalized RCUTs

Type	Number of RCUTs
4-legged RCUT with 2 U-turns	*69*
4-legged RCUT with 1 U-turns	*22*
3-legged RCUT with 2 U-turns	*8*
3-legged RCUT with 1 U-turns	*8*
4- or 3-legged RCUT without U-turn	*64*
Total	***171***

Along with the identification of signalized RCUT types, traffic, geometric design, and environmental characteristics as well as crashes that occurred in these RCUTs were obtained as part of this task. For this purpose, the following variables were identified and documented (please see Appendix F for list of these variables):

1. Crashes: Total number of crashes, number of possible injury crashes, number of non-incapacitating injury crashes, number of incapacitating injury crashes, and number of fatality crashes.

2. Traffic: Major roadway AADT, minor roadway AADT.

3. Geometric design: Number of legs, number of U-turns, number of lanes on major roadway first direction, number of lanes on major roadway second direction, number of lanes on minor roadway first direction, number of lanes on minor roadway second direction, lane width of major roadway, shoulder type of major roadway, shoulder width of major roadway, offset distance of major roadway first direction, offset distance of major roadway second direction, presence of acceleration lane on major roadway first direction, presence of acceleration lane on major roadway second direction, acceleration lane length on major roadway first direction, acceleration lane length on major roadway second direction, presence of deceleration lane on major roadway first direction, presence of deceleration lane on major roadway second direction, deceleration lane length on major roadway first direction, deceleration lane length on major roadway second direction, weaving length on major roadway first direction, weaving length on major roadway second direction, median width of major roadway first direction, median width of major roadway second direction, number of

U-turn lanes on first U-turn, number of U-turn lanes on second U-turn, median width of first U-turn, median width of second U-turn, number of right turn lanes on major roadway first direction, number of right turn lanes on major roadway second direction, number of left-turn lanes on major roadway first direction, number of left-turn lanes on major roadway second direction, and presence of concrete channelization.

4. Environment: Presence of lighting, number of driveways, presence of business, presence of residence, and presence of pedestrian crossing.

Following the documentation of these traffic-, geometric design-, and environment-related characteristics, the variables that can be used in safety performance functions were determined. Table 49 presents these candidate variables and their descriptions whereas Table 50 provides the descriptive statistics of these variables. These candidate variables were chosen based on their potential strong relationship with crashes occurring at RCUT locations as well as considering the practical applications of developed SPFs. Moreover, environment-related variables were avoided in the models as much as possible since they are usually qualitative, and they depend on the personal assessment of SPF user (e.g., urbanization, presence of business/residence). Furthermore, base conditions were identified for all RCUTs, and therefore, they were excluded from the SPF analysis. These base conditions include: Shoulder Type (Paved), Lane Width (12 feet), Presence of Deceleration Lane (1 Deceleration Lane), Number of Major Approach Lanes (2 Lanes), and Number of Minor Approach Lanes (1 Lane).

Table 49 Candidate variables for unsignalized RCUT SPFs

Variables	**Description**
Major Road AADT	*The major approach AADTs entering to the intersection*
Minor Road AADT	*The minor approach AADTs entering to the intersection*
Number of Legs	*Number of legs of the RCUT intersection, either 3 or 4.*
Number of U-turns	*Number of U-turns of the RCUT intersection, either 1 or 2 (RCUTs which do not have U-turns were excluded from analysis).*
Maximum Offset Distance	*The maximum distance between the center of intersection and the U-turn locations (e.g., if one approach has 800 ft. offset and the other one has 600 ft., then 800 ft. is chosen as maximum offset distance).*
Total Offset Distance	*The total distance between the center of intersection and the U-turn locations (e.g., if one approach has 800 ft. offset and the other one has 600 ft., then total offset distance is 1400 ft.).*
Total Acceleration Lane Length	*The maximum length of the deceleration lanes before U-turn locations (e.g., if one approach has 400 ft. deceleration lane and the other one has 250 ft., then 400 ft. is chosen as maximum deceleration lane length).*
Total Deceleration Lane Length	*The total length of the deceleration lanes before U-turn locations (e.g., if one approach has 400 ft. deceleration lane and the other one has 250 ft., then total deceleration lane length is 650 ft.).*
Maximum Median Width	*The maximum median width of the major approaches (e.g., if one approach has 40 ft. median and the other one has 25 ft., then 40 ft. is chosen as maximum median width).*
Maximum U-turn Median Width	*The maximum U-turn median width of the U-turns (e.g., if one U-turn has 20 ft. median and the other one has 25 ft., then 25 ft. is chosen as maximum U-turn median width).*
Total Weaving Length	*The total weaving length between right turn lanes of minor road and beginning of deceleration lanes (e.g., if one approach has 400 ft. weaving length and the other one has 250 ft., then total weaving length is 650 ft.).*
Number of Right Turn Lanes from Major Road	*The maximum number of right turn lanes from major approach to minor approach*
Number of Left-Turn Lanes from Major Road	*The maximum number of left-turn lanes from major approach to minor approach*
Number of Driveways	*The number of driveways within the whole footprint (including intersection center, U-turns, and segment between intersection center and U-turns) of the RCUT intersection.*

Table 50 Descriptive statistics of unsignalized RCUT candidate variables

Variables	**Min.**	**Max.**	**Mean**	**St. D.**	**Med.**	**25th%**	**75th%**	**95th%**
Major Road AADT	2,950	47,722	18,509	9,417	18,000	11,000	23,500	37,000
Minor Road AADT	40	11,500	2,692	2,285	2,030	1,200	3,400	8,700
Number of Legs	3	4	3.88	0.32	4	4	4	4
Number of U-turns	1	2	1.74	0.44	2	1	2	2
Maximum Offset Distance	425	8,000	1,750	884	1,650	1,100	2,150	3,225
Total Offset Distance	600	5,575	26,49	1,119	2,550	1,675	3,550	4,775
Total Acceleration Lane Length	0	1,600	186	361	0	0	250	1050
Total Deceleration Lane Length	0	1,525	646	361	550	375	850	1,400
Maximum Median Width	0	150	40.73	20.26	40	30	45	85
Maximum U-turn Median Width	0	200	36.89	27.61	30	25	45	85
Total Weaving Length	150	6,275	1,795	1,099	1,525	975	2,450	4,300
Number of Right Turn Lanes from Major Road	0	1	0.83	0.38	1	1	1	1
Number of Left-Turn Lanes from Major Road	0	1	0.97	0.16	1	1	1	1
Number of Driveways	0	6	1.84	1.60	2	0	3	5
Abbreviations	Min: minimum, Max: maximum, St. D.: standard deviation, Med: Median, 25th%: 25th percentile, 75th%: 75th percentile, 95th%: 95th percentile,							

In addition to traffic-, geometric design-, and environment-related variables, crashes along with their severities were documented. Table 51 presents the descriptive statistics for these crashes while Figure 47 shows histograms of those crashes collected at RCUTs. Moreover, Figure 48 presents the combined histograms of crashes based on severity levels. Figure 49, on the other hand, shows the histogram of the ratio between major approach AADT and minor approach AADT at unsignalized RCUTs. Furthermore, Figure 50 presents the relationship between the ratio of Major AADT with Minor AADT and number of crashes at unsignalized RCUTs. Note that for unsignalized RCUTs, all crashes that occurred on the whole footprint of an RCUT were included (Please refer Appendix I for a full list of crashes and AADTs of RCUTs). That is, all crashes occurred at the intersection center (250 ft. upstream from minor approaches), U-turns (including 250 ft. upstreams approaching to U-turns), and segment between the intersection center and U-turns were collected. Crashes were investigated in three categories: 1) “all crashes” including all severities, 2) “fatal and injury crashes” including all crashes involving some level of injury (i.e., PDO crashes excluded), and 3) “fatal and severe injury crashes” including incapacitating injuries and fatalities.

Table 51 Descriptive statistics of unsignalized RCUT crashes

Crashes	**Total**	**Min.**	**Max.**	**Mean**	**St. D.**	**Med.**	**25th%**	**75th%**	**95th%**
All Crashes	788	0	21	3.75	3.57	3	1	5	11
Fatal and Injury Crashes	261	0	8	1.21	1.48	1	1	2	4
Fatal and Severe Injury Crashes	41	0	4	0.18	0.58	0	0	0	1
Abbreviations	Min: minimum, Max: maximum, St. D.: standard deviation, Med: Median, 25th%: 25th percentile, 75th%: 75th percentile, 95th%: 95th percentile,								

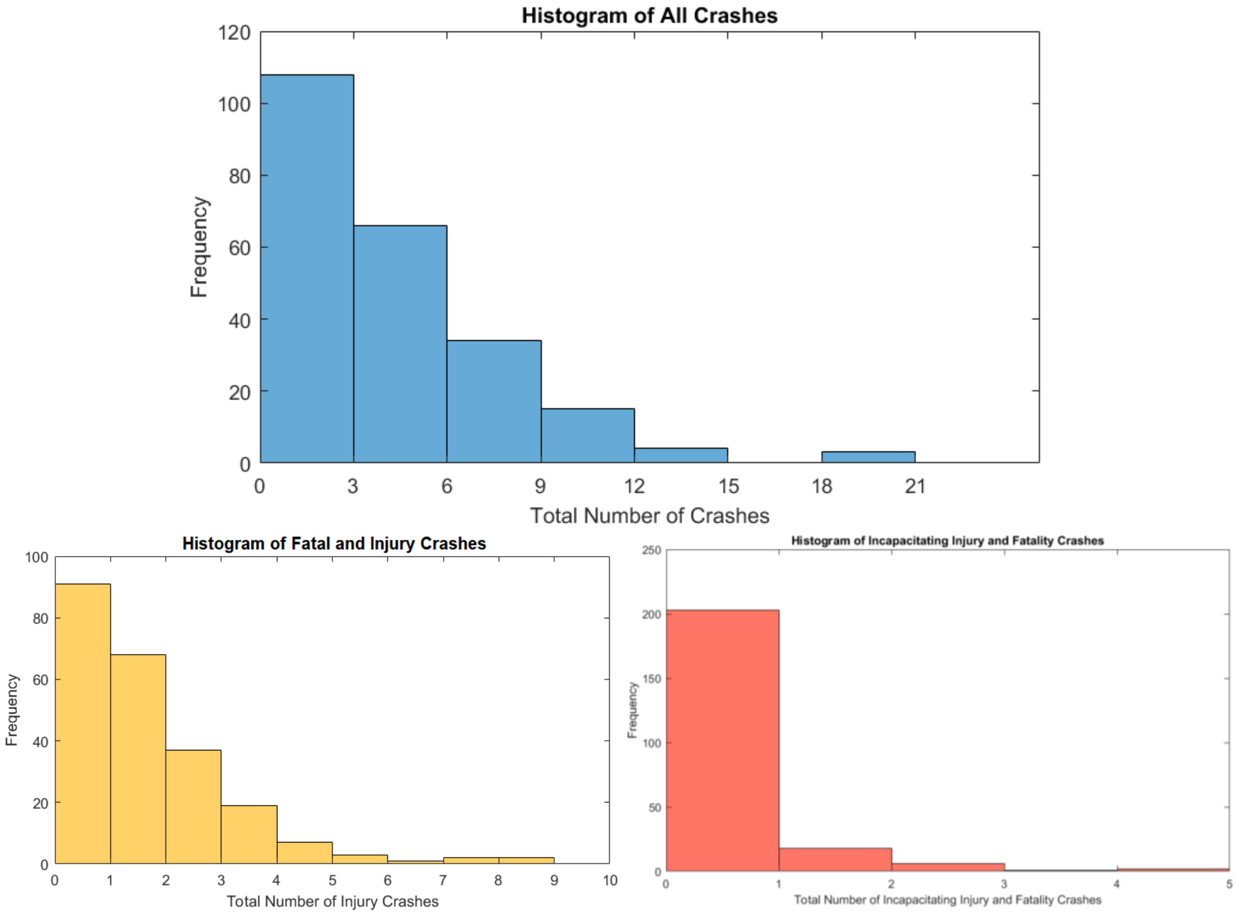


Figure 47. Histograms of unsignalized RCUT crashes

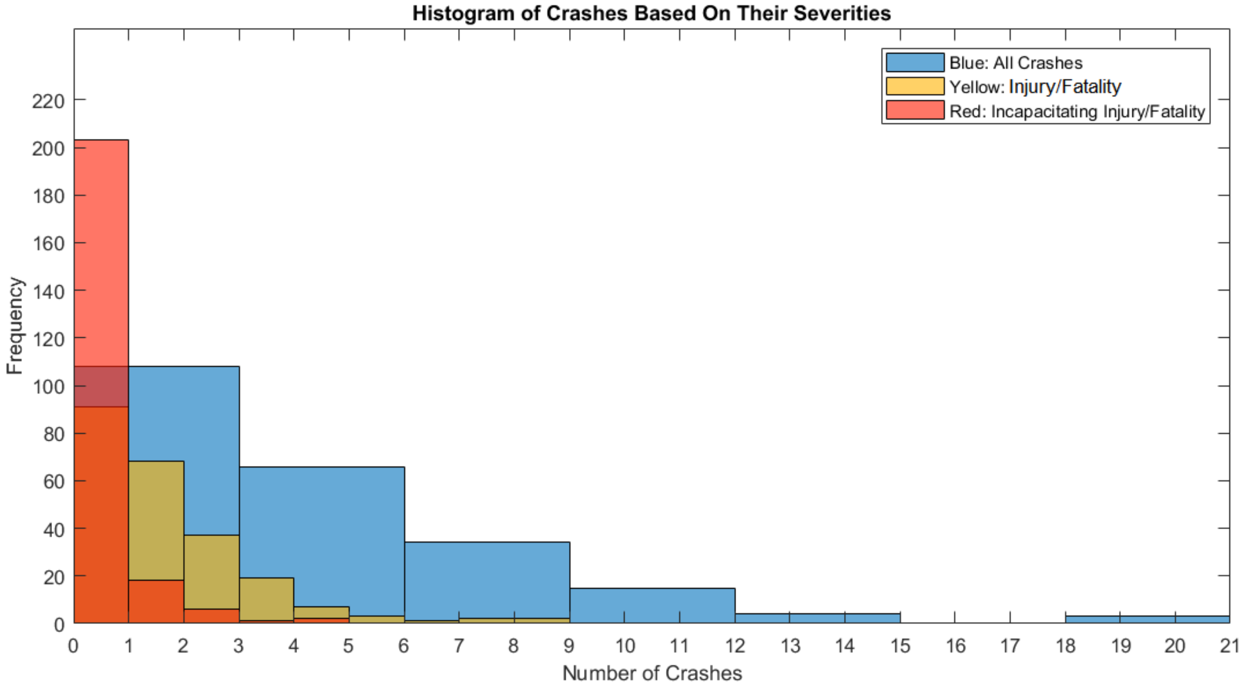


Figure 48. Combined Histograms of unsignalized RCUT crashes with different severities

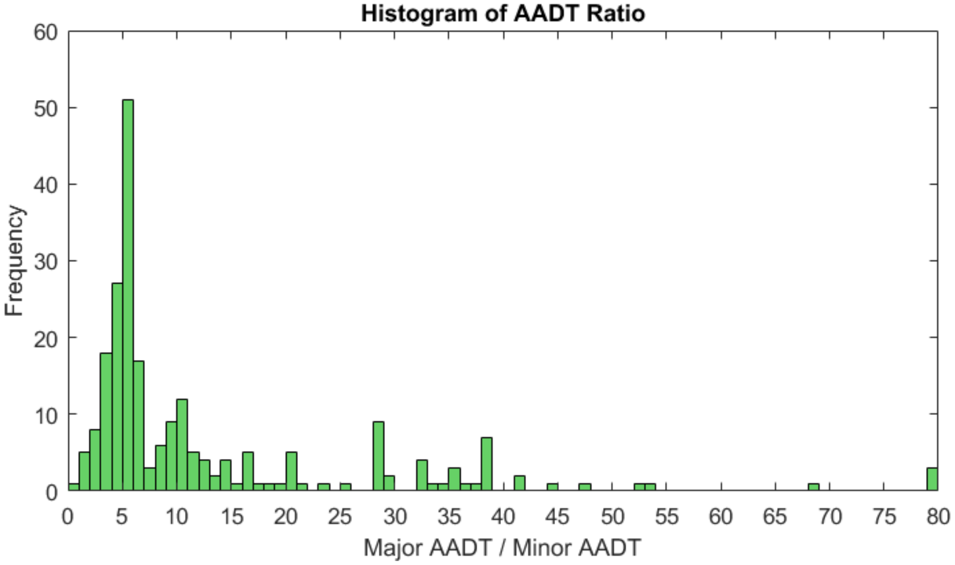


Figure 49. Histogram of ratio of major AADT to minor AADT at unsignalized RCUTs

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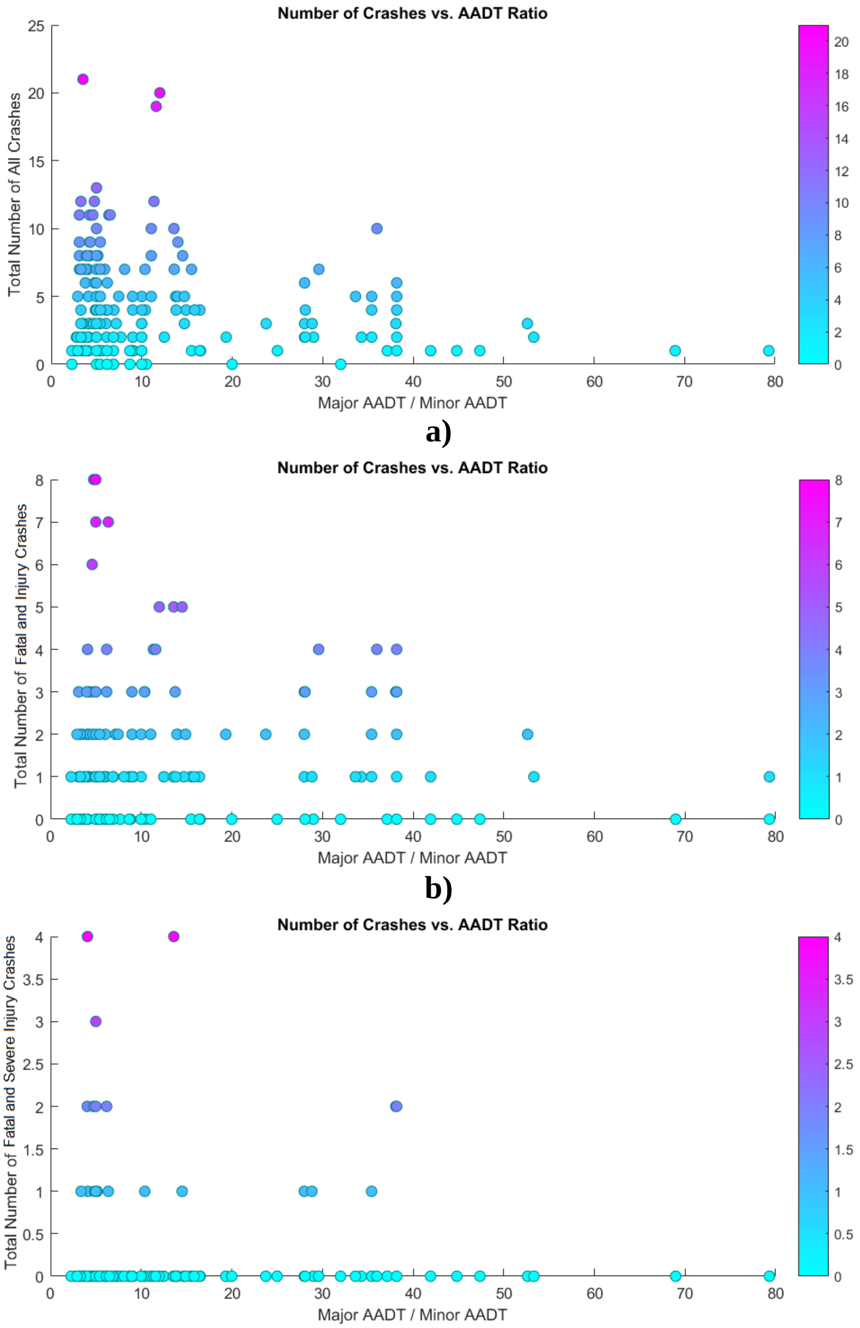


a)

b)

c)

Figure 50. Relationship between ratio of major AADT to minor AADT and number of crashes at unsignalized RCUTs: (a) total number of all crashes, (b) total number of fatal and injury crashes, (c) total number of fatal and severe injury crashes

The relationship between crashes and the candidate variables was also investigated. To understand these relationships, 2-D histograms were plotted as shown in Figure 51 (All Crashes), Figure 52 (Fatal and Injury Crashes), and Figure 53 (Fatal and Severe Injury Crashes). These plots work as traditional histograms but at a two dimensional space. That is, color of the each hexagon in the 2-D histogram reflects how many data points (counts) are within that hexagon boundary. For instance, the dark red hexagon in the first 2-D histogram in Figure 51 (Total Number of Crashes vs. Maximum Major AADT) indicates that there are 11 data points (observations) that have total number of crashes equal to 1 while major approach AADT of these data points is approximately 10,000. Blue/purple hexagons, on the other hand, indicate that there is only one observation within the boundary of those hexagons.

2-D histograms show that there is a substantial trend between major approach AADTs and total number of all crashes as well as total number of fatal and injury crashes. A similar observation can also be made for the minor approach AADTs and number of crashes even though the trend is not as clear as the trend observed for the major approach AADT case. The relationships between other candidate variables and total number of crashes are more obscure than the relationships between AADTs and number of crashes. Nevertheless, it is still possible to claim that 2-D histograms of offset distance, weaving distance, median width, and deceleration lane length have relatively strong correlations with number of crashes.

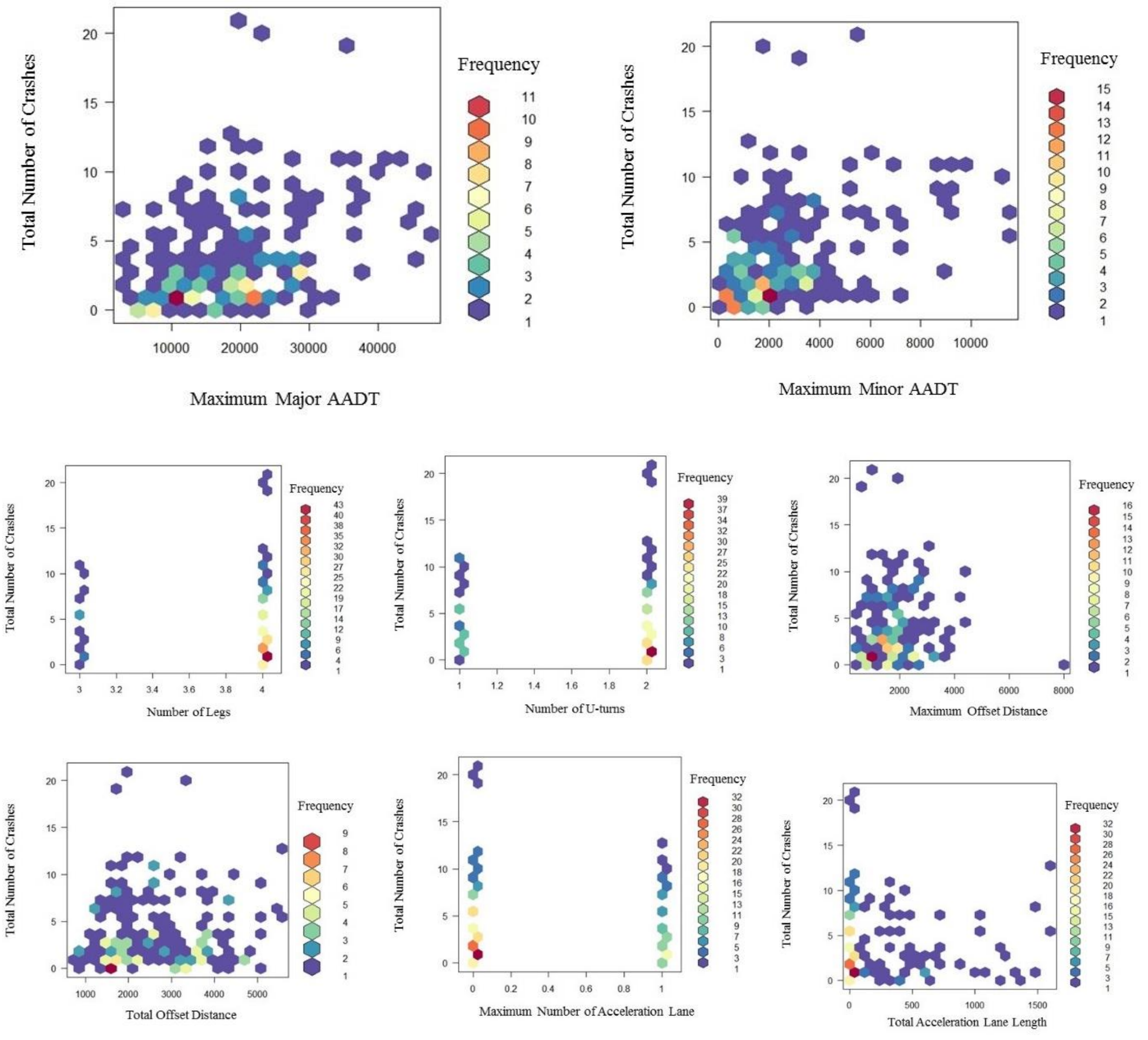


Figure 51. 2-D Histograms for the relationship between unsignalized RCUT "all crashes" and candidate analysis variables

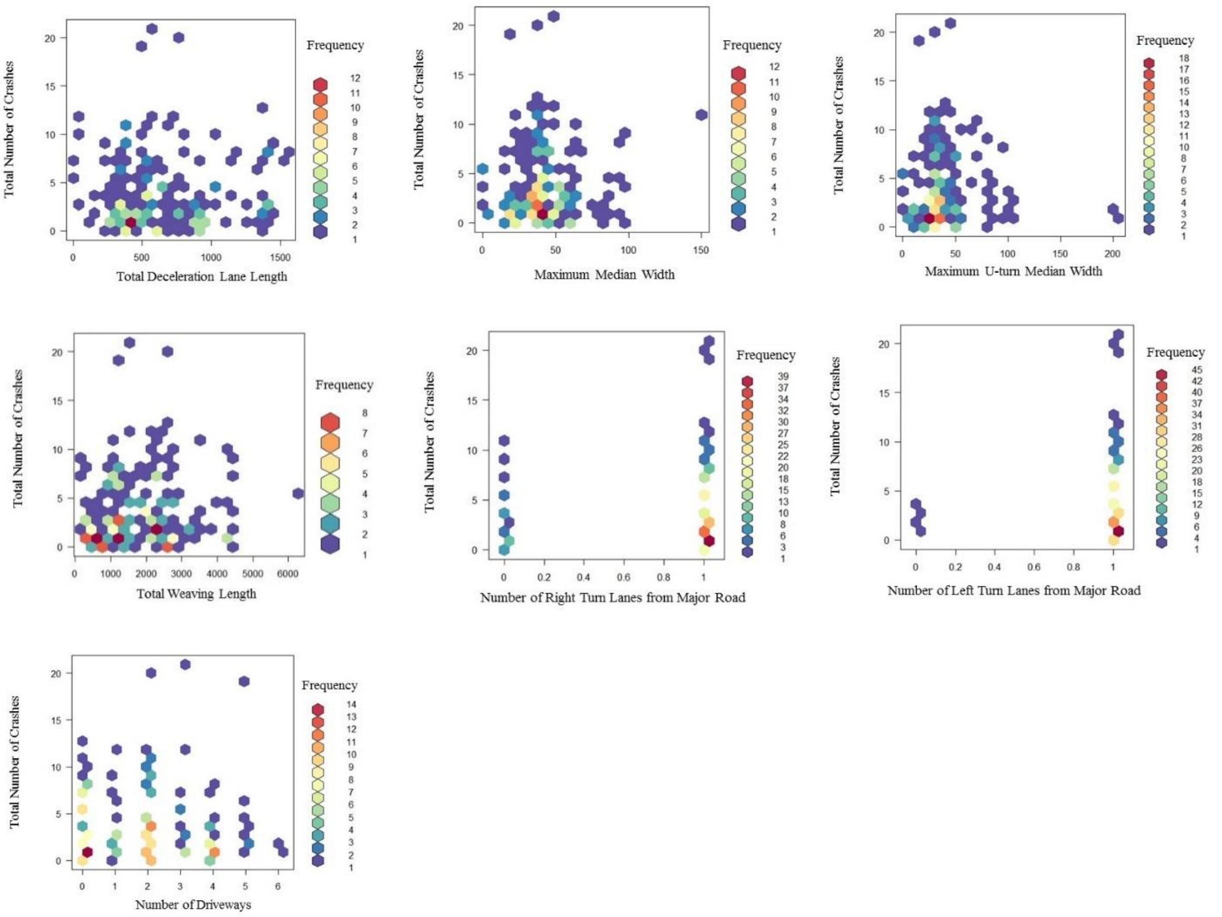


Figure 51. 2-D Histograms for the relationship between unsignalized RCUT "all crashes" and candidate analysis variables

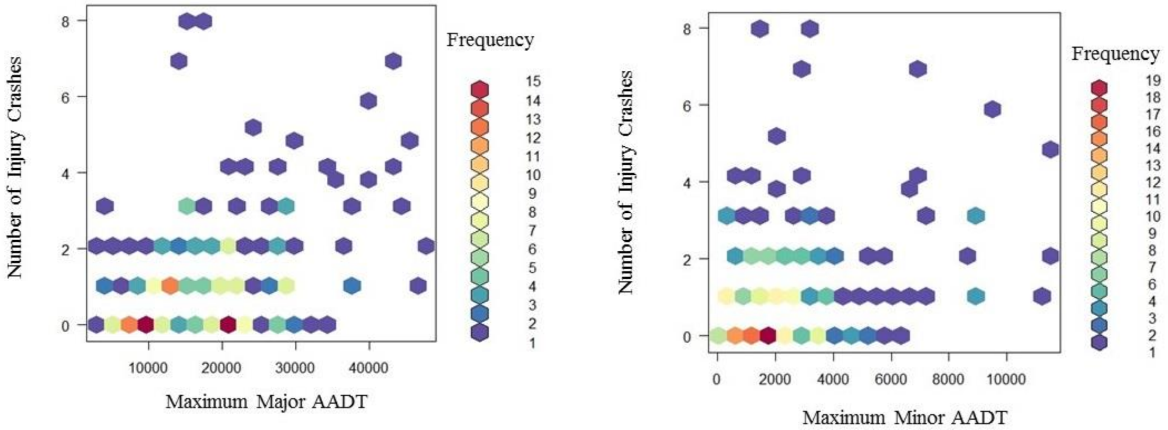


Figure 52. 2-D Histograms for the relationship between unsignalized RCUT "fatal and injury crashes" and candidate analysis variables

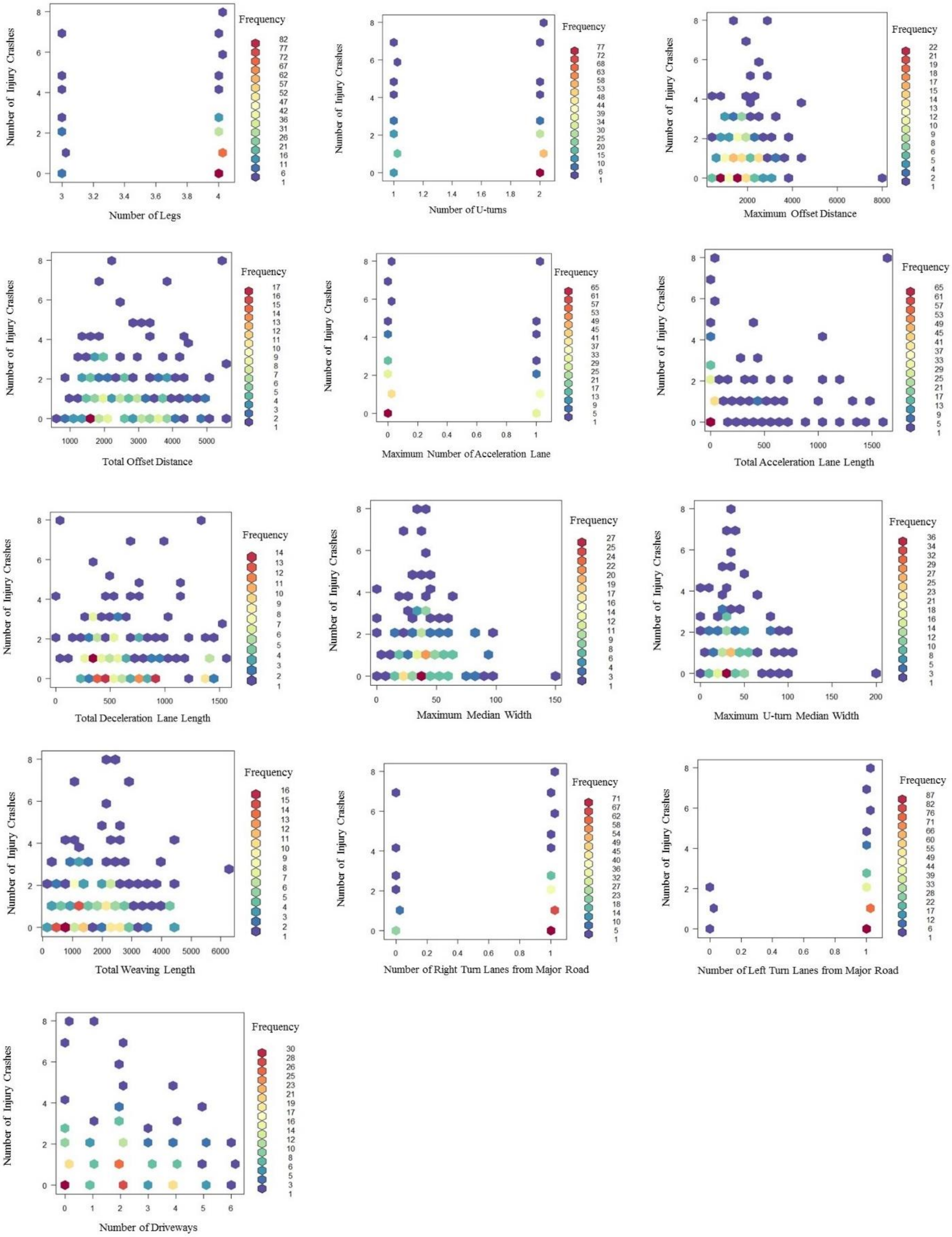


Figure 52. 2-D Histograms for the relationship between unsignalized RCUT "fatal and injury crashes" and candidate analysis variables

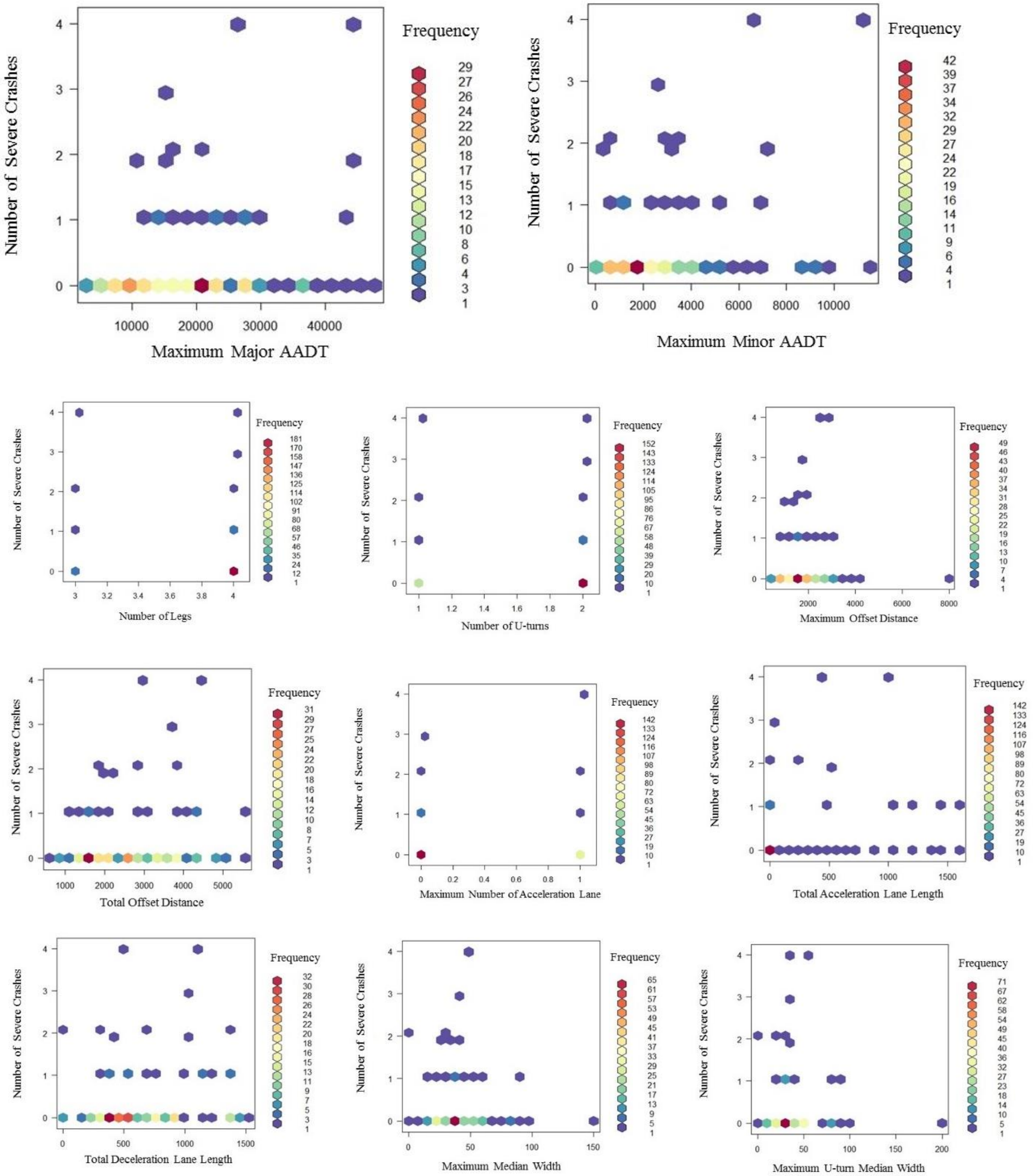


Figure 53. 2-D Histograms for the relationship between unsignalized RCUT fatal and severe injury crashes and candidate analysis variables

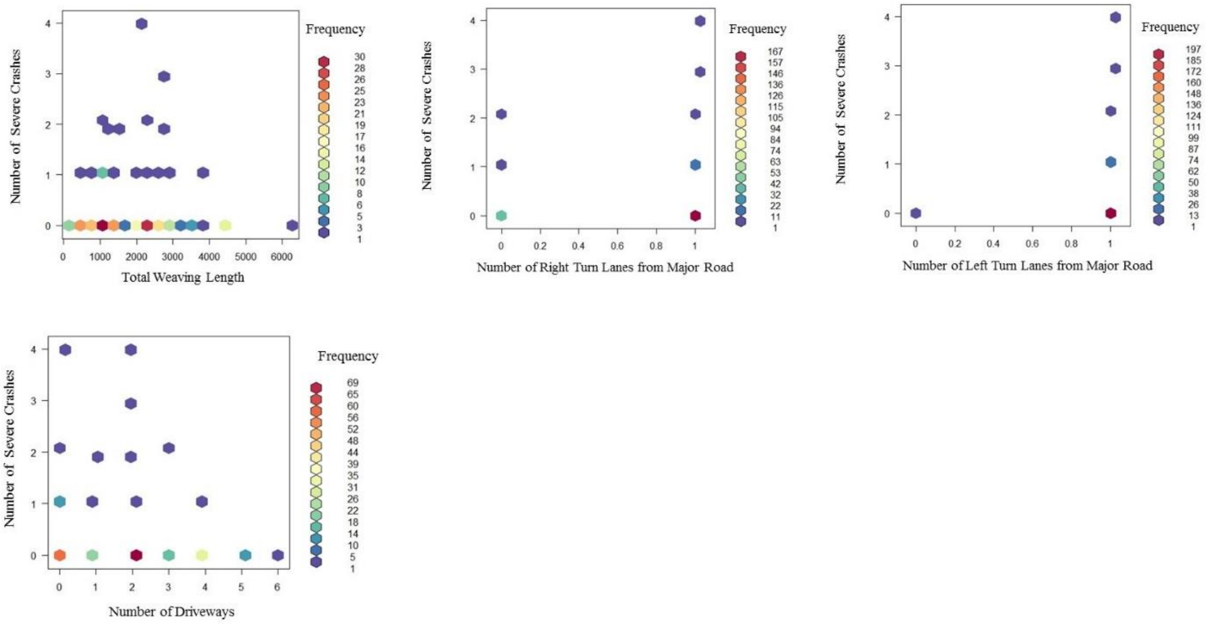


Figure 53. 2-D Histograms for the relationship between unsignalized RCUT fatal and severe injury crashes and candidate analysis variables

The exploratory analysis of the data indicates that the most critical variables for unsignalized RCUTs are the major approach and minor approach AADTs. These variables also constitute the final SPF model of both "all crashes" and "fatal and injury crashes" (Model 5 of "all crash" SPFs and Model 4 of "fatal and injury crash" SPFs – Please see the next section). Therefore, Figure 54 and Figure 55 were plotted to illustrate the relationship between these variables and the number of crashes. These figures show that there is a strong increasing trend in number of crashes with the increase in major AADT and/or minor AADT values.

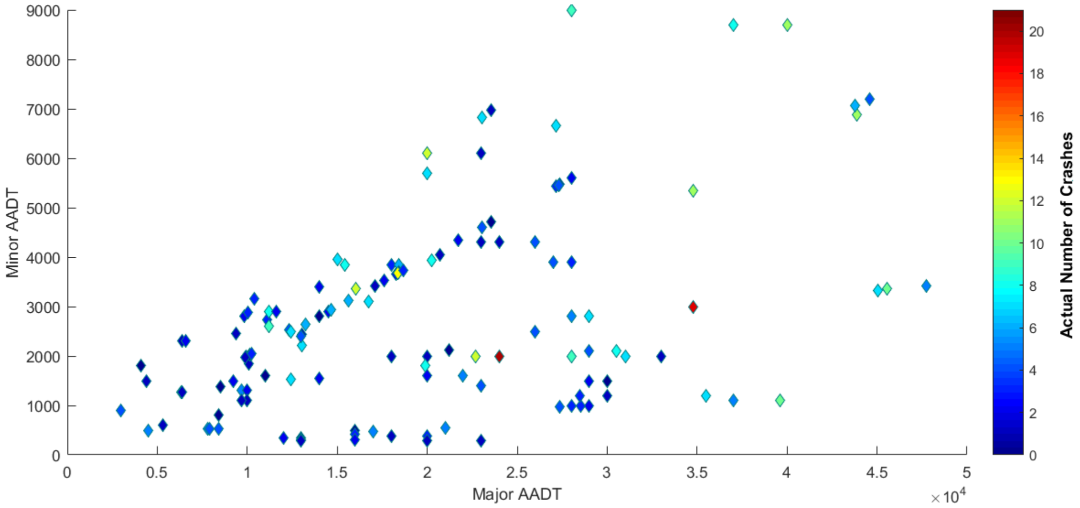


Figure 54. Relationship between minor and major approach AADT with color-scaled unsignalized RCUT crash numbers

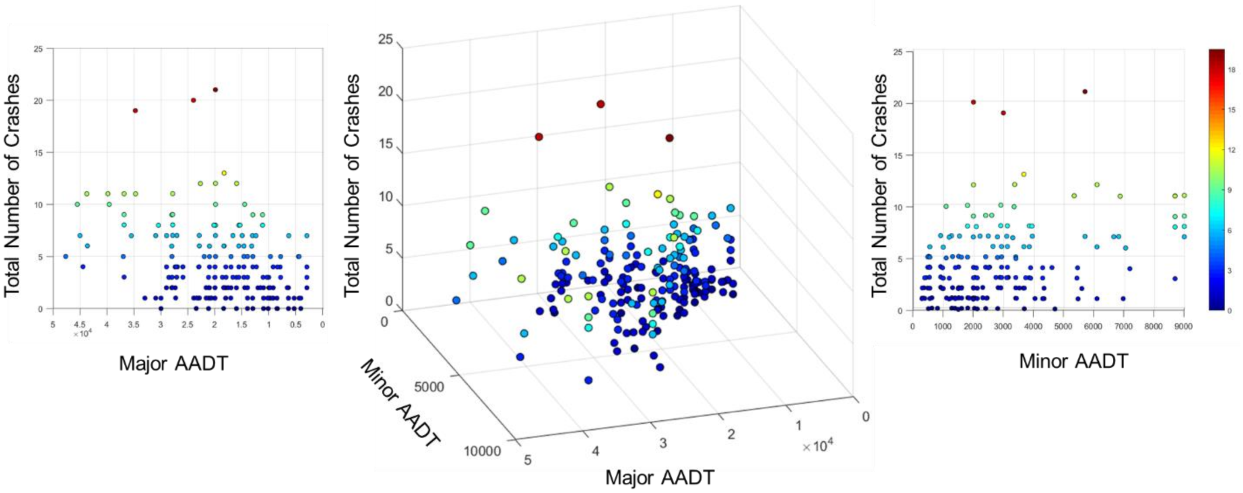


Figure 55. Relationship between total number of crashes and AADTs of major and minor approaches with color scaled unsignalized RCUT crash numbers: (a) total number of crashes vs. major AADT, (b) total number of crashes vs. minor AADT, and (c) 3-D plot showing relationship of these three variables

4.2.1. Unsignalized RCUT SPF Models

After the analysis on crash data and candidate variables, the Safety Performance Functions (SPFs) were developed for unsignalized RCUT intersections. All candidate variables were considered for SPFs; however, final sets of variables were determined based on the following criteria: a) variable has a statistically significant effect on number of crashes; b) data related to variable is convenient and easy to collect and obtain, and c) it is practical to implement from a transportation agency perspective. Several models were developed for “all crashes” (five models) and “fatal and injury crashes” (four models) to provide flexibility in choosing the most appropriate model for local agencies and departments of transportation. Note that it was not possible to develop SPF models for fatal and severe injury crashes due to the scarcity of severe crashes (incapacitating injury and fatality), which in turn led to very few observations. This lack of severe crashes clearly shows the power of RCUTs in reducing or eliminating severe injuries and advocates in the favor of RCUT implementations.

In this report, the U-turns are crossovers just for the RCUT; however, not the main intersection of an adjacent RCUT. “Standalone RCUTs” were used to develop SPFs. That is, the system of RCUTs was not used where main intersection of one RCUT is the U-turn of the other. The number of left-turn lanes from major approach lanes counts only the turning lanes but not the through lanes. The offset distance was measured starting from the right edge of the rightmost lane of the minor approach and ending at the beginning of the U-turn curve. Total offset distance was found by using offsets at both legs of the RCUT. The deceleration lane “starts” where taper ends (deceleration lane reaches full width) and “ends” where the U-turn curve starts. Even when there are dual U-turn lanes, it does not influence the length of the deceleration lane since the curved part of the U-turn location is not measured. Total deceleration lane length was found by using the total length of deceleration lanes at both legs of the RCUT. The median width was measured from edge of pavement to edge of pavement. Note that the maximum gap was measured to identify the median width on each side of the RCUT.

4.2.1.1. Unsignalized RCUT SPF Models for All Crashes

The following section presents the developed models for all crashes occurred at unsignalized RCUT locations. A total of five models with different variable sets were developed to provide alternative models with different complexities, which span from complex models to relatively simple and easily implementable models. This can aid in creating a flexibility for safety agencies/officials that can prefer more complex models in the case of available data while it is also possible to implement more practical/simpler models if less number of variables are available. Analysis results are presented in five tables that summarize the model findings whereas Appendix H presents a more detailed analysis of the results. Table 52 presents the variable sets of six developed models. Note that Model 1 represents the full model, and the following models are composed of subsets of the Model 1 variables. In each model, moving from Model 1 to Model 5, the least significant variable was excluded from the predecessor model, and hence successor model was formed. Furthermore, for the sake of simplicity, abbreviations for variable names were created and presented in Table 53 and model functions are written using these abbreviations as shown in Table 54. Moreover, the variable coefficients of these models are given in Table 55. The model parameters such as over-dispersion parameter as well as model quality measures such as log-likelihood and AIC (Akaike's Information Criterion) are provided in Table 56. Furthermore, Figure 56 shows crash prediction plane of the Model 5. This figure was created to illustrate the variation of number of predicted crashes with respect major and minor AADT.

Table 52 Unsignalized RCUT SPF models for all crashes

Model	**Variables**
Model 1	*Major AADT, Minor AADT, Total Offset Distance, Total Deceleration Lane Length, Maximum Median Width, Number of Left-Turn Lanes from Major Road*
Model 2	*Major AADT, Minor AADT, Total Offset Distance, Total Deceleration Lane Length, Number of Left-Turn Lanes from Major Road*
Model 3	*Major AADT, Minor AADT, Total Offset Distance, Total Deceleration Lane Length*
Model 4	*Major AADT, Minor AADT, Total Offset Distance*
Model 5	*Major AADT, Minor AADT*

Table 53 Unsignalized RCUT SPF model variable abbreviations for all crashes

Variables	**Abbreviation**
Major AADT	$AADT_{major}$
Minor AADT	$AADT_{minor}$
Total Offset Distance	TOD
Total Deceleration Lane Length	$TDLL$
Maximum Median Width	$MMeW$
Number of Left-Turn Lanes from Major Road	$LTLM$

Table 54 Unsignalized RCUT SPF model functions for all crashes

Model	**Functions**
Model 1	$N_p = \exp\left(Intercept + AADT_{major} + \ln(AADT_{minor}) + \ln(TOD) + \ln(TDLL) + \ln(TMeW) + LTLM\right)$
Model 2	$N_p = \exp\left(Intercept + AADT_{major} + \ln(AADT_{minor}) + \ln(TOD) + \ln(TDLL) + LTLM\right)$
Model 3	$N_p = \exp\left(Intercept + AADT_{major} + \ln(AADT_{minor}) + \ln(TOD) + \ln(TDLL)\right)$
Model 4	$N_p = \exp\left(Intercept + AADT_{major} + \ln(AADT_{minor}) + \ln(TOD)\right)$
Model 5	$N_p = \exp\left(Intercept + AADT_{major} + \ln(AADT_{minor})\right)$

N_p: Number of Predicted Crashes

Table 55 Unsignalized RCUT SPF model coefficients for all crashes

Model	*Intercept*	$\boldsymbol{AADT_{major}}$	$\mathbf{ln}(\boldsymbol{AADT_{minor}})$	$\mathbf{ln}(\boldsymbol{TOD})$	$\mathbf{ln}(\boldsymbol{TDLL})$	$\mathbf{ln}(\boldsymbol{TMeW})$	$\boldsymbol{LTLM}$
Model 1	-4.884	1.63e-5	0.433	0.368	-0.091	-0.126	0.623
Model 2	-4.283	1.77e-5	0.394	0.259	-0.085	-	0.667
Model 3	-3.662	1.78e-5	0.391	0.263	-0.081	-	-
Model 4	-4.037	2.13e-5	0.365	0.264	-	-	-
Model 5	-1.852	2.09e-5	0.350				

Table 56 Unsignalized RCUT SPF model parameters and model quality measures for all crashes

Model	*# of Variables*	# of Observations	$\boldsymbol{\theta}$	*Log-likelihood*	*AIC*
Model 1	6	224	3.54	-982.7	998.7
Model 2	5	224	3.49	-985.0	999.0
Model 3	4	224	3.37	-988.4	1000.4
Model 4	3	224	3.19	-992.5	1002.5
Model 5	2	224	3.03	-997.0	1005.0

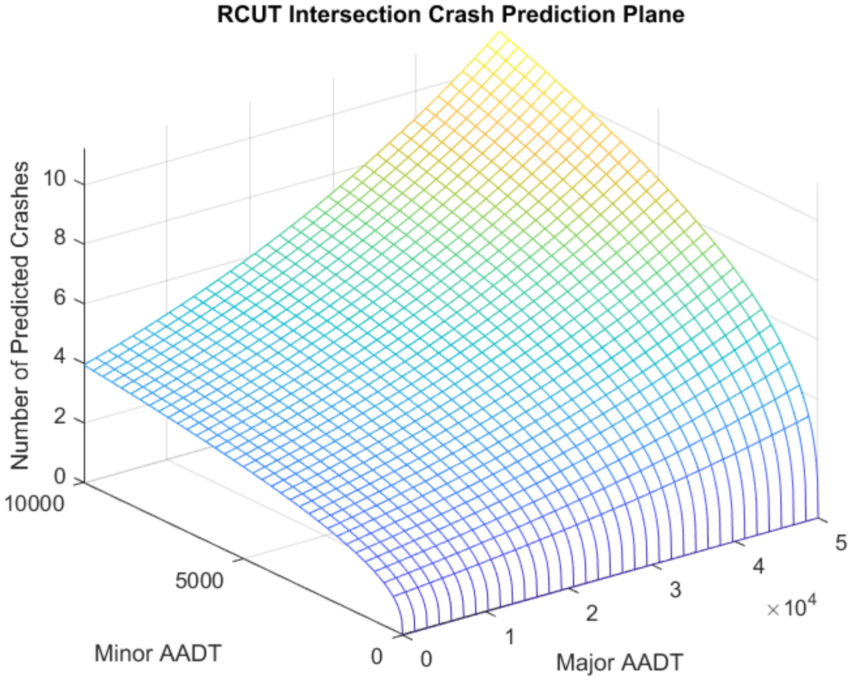


Figure 56. Unsignalized RCUT crash prediction plane of Model-5 SPF for all crashes

4.2.1.2. Unsignalized RCUT SPF Models for Fatal and Injury Crashes

The following section presents developed models for fatal and injury crashes occurred at unsignalized RCUTs. A total of 4 models with different variable sets were developed to provide alternative models with different complexities which span from complex models to relatively simple and practical models. This aid in creating flexibility for safety agencies/officials that can prefer more complex models in the case of available data while implement more practical/simpler models if less number of variables are available. The analysis results are presented in 5 tables that summarizes the model findings whereas Appendix H present detailed analysis results for these models. Table 57 presents the variable sets of three developed models. Note that Model 1 represents the full model and following models are composed of subsets of Model 1 variables. In each, model from Model 1 to Model 4, the least significant variable is excluded from the predecessor model and hence successor model was formed. Furthermore, for the sake of simplicity, abbreviations will be used for variable names as presented in Table 58, and model functions are written using these abbreviations as shown in Table 59. Moreover, the variable coefficients of these models are given in Table 60. The model parameters such as over-dispersion parameter as well as model quality measures such as log-likelihood and AIC (Akaike’s Information Criterion) are provided in Table 61 Furthermore, Figure 57 shows the crash prediction plane of the Model 3. This figure was created to illustrate the variation of number of predicted crashes with respect major and minor AADTs.

Table 57 Unsignalized RCUT SPF models for fatal and injury crashes

Model	**Variables**
Model 1	*Major AADT, Minor AADT, Total Offset Distance, Total Deceleration Lane Length, Maximum Median Width*
Model 2	*Major AADT, Minor AADT, Total Offset Distance, Total Deceleration Lane Length*
Model 3	*Major AADT, Minor AADT, Total Deceleration Lane Length*
Model 4	*Major AADT, Minor AADT*

Table 58 Unsignalized RCUT SPF model variable abbreviations for fatal and injury crashes

Variables	**Abbreviation**
Major AADT	$AADT_{major}$
Minor AADT	$AADT_{minor}$
Total Offset Distance	TOD
Total Deceleration Lane Length	$TDLL$
Maximum Median Width	$MMeW$

Table 59 Unsignalized RCUT SPF model functions for fatal and injury crashes

Model	**Functions**
Model 1	$N_p = \exp\left(Intercept + \ln(AADT_{major}) + \ln(AADT_{minor}) + \ln(TOD) + \ln(TDLL) + \ln(TMeW)\right)$
Model 2	$N_p = \exp\left(Intercept + \ln(AADT_{major}) + \ln(AADT_{minor}) + \ln(TOD) + \ln(TDLL)\right)$
Model 3	$N_p = \exp\left(Intercept + \ln(AADT_{major}) + \ln(AADT_{minor}) + \ln(TDLL)\right)$
Model 4	$N_p = \exp\left(Intercept + \ln(AADT_{major}) + \ln(AADT_{minor})\right)$

N_p: *Number of Predicted Crashes*

Table 60 Unsignalized RCUT SPF model coefficients for fatal and injury crashes

Model	*Intercept*	$\mathbf{ln}(\boldsymbol{AADT_{major}})$	$\mathbf{ln}(\boldsymbol{AADT_{minor}})$	$\mathbf{ln}(\boldsymbol{TOD})$	$\mathbf{ln}(\boldsymbol{TDLL})$	$\mathbf{ln}(\boldsymbol{TMeW})$
Model 1	-9.234	0.501	0.265	0.506	-0.133	-0.197
Model 2	-8.648	0.543	0.205	0.343	-0.125	-
Model 3	-5.570	0.515	0.191	-	-0.129	-
Model 4	-6.886	0.599	0.153	-	-	-

Table 61 Unsignalized RCUT SPF model parameters and model quality measures for fatal and injury crashes

Model	*# of Variables*	# of Observations	θ	*Log-likelihood*	*AIC*
Model 1	5	224	3.53	-624.8	638.8
Model 2	4	224	3.28	-627.9	639.9
Model 3	3	224	3.05	-632.0	642.0
Model 4	2	224	2.66	-638.1	646.1

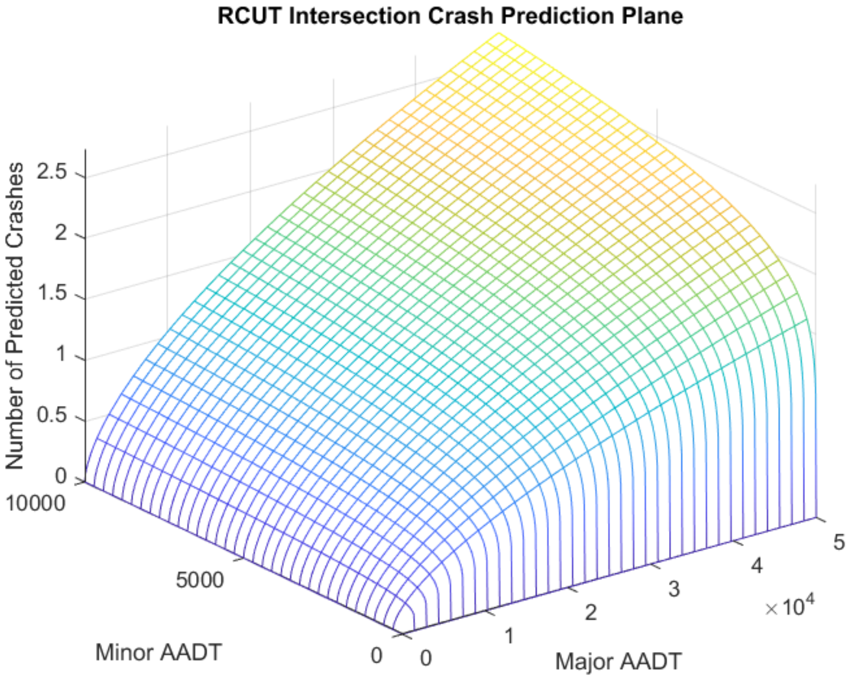


Figure 57. Unsignalized RCUT crash prediction plane of Model-4 SPF for fatal and injury crashes

4.2.2. Criteria for Implementation of Unsignalized RCUT SPFs

The RCUTs are known to be successful when minor approach AADT is not very high compared to the major approach AADT. Accordingly, RCUT implementations used in this study were found to comply with this general rule of thumb. Figure 58 shows the major approach to minor approach AADT ratio with respect to the major approach AADT for the studied unsignalized RCUTs in the U.S. The AADT ratio limit shown on this figure was shown as the limit to implement unsignalized RCUT SPFs developed in this report. This limit may also be assessed as the feasible limit to implement unsignalized RCUTs at a potential location. Figure 59, on the other hand, illustrates this limit for SPF-predicted crash numbers (using model 5 for all crashes and model 4 for fatal and injury crashes) based on alternative minor to major approach AADT ratios (alpha). Note that the major approach AADT should not be higher than 60,000 whereas minor approach AADT can be identified using the following empiric equation for a given major approach AADT:

$$Ratio\ Function = 0.493 * \exp\left(-3.25 * 10^{-5} * AADT_{major}\right)$$
$$AADT_{minor}(limit) = AADT_{major} * Ratio\ Function$$

Major AADT	Ratio Factor	Minor AADT Limit
5,000	0.419	2,100
10,000	0.356	3,560
15,000	0.303	4,550
20,000	0.257	5,150
25,000	0.219	5,450
30,000	0.186	5,575
35,000	0.158	5,525
40,000	0.134	5,370
45,000	0.114	5,135
50,000	0.097	4,850

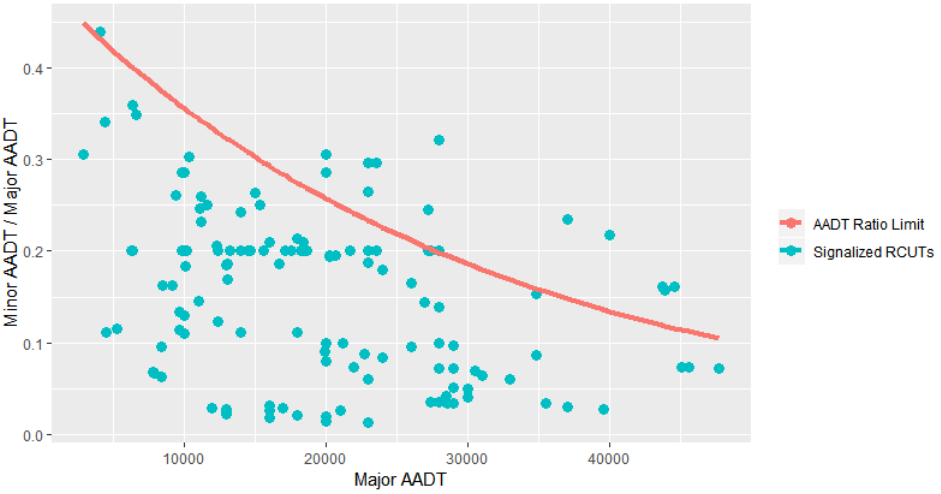
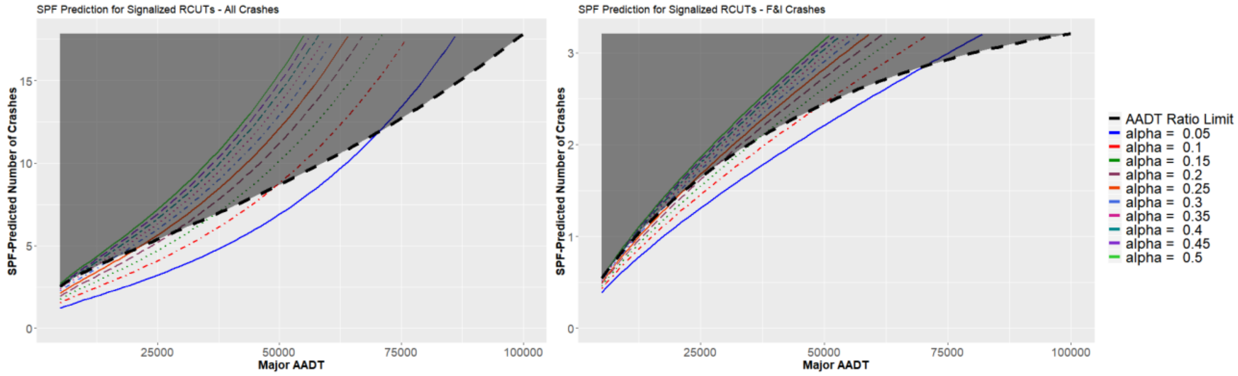


Figure 58. Major and minor approach ratios of unsignalized RCUTs in the U.S. and the proposed AADT ratio limit



a) b)

Figure 59. Limit for SPF-predicted crash numbers based on the minor/major approach AADT ratio (alpha): a) All crashes; b) F&I crashes. Shaded zone is out of the proposed limit

4.2.3. Discussion and Recommendations for Unsignalized RCUTs

The comprehensive analysis of unsignalized RCUT crashes and developed SPFs provided important insights and recommendations for transportation agencies related to the implementation of this alternative intersection type. To begin with, almost all unsignalized RCUTs were observed to be implemented at rural areas whereas signalized RCUTs were implemented in suburban and urban areas. Therefore, the location selection for a future unsignalized RCUT implementation should be conducted after considering if there is a possibility of potential future land development that can change rural nature of the region. Similar to signalized RCUTs, Figure 55 shows that the higher the major and minor AADT, the higher the total number of crashes. More importantly, when the ratio of major AADT to minor AADT is small due to high minor approach traffic, there is a considerable increase in the number of crashes compared to RCUTs which have larger major AADT to minor AADT ratio (Figure 50). Therefore, transportation agencies should avoid implementing RCUTs at locations where high minor traffic volume is being experienced.

2-D histograms of Figure 51, Figure 52, and Figure 53 show that shorter deceleration lanes and acceleration lanes might be associated with higher number of crashes. Indeed, deceleration lane length variable was found to be statistically significant in predicting the total number of “all crashes” and “fatal and injury crashes”. In addition to the deceleration lane length, another geometric variable, namely offset distance, was also used in modeling for total crash numbers, and was adopted as one of the SPF variables. However, it was found that offset distance has been slightly increasing the effect on the total number of crashes. This is due to the fact that all crashes occurred along the footprint of an RCUT intersection is included into the analysis, and the longer the offset, the more the number of crashes are observed between the intersection center and U-turns. However, this does not necessarily mean that offset distance should be kept as minimum as possible. Indeed, number of fatal and severe injury crashes are observed to decrease with longer offset distance even though the total number of all crashes seems to increase. Further research is necessary to determine the optimal offset distance in terms of their effect on reducing crashes (Figure 51, Figure 52, and Figure 53).

There are 5 SPF models developed for “all crashes”, and 4 SPF models for “fatal and injury crashes”. These different models were developed to provide a flexibility to agencies and safety officials on the selection of proper SPF model for RCUTs. As such, the research team proposes the adoption of 4th or 5th SPF models for “all crashes”, and 4th SPF for “fatal and injury crashes” due to their simplicity. These models are practical to implement from an agency perspective and especially when there is data scarcity regarding the geometric design features. Moreover, statistically speaking, the quality of these simpler models is close to the more complex models as evidenced by their respective AIC values (Table 56 and Table 61). Nevertheless, all developed SPF models are suitable for accurate in predicting crashes of RCUTs.

4.3. SUMMARY

This chapter intends to provide a comprehensive investigation of Restricted Crossing U-Turn (RCUT) crashes and to develop Safety Performance Functions (SPF) for both signalized and unsignalized RCUTs. For this purpose, data on the total number of crashes with different severity levels as well as traffic-, geometric design-, and environment-related data were collected and utilized in the creation of these SPFs (See Appendix J for the state contacts). Moreover, the relationship of number of crashes with these variables were explored through an extensive exploratory analysis including histograms, and 2-D and 3-D plots. A comprehensive analysis has been performed in order to develop the Safety Performance Functions (SPFs) for the Restricted Crossing U-Turn (RCUT) intersections, which can be successfully used by transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies) in identifying prospective locations for RCUT implementations, and analyzing them.

Consequently, for signalized RCUTs, 6 SPF models for "all crashes" and 3 SPF models for "fatal and injury crashes" were developed. For unsignalized RCUTs, on the other hand, 5 SPF models for "all crashes" and 4 SPF models for "fatal and injury crashes" were developed. The purpose of developing several models was to provide flexibility in choosing the most appropriate model satisfying the needs of local agencies and departments of transportation. Findings present guidelines for transportation agencies in decision making for RCUT implementations, and specifically illustrate that the selection of an RCUT location depends significantly on the major and minor AADTs, and their ratio. The developed SPF models can be successfully used by transportation agencies to evaluate and justify the installation of innovative intersection designs that will drastically improve intersection safety and operations. Findings will also be used with the new Intersection Control Evaluation (ICE) Policy and Procedure, and RCUT safety performance functions (SPFs) will be incorporated into the SPICE Tool.

5. TASK 4: DEVELOPMENT OF CRASH MODIFICATION FACTORS AND FUNCTIONS

In Task 4, working collaboratively with the Project Manager, all the RCUT intersections in the U.S. are utilized to develop the Crash Modification Factors and Functions (CMFs) by the PIs and their graduate students. In 2014, FHWA released a report (Hummer et al., 2014) which shows a total of 51 RCUTs that could be utilized in determining SPFs. On the other hand, Task 2 of this project revealed that a total of 240 RCUTs exist or have been implemented since the FHWA study was completed. All known to exist RCUTs are targeted for data collection in this task, and states are asked to provide data on other RCUT locations, which were not known before. For each RCUT intersection, geometric, traffic and crash data are collected. When possible, the crash data covers 3 to 5 years before and 3 to 5 years after the construction of the RCUTs. All pertinent data is requested from federal, state, and municipal agencies. In addition, databases such as Ohio's Transportation Information Mapping System – Crash Analysis Tool (TIMS – GCAT), Tennessee's Enhanced Tennessee Roadway Information Management System (E-TRIMS), Georgia's Electronic Accident Reporting System (GEARS), Maryland's Open Data Portal, Texas' Crash Records Information System (CRIS) GIS files, roadway inventory files, and online resources such as Google maps and aerial photographs are also used in acquiring and verifying information. From the collected geometric and traffic data, all independent variables likely to influence traffic crashes are extracted – including intersection area type (urban, suburban, rural), roadway functional classification (arterial, collector, distributor), segment lengths, median offset lengths, number of lanes and legs, shoulder widths, presence of a median, geographical location, AADT and posted speed limit. From several states, construction cost data as well as signalization and timing data and/or plans were also collected. These variables are used to create the CMFs for both signalized and unsignalized intersections. These CMFs can be successfully used by transportation agencies to evaluate and justify the installation of innovative intersection designs that will drastically improve intersection safety and operations. Results of this task will also be used with the new Intersection Control Evaluation (ICE) Policy and Procedure. RCUT Crash Modification Factors and Functions will be incorporated into the SPICE Tool in addition to already developed SPFs in Task 3.

5.1. DEVELOPMENT OF CRASH MODIFICATION FACTORS AND FUNCTIONS

In this task, a comprehensive analysis has been performed in order to develop CMFs for the Restricted Crossing U-Turn (RCUT) intersections, which may be under the jurisdiction of a variety of transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies). In order to conduct this analysis, the impact of traffic-, geometric design- and environment-related variables on the crashes occurred at RCUTs has been investigated. Consequently, a final comprehensive list of proposed CMFs are presented for signalized and unsignalized RCUTs. Note that the CMFs were developed by modeling all variables jointly (all variables were included in the model), and they are intended to adjust the crash numbers predicted by the following SPF models: a) SPF Model 6 for signalized RCUT all crashes; b) SPF Model 3 for signalized RCUT fatal and injury crashes; c) SPF Model 5 for unsignalized RCUT all crashes; b) SPF Model 4 for unsignalized RCUT fatal and injury crashes.

Crash models are crucial in terms of traffic safety in order to understand the factors affecting the crash rates, frequencies and severities. The following geometry-, operation-, and traffic-related information are useful for the crash analysis (Savolainen et al., 2015): (a) number of intersection legs, (b) type of traffic control, (c) AADT for the major and minor roadways, (d) number of approaches with left-turn lanes, (e) number of approaches with right-turn lanes, (f) presence of lighting, (g) presence of one-way or two-way traffic, (h) intersection sight distance, (i) intersection skew angle, (j) presence/type of left-turn phasing, (k) pedestrian volumes, (l) presence of bus stops, (m) presence of on-street parking, and (n) presence of median. Note that SPFs are intended to be simple and easily implementable mathematical equations. Therefore, complex models or high number of variables are not favored due to practical and computational reasons. This is because SPFs are crash frequency models commonly used by practitioners who may or may not have statistical expertise. As such, complex and hard to apply models are unfavorable. The number of variables, on the other hand, are also kept limited in order to ease the data collection process. For practical purposes, agencies usually prefer simpler and user-friendly SPFs. Major and minor approach traffic volumes should also be introduced separately into the models in order to enhance the accuracy, and that minor approach volume is sometimes more important than major approach volume (Maze et al., 2010). However, the effect of other variables are still important to consider since they may change the number of expected crashes dramatically. For this purpose, the crash modification factors and functions (CMFs) are introduced to calibrate and adjust the expected crash numbers that are determined using SPFs. The CMFs are defined as follows (Gross, Persaud, and Lyon, 2010): “A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site. The CMF is multiplied by the expected crash frequency without treatment. A CMF greater than 1.0 indicates an expected increase in crashes, while a value less than 1.0 indicates an expected reduction in crashes after implementation of a given countermeasure.” Recently, a new term, adjustment factor (AF) is coined to refer to these crash modification factors, and HSM is planning to adopt this new term since “adjustment factor” describes the objective of these factors and functions better than “crash modification”. Nonetheless, currently CMFs are still the terms officially adopted by federal and state agencies in addition to the HSM, and hence these terms were used throughout this report.

CMFs were developed for the specific conditions varying between different RCUT intersections for which substantial amount of data can be obtained. State-of-art CMF production methods were used as in order to develop these CMFs as recommended by the HSM. CMFs were developed for: (a) number of lanes on major approach, (b) median width, (c) offset distance, (d), number of driveways, (e) number of left-turn lanes from major approach, (f) deceleration lane length, (g) acceleration lane length, (h) major road speed limit, and (i) number of U-turns. Development of these CMFs will be helpful when FDOT officer needs to modify (using CMFs) the results obtained from safety performance functions (SPFs) developed for the RCUTs. Highway Safety Manual describes CMFs as follows: “CMF is the ratio of the estimated average crash frequency of a site under two different conditions. Therefore, a CMF shows the relative change in estimated average crash frequency due to a change in one specific condition when all other conditions and site characteristics remain constant.” As such, developed CMFs can be used to accurately predict crash numbers conforming to different geometric features present at the analyzed RCUT. Alternative approaches to develop CMFs in the literature were investigated to adopt methods that are appropriate for the given task since the traditional method of CMF development is not adequate to develop proposed CMFs. In the future, FDOT can use these

CMFs in order to modify crash numbers predicted by SPFs and to conduct a before and after evaluation based on the Empirical Bayes method in order to estimate the effectiveness of the implemented RCUT design. This approach can also be utilized in order to conduct a benefit-cost analysis, where monetary benefits of RCUT intersections can be evaluated through calculating the CMF modified crash costs using the "KABCO" injury scale.

There are different approaches that can be implemented to develop CMFs. Two main approaches adopted by HSM can be listed as follows (Gross et al., 2010): 1) Before-After Studies, 2) Cross-Sectional Studies.

1) <u>Before-After Studies</u>: An untreated group of sites similar to the treated ones are compared to account for changes in crashes unrelated to the treatment such as time and traffic volume trends.
2) <u>Cross-Sectional Studies</u>: The crash experience of locations with and without some features are investigated and then the difference in safety attributed to that feature is identified.

In the before-after studies, a specific treatment is applied to the chosen sites, and then effect of treatment in terms of number of crashes is compared with the untreated sites. That is, the ratio of observed crash frequency in the after period of an implementation (e.g., increased median width) to that in the before period is estimated. However, this process requires several sites with very similar features in terms of roadway geometry and traffic conditions. Cross-sectional studies, on the other hand, are useful for estimating CMFs where there are insufficient instances where the treatment was applied to conduct a before-after study. That is, it is difficult to collect data for enough locations that are alike in all factors affecting the crash risk. Hence, cross-sectional analyses are often accomplished through multiple variable regression models. In these models, all variables that affect safety are accounted for, and the change in number of crashes that results from a unit change in a specific variable are estimated. As a result, the nature of the RCUT data fits to the Cross-Sectional Study since there are not many sites, which can be used to evaluate individual effects of features via isolating the similar RCUT implementations.

To conduct the cross-sectional approach for developing the CMFs, Negative Binomial regression was used, which is the approach adopted to develop the SPFs, as suggested by HSM. The coefficients estimated in the model are used to develop the CMFs. Negative binomial regression is an extension or generalization of the Poisson regression; however, on the contrary to Poisson regression, it can account for the overdispersion issue, which is commonly experienced with the crash data. That is, the crash data usually has a larger variability (overdispersion) than what a Poisson regression can handle. Note that mean and variance is equal to each other for a Poisson distribution, and therefore, Poisson regression models result in biased estimates. This larger variability can be introduced into the negative binomial model using an overdispersion parameter, which increases the accuracy of estimates. This overdispersion parameter constitutes the basis of before and after crash analysis conducted using the empirical Bayes approach (Hauer, 2001). The overdispersion parameter is estimated in the model along with the coefficients of variables (e.g., AADT, length) employed in order to create the model itself. The negative binomial regression distribution is a generalization of Poisson distribution by including a gamma noise variable, which introduces an extra variance due to the over-dispersion of crash data. The negative binomial distribution can be defined as follows:

$$\Pr(Y = y_i | \mu_i, \alpha) = \frac{\Gamma(y_i + \alpha^{-1})}{\Gamma(y_i + 1)\Gamma(\alpha^{-1})} \left(\frac{\alpha^{-1}}{\alpha^{-1} + \mu_i}\right) \left(\frac{\mu_i}{\alpha^{-1} + \mu_i}\right)^{y_i}$$

where μ is the mean incident rate of y. In the case of crashes, μ is usually the number of crashes per year at a roadway segment or an intersection. $\alpha = 1/\nu$, where ν is the scale parameter of gamma distributed noise. The mean incident rate μ can be modeled as follows:

$$\mu_i = \exp(\beta_k X_k + Offset(N_{SPF}))$$

where $k=1,2, \ldots$, indicate the variables which CMFs are produced for. The negative binomial regression analysis was conducted using the "glm.nb" function of "glmnet" package of the R programming software. Note that Safety Performance Functions (SPFs) were also developed using negative binomial regression approach, and same dataset was used for this purpose. Therefore, the developed SPFs were used as an offset value in the regression model since CMFs are implemented to adjust the crash numbers that are predicted using the SPFs. Note that the CMFs were developed by modeling all variables jointly (all variables were included in the model) and they are intended to adjust the crash numbers predicted by the following SPF models: a) SPF Model 6 for signalized RCUT all crashes; b) SPF Model 3 for signalized RCUT fatal and injury crashes; c) SPF Model 5 for unsignalized RCUT all crashes; b) SPF Model 4 for unsignalized RCUT fatal and injury crashes. The resultant CMFs can be estimated as follows:

$$CMF_{X_k} = \exp(\beta_k)$$

$$CMFunction_{X_k} = \exp(\beta_k * X_k)$$

5.1.1. Signalized RCUTs

This section presents the developed CMFs for all crashes as well as fatal and injury crashes occurred at signalized RCUTs. CMFs were produced for a total of 8 variables, namely: (a) Number of Major Road Lanes (MaLa), (b) Number of Minor Road Lanes (MiLa), (c) Total Median Width (TMeW), (d) Total Offset Distance (TOD), (e) Number of Driveways (NDW), (f) Number of Left-Turn Lanes from Major Road (LTL), (g) Total Deceleration Lane Length (TDLL), and (h) Major Road Speed Limit (SL). Table 62 presents the determined CMFs for the all crashes at the signalized RCUTs. Figure 60 illustrates these CMFs and the variation of their values depending on the changing value (e.g., offset distance, median width). Figure 61, on the other hand, shows examples of combined effect of different CMFs on the resultant CMF.

Table 63 present the determined CMFs for the fatal and injury crashes (excluding the PDO crashes) at the signalized RCUTs. Figure 62 illustrates these CMFs and variation of their values depending on the changing value (e.g., offset distance, median width). Figure 63, on the other hand, shows examples of combined effect of different CMFs on the resultant CMF.

Tables that provide the results of the analyses have columns showing the regression parameters, confidence intervals, resultant CMF, as well as the reliability of the these CMFs. The reliability of CMFs were assessed based on the obtained confidence interval. Note that all CMFs can be implemented in crash number prediction no matter the reliability of that CMF is; however, low reliability CMFs are advised to be used with caution.

Table 62 Signalized RCUT CMFs for all crashes

CMF Variable	**Description**	$\boldsymbol{\beta}$	**SE**	**95% CI of $\boldsymbol{\beta}$**	**CMF**	**Reliability**
Number of Major Road Lanes (MaLa)	MaLa = 2: 0 MaLa = 3: 1	$3.292\ x10^{-1}$	$1.553\ x10^{-1}$	$1.052\ x10^{-1}$ / $5.535\ x10^{-1}$	1.000 1.390	High
Number of Minor Road Lanes (MiLa)	MiLa ≤ 2: 0 MiLa = 3: 1	$-3.174\ x10^{-1}$	$0.952\ x10^{-1}$	$-5.820\ x10^{-1}$ / $-0.465\ x10^{-1}$	1.000 0.728	High
Total Median Width (TMeW)	Continuous variable measured in feet	$-4.662\ x10^{-3}$	$1.912\ x10^{-3}$	$-8.708\ x10^{-3}$ / $-0.369\ x10^{-3}$	$exp(\beta_{TMeW} * TMeW)$	Moderate
Total Offset Distance (TOD)	Continuous variable measured in feet	$9.478\ x10^{-5}$	$5.636\ x10^{-5}$	$-2.488\ x10^{-5}$ / $21.211\ x10^{-5}$	$exp(\beta_{TOD} * TOD)$	Moderate
Number of Driveways (NDW)	Count of driveways along the RCUT	$2.405\ x10^{-2}$	$1.576\ x10^{-2}$	-0.006 / 0.054	$exp(\beta_{NDW} * NDW)$	Moderate
Number of Left-Turn Lanes from Major Road (LTL)	LTL = 1: 0 LTL ≥ 2: 1	$-5.569\ x10^{-2}$	$9.034\ x10^{-2}$	-0.236 / 0.126	1.000 0.946	Low
Total Deceleration Lane Length (TDLL)	Continuous variable measured in feet	$-6.598\ x10^{-5}$	$1.993\ x10^{-4}$	$-4.645\ x10^{-4}$ / $3.332\ x10^{-4}$	$exp(\beta_{TDLL} * TDLL)$	Low
Major Road Speed Limit (SL)	SL ≤ 50 mph: 0 SL > 50 mph: 1	$8.984\ x10^{-3}$	$9.656\ x10^{-2}$	-0.182 / 0.201	1.000 1.009	Low

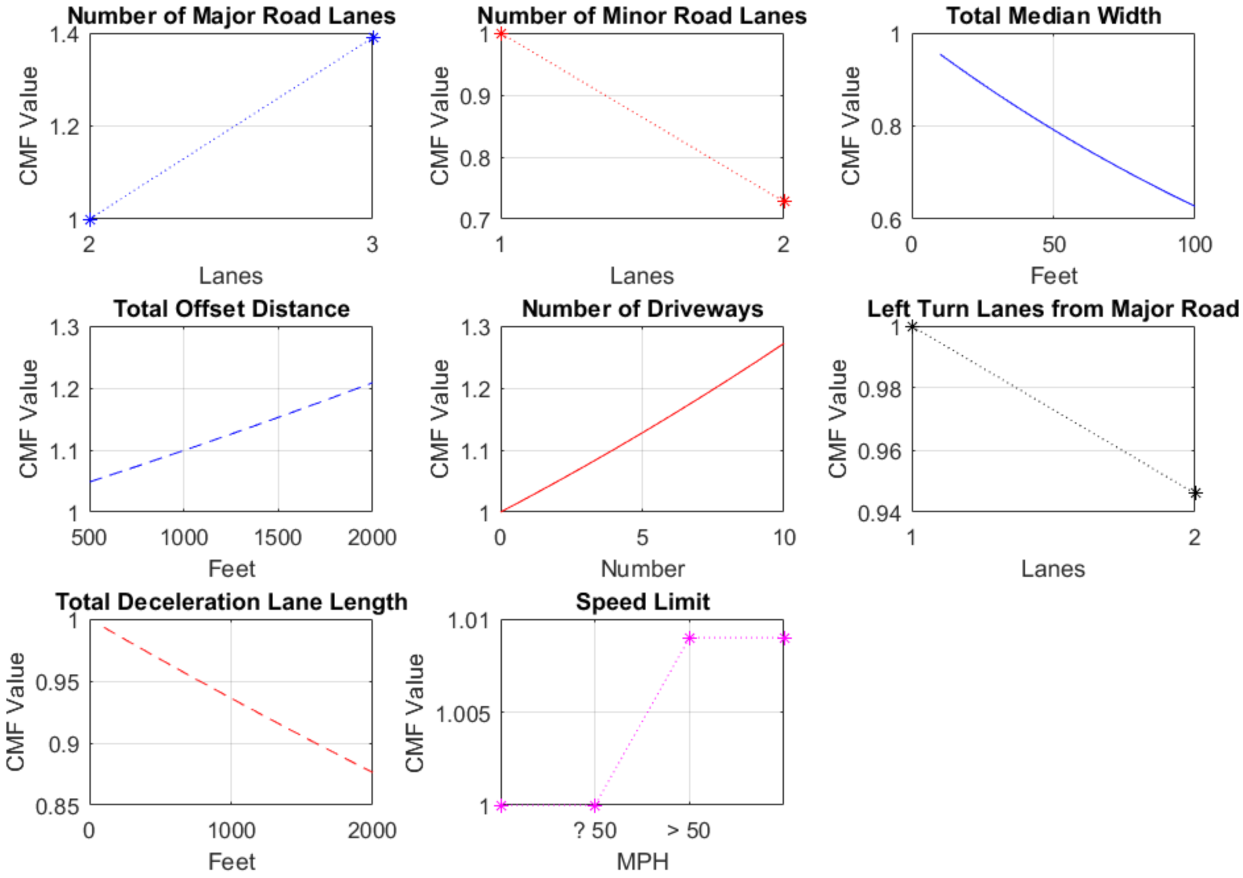


Figure 60. Signalized RCUT CMF plots for all crashes

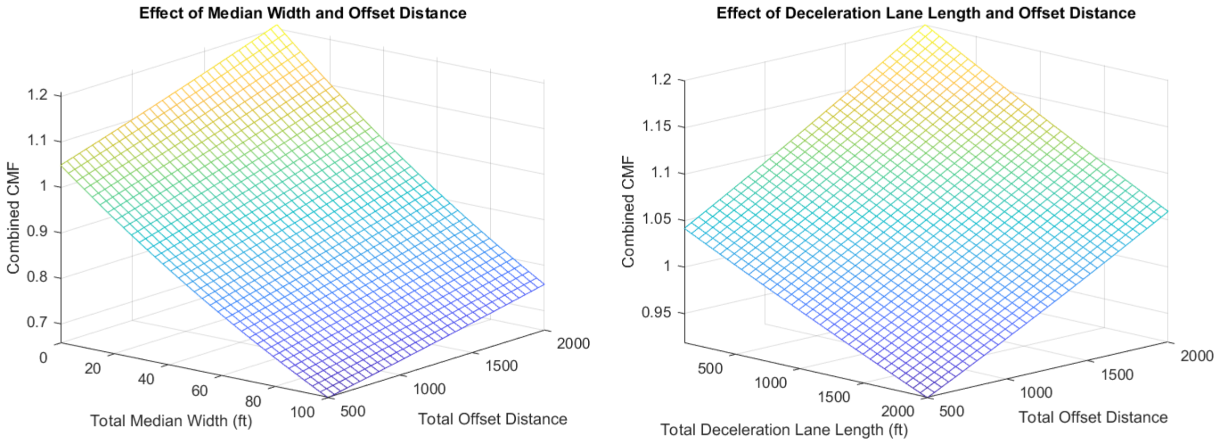


Figure 61. Signalized RCUT combined CMFs planes for all crashes

Table 63 Signalized RCUT CMFs for fatal and injury crashes

CMF Variable	**Description**	$\boldsymbol{\beta}$	**SE**	**95% CI of $\boldsymbol{\beta}$**	**CMF**	**Reliability**
Number of Major Road Lanes (MaLa)	MaLa = 2: 0 MaLa = 3: 1	$3.236\ x10^{-1}$	$1.577\ x10^{-1}$	$0.980\ x10^{-1}$ / $5.514\ x10^{-1}$	1.000 1.382	High
Total Median Width (TMeW)	Continuous variable measured in feet	$-6.657\ x10^{-3}$	$1.851\ x10^{-3}$	$-10.434\ x10^{-3}$/ $-2.864\ x10^{-3}$	$exp(\beta_{TMeW} * TMeW)$	High
Total Offset Distance (TOD)	Continuous variable measured in feet	$2.124\ x10^{-4}$	$1.067\ x10^{-4}$	$0.003\ x10^{-4}$ / $4.261\ x10^{-4}$	$exp(\beta_{TOD} * TO.D)$	Moderate
Total Deceleration Lane Length (TDLL)	Continuous variable measured in feet	$-2.667\ x10^{-4}$	$1.767\ x10^{-4}$	$-6.237\ x10^{-4}$ / $0.860\ x10^{-4}$	$exp(\beta_{TDLL} * TDLL)$	Moderate
Number of Driveways (NDW)	Count of driveways along the RCUT	$-7.465\ x10^{-3}$	$18.758\ x10^{-3}$	$-4.420\ x10^{-2}$ / $2.916\ x10^{-2}$	$exp(\beta_{NDW} * NDW)$	Low
Number of Left-Turn Lanes from Major Road (LTL)	LTL = 1: 0 LTL ≥ 2: 1	$-3.342\ x10^{-2}$	$9.933\ x10^{-2}$	-0.238 / 0.171	1.000 0.967	Low
Number of Minor Road Lanes (MiLa)	MiLa ≤ 2: 0 MiLa = 3: 1	$3.159\ x10^{-3}$	$1.382\ x10^{-1}$	$-2.646\ x10^{-1}$ / $2.736\ x10^{-1}$	1.000 1.003	Low
Major Road Speed Limit (SL)	SL ≤ 50 mph: 0 SL > 50 mph: 1	$1.477\ x10^{-2}$	$10.850\ x10^{-2}$	-0.196 / 0.224	1.000 1.015	Low

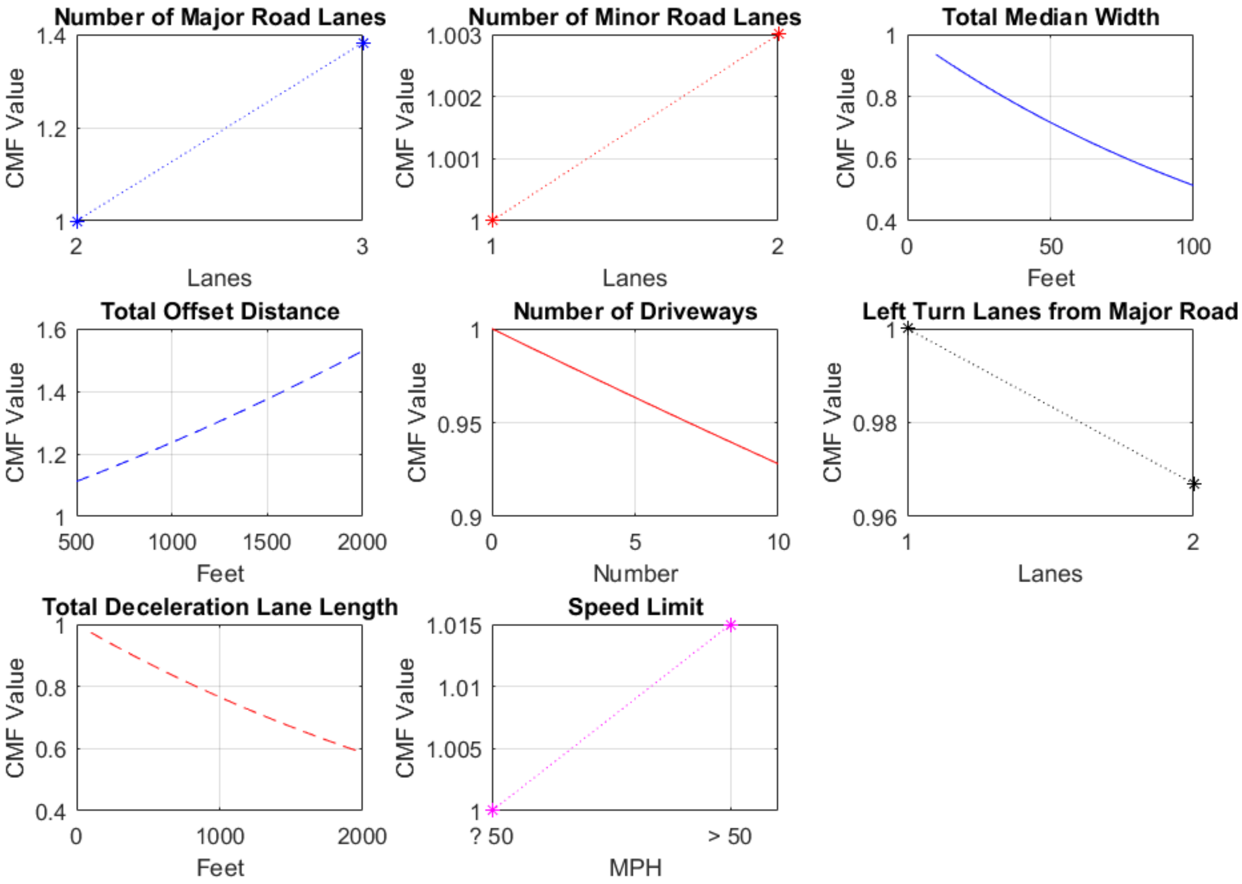


Figure 62. Signalized RCUT CMF plots for fatal and injury crashes

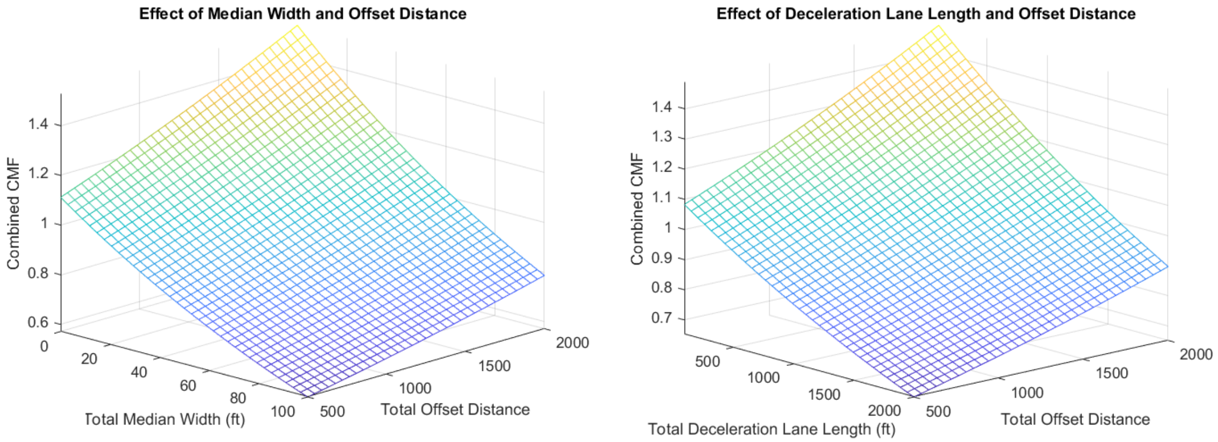


Figure 63. Signalized RCUT combined CMFs planes for fatal and injury crashes

5.1.2. Unsignalized RCUTs

This section presents the developed CMFs for all crashes as well as fatal and injury crashes occurred at unsignalized RCUTs. CMFs were produced for a total of 6 variables, namely: (a) Total Deceleration Lane Length (TDLL), (b) Total Offset Distance (TOD), (c) Number of U-Turns (UT), (d) Maximum Median Width (MMeW), (e) Number of Driveways (NDW), and (f)

Total Acceleration Lane Length (TALL). Table 64 presents the determined CMFs for the all crashes at the unsignalized RCUTs. Figure 64 illustrates these CMFs and variation of their values depending on the changing value (e.g., offset distance, median width). Figure 65, on the other hand, shows examples of combined effect of different CMFs on the resultant CMF.

Table 65 present the determined CMFs for the fatal and injury crashes (excluding the PDO crashes) at the unsignalized RCUTs. Figure 66 illustrates these CMFs and variation of their values depending on the changing value (e.g., offset distance, median width). Figure 67, on the other hand, shows examples of combined effect of different CMFs on the resultant CMF.

Tables that provide the results of the analyses have columns showing the regression parameters, confidence intervals, resultant CMF, as well as the reliability of the these CMFs. The reliability of CMFs were assessed based on the obtained confidence interval. Note that all CMFs can be implemented in crash number prediction no matter the reliability of that CMF is; however, low reliability CMFs are advised to be used with caution.

Table 64 Unsignalized RCUT CMFs for all crashes

CMF Variable	**Description**	$\boldsymbol{\beta}$	**SE**	**95% CI of $\boldsymbol{\beta}$**	**CMF**	**Reliability**
Total Deceleration Lane Length (TDLL)	Continuous variable measured in feet	-0.156	0.088	-0.321 / 0.008	$TDLL^{-0.156}$	High
Total Offset Distance (TOD)	Continuous variable measured in feet	0.158	0.088	-0.007 / 0.323	$TOD^{0.158}$	High
Number of U-Turns (UT)	UT = 1: 0 UT = 2: 1	0.156	0.129	-0.098 / 0.410	1.000 1.169	Moderate
Maximum Median Width (MMeW)	Continuous variable measured in feet	$-8.838\ x10^{-2}$	$9.341\ x10^{-2}$	$-26.77\ x10^{-2}$ / $9.257\ x10^{-2}$	$MMeW^{-8.838\ x10^{-2}}$	Low
Number of Driveways (NDW)	Count of driveways along the RCUT	$-2.956\ x10^{-2}$	$3.863\ x10^{-2}$	$-10.48\ x10^{-2}$ / $4.534\ x10^{-2}$	$exp(\beta_{NDW} * NDW)$	Low
Total Acceleration Lane Length (TALL)	Continuous variable measured in feet	$5.735\ x10^{-3}$	$20.70\ x10^{-3}$	$-3.464\ x10^{-2}$ / $4.609\ x10^{-2}$	$TALL^{5.735\ x10^{-3}}$	Low

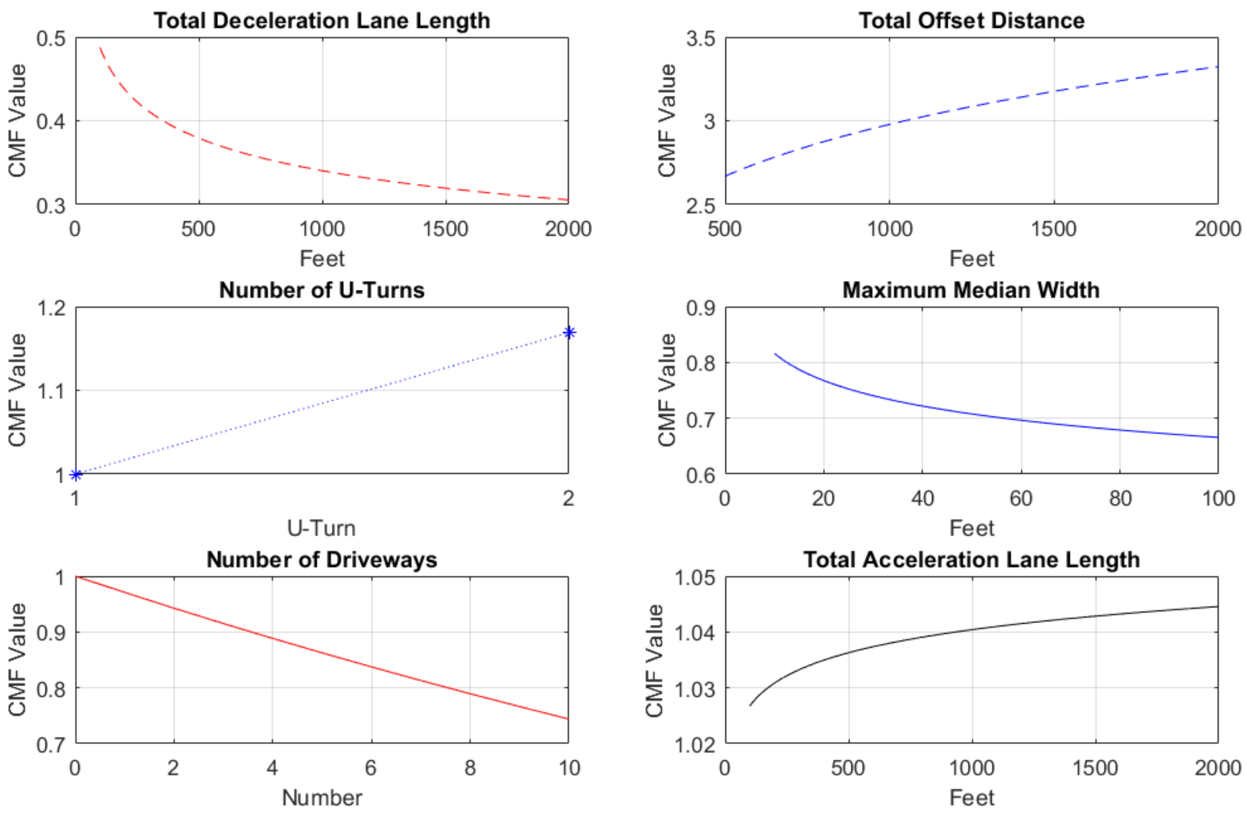


Figure 64 Unsignalized RCUT CMF plots for all crashes

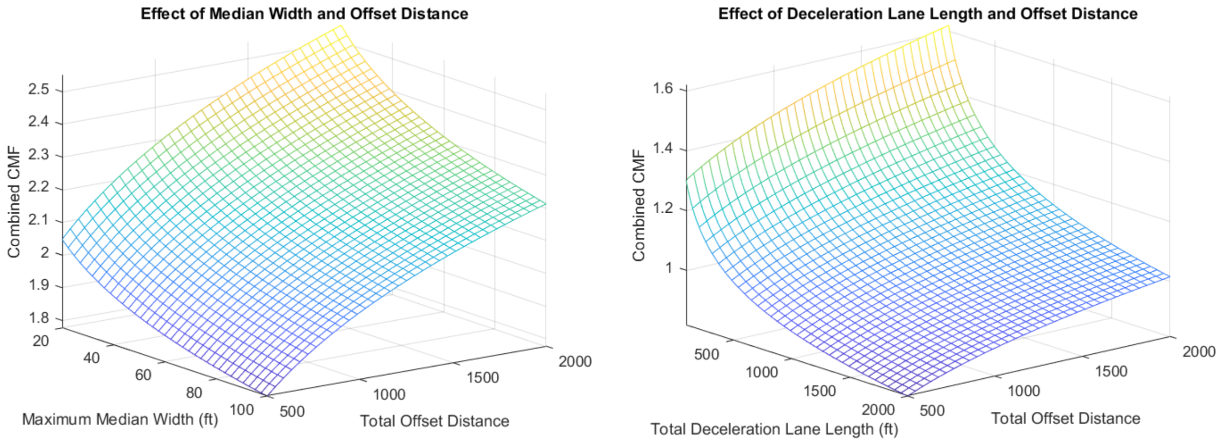


Figure 65. Unsignalized RCUT combined CMFs planes for all crashes

Table 65 Unsignalized RCUT CMFs for fatal and injury crashes

CMF Variable	**Description**	$\boldsymbol{\beta}$	**SE**	**95% CI of $\boldsymbol{\beta}$**	**CMF**	**Reliability**
Total Offset Distance (TOD)	Continuous variable measured in feet	0.305	0.114	0.080 / 0.530	$TOD^{0.305}$	High
Total Deceleration Lane Length (TDLL)	Continuous variable measured in feet	-0.263	0.119	-0.490 / -0.034	$TDLL^{-0.263}$	High
Maximum Median Width (MMeW)	Continuous variable measured in feet	-0.163	0.118	-0.395 / 0.078	$MMeW^{-0.163}$	Moderate
Number of Driveways (NDW)	Count of driveways along the RCUT	$-6.799\,x10^{-2}$	$5.390\,x10^{-2}$	-0.174 / 0.037	$exp(\beta_{NDW} * NDW)$	Moderate
Total Acceleration Lane Length (TALL)	Continuous variable measured in feet	$9.632\,x10^{-3}$	$29.43\,x10^{-3}$	$-4.848\,x10^{-2}$ / $6.693\,x10^{-2}$	$TALL^{9.632\,x10^{-3}}$	Low
Number of U-Turns (UT)	UT = 1: 0 UT = 2: 1	$-4.562\,x10^{-2}$	$17.10\,x10^{-2}$	-0.380 / 0.291	1.000 0.955	Low

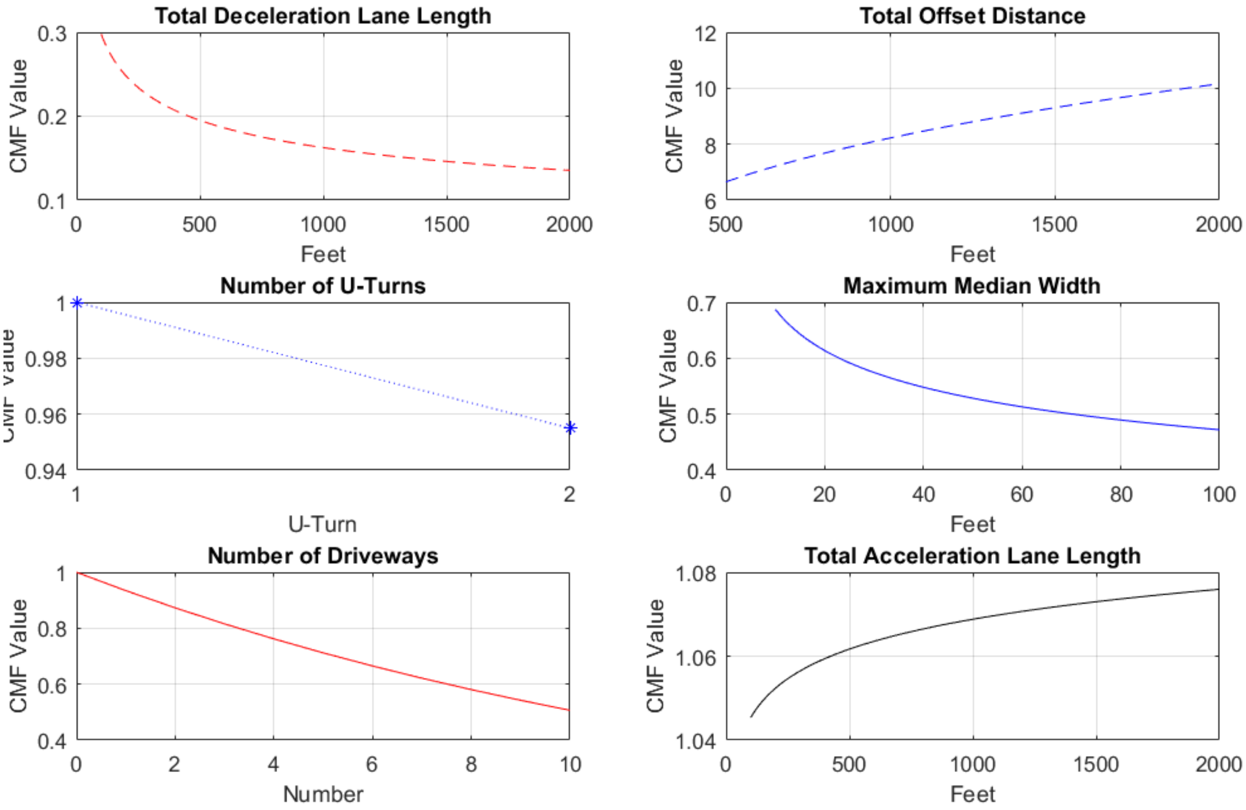
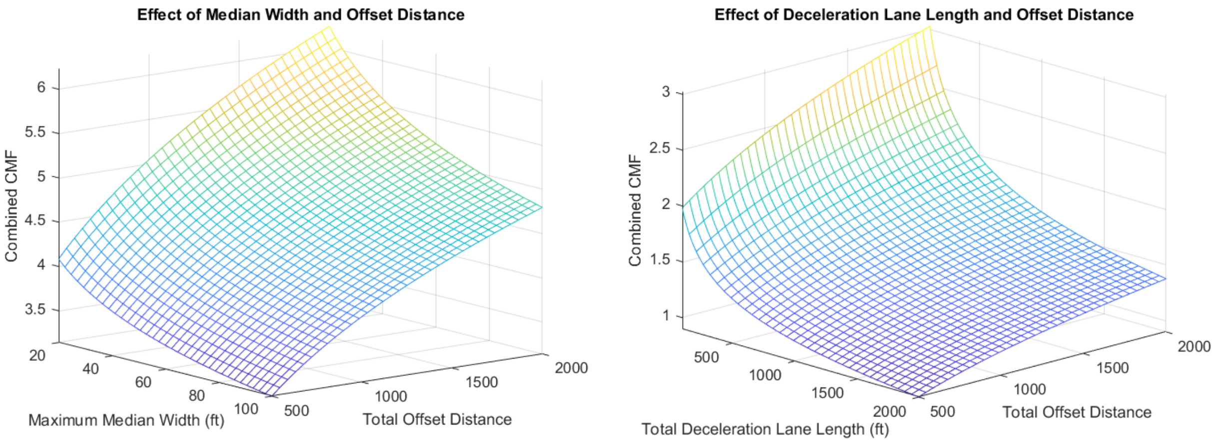


Figure 66. Unsignalized RCUT CMF plots for fatal and injury crashes



Effect of Median Width and Offset Distance

Effect of Deceleration Lane Length and Offset Distance

Figure 67. Unsignalized RCUT combined CMFs planes for fatal and injury crashes

5.2. SUMMARY

Task 4 intends to provide a comprehensive investigation of Restricted Crossing U-Turn (RCUT) crashes and to develop Crash Modification Factors and Crash Modification Functions for both signalized and unsignalized RCUTs. For this purpose, data on the total number of crashes with different severity levels as well as traffic-, geometric design-, and environment-related data were collected and utilized in the creation of these CMFs (See Appendix A for the state contacts). Provided CMFs for the Restricted Crossing U-Turn (RCUT) intersections can be successfully used by transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies) in identifying prospective locations for RCUT implementations, and analyzing them.

Consequently, for signalized RCUTs, 8 CMFs for “all crashes” and “fatal and injury crashes” were provided. For unsignalized RCUTs, on the other hand, 6 CMFs for “all crashes” and “fatal and injury crashes” were provided. The purpose of providing several CMFs was to be able to cover the potential effect of several geometric and traffic related variables on the predicted crash numbers. These CMFs can be successfully used by transportation agencies to evaluate and justify the installation of innovative intersection designs that will drastically improve intersection safety and operations. Results of this task combined with the findings of Task 3 (SPFs) will also be used with the new Intersection Control Evaluation (ICE) Policy and Procedure. RCUT Crash Modification Factors and Functions will be incorporated into the SPICE Tool, can be added to CMF clearinghouse (http://www.cmfclearinghouse.org/) for the RCUTs.

6. CONCLUSIONS

The overall goal of this project was to provide appropriate safety performance functions for different types of RCUT intersections for use by FDOT planners and engineers at various levels of project development and safety analysis. Consistent with this goal, the following tasks have been completed as part of the project: (a) a comprehensive search was performed to identify the experiences of other transportation agencies (federal and state agencies, cities, counties, MPOs and other local agencies) related to the RCUT implementations; (b) a survey questionnaire was prepared and used to solicit information on RCUT intersections from these agencies; (c) geometric, traffic and crash data were collected for all the existing RCUT intersections in the U.S.; (d) significant factors influencing the RCUT intersection safety were determined; and (e) safety performance functions (SPFs) were developed for signalized and unsignalized RCUT intersections based on the collected data; (f) crash modification factors and functions (CMFs) were developed for various traffic and geometric variables. Meeting these objectives led to appropriate recommendations to Florida DOT in terms of evaluating and justifying the feasibility of RCUT intersections as safer intersection alternatives, and identifying promising locations in Florida that will drastically improve intersection safety and operations (those locations that may benefit the most from RCUT implementations).

The comprehensive analysis of signalized and unsignalized RCUT crashes and developed SPFs provided important insights and recommendations for transportation agencies related to the implementation of this alternative intersection type. To begin with, analysis findings show that the possible location for a future signalized RCUT implementation should be chosen by ultimate care since traffic volumes of major and minor approaches as well as their ratios play a critical role in the efficient and successful signalized RCUT implementations. On the other hand, almost all unsignalized RCUTs were observed to be implemented at rural areas whereas signalized RCUTs were implemented in suburban and urban areas. Therefore, the location selection for a future unsignalized RCUT implementation should be conducted after considering if there is a possibility of potential future land development that can change rural nature of the region. For signalized and unsignalized RCUTs, Figure 41 and Figure 55 show that the higher the major and minor AADTs, the higher the total number of crashes, respectively. More importantly, when the ratio of major AADT to minor AADT is small due to high minor approach traffic, there is a considerable increase in the number of crashes compared to RCUTs which have larger major AADT to minor AADT ratios (Figure 36, Figure 50). Therefore, transportation agencies should avoid implementing RCUTs at locations where high minor traffic volume is being experienced.

For signalized RCUT intersections, another insight obtained through the investigation of RCUT crashes is that RCUTs appear to be more suitable for suburban and less urbanized areas since very high crash numbers are observed for those located at highly urbanized areas (Figure 37). Figure 37 also shows that shorter deceleration lanes might be associated with higher number of crashes. However, this variable was not found to be statistically significant in predicting the total crash number. Another geometric variable, namely offset distance, was used in modeling total crash numbers, and was adopted as one of the SPF variables. However, it was found that offset distance has been slightly increasing the effect on the total number of crashes. This is due to the fact that all crashes occurred along the footprint of an RCUT intersection is included into the analysis, and the longer the offset, the more the number of crashes are observed between the intersection center and U-turns. However, this does not necessarily mean that offset distance should be kept as minimum as possible. Indeed, number of fatal and severe injury crashes are observed to decrease with longer offset distance even though the total number of all crashes seems to increase. Further research is necessary to determine the optimal offset distance in terms of their effect on reducing crashes (Figure 37 and Figure 39).

For unsignalized RCUT intersections, 2-D histograms of Figure 51, Figure 52, and Figure 53 show that shorter deceleration lanes and acceleration lanes might be associated with higher number of crashes. Indeed, deceleration lane length variable was found to be statistically significant in predicting the total number of “all crashes” and “fatal and injury crashes”. In addition to the deceleration lane length, another geometric variable, namely offset distance, was also used in modeling for total crash numbers, and was adopted as one of the SPF variables. However, it was found that offset distance has been slightly increasing the effect on the total number of crashes. This is due to the fact that all crashes occurred along the footprint of an RCUT intersection is included into the analysis, and the longer the offset, the more the number of crashes are observed between the intersection center and U-turns. However, this does not necessarily mean that offset distance should be kept as minimum as possible. Indeed, number of fatal and severe injury crashes are observed to decrease with longer offset distance even though the total number of all crashes seems to increase. Further research is necessary to determine the optimal offset distance in terms of their effect on reducing crashes (Figure 51, Figure 52, and Figure 53).

For signalized RCUTs, there are 6 SPF models developed for all crashes and 3 SPF models for fatal and injury crashes. Furthermore, the 6th SPF for “all crashes” and 3rd SPF for “fatal and injury crashes” were also modified after outlier observations (2 observations) were excluded. For unsignalized RCUTS, on the other hand, there are 5 SPF models developed for “all crashes”, and 4 SPF models for “fatal and injury crashes”. These different models were developed to provide a flexibility to agencies and safety officials on the selection of proper SPF model for RCUTs. As such, due to their simplicity, for signalized RCUTs, the research team proposes the adoption of 5th or 6th SPF models for “all crashes”, and 3rd SPF for “fatal and injury crashes”, and for unsignalized RCUTs, the research team proposes the adoption of 4th or 5th SPF models for “all crashes”, and 4th SPF for “fatal and injury crashes”. These models are practical to implement from an agency perspective and especially when there is data scarcity regarding the geometric design features. Moreover, statistically speaking, the quality of these simpler models is close to the more complex models as evidenced by their respective AIC values (Table 42 and Table 47 for signalized RCUTS, Table 56 and Table 61 for unsignalized RCUTs). Nevertheless, all developed SPF models are suitable for accurately predicting crashes of RCUTs.

Furthermore, for signalized RCUTs, 8 CMFs for “all crashes” and “fatal and injury crashes” were provided. For unsignalized RCUTs, on the other hand, 6 CMFs for “all crashes” and “fatal and injury crashes” were provided. The purpose of providing several CMFs was to be able to cover the potential effect of several geometric and traffic related variables on the predicted crash numbers. Note that the CMFs were developed by modeling all variables jointly (all variables were included in the model), and they are intended to adjust the crash numbers predicted by the following SPF models: a) SPF Model 6 for signalized RCUT all crashes; b) SPF Model 3 for signalized RCUT fatal and injury crashes; c) SPF Model 5 for unsignalized RCUT all crashes; b) SPF Model 4 for unsignalized RCUT fatal and injury crashes. These CMFs can be successfully used by transportation agencies to evaluate and justify the installation of innovative intersection designs that will drastically improve intersection safety and operations.

Findings present guidelines for transportation agencies in decision making for RCUT implementations, and specifically illustrate that the selection of an RCUT location depends significantly on the major and minor AADTs, and their ratio. The developed SPF models can be successfully used by transportation agencies to evaluate and justify the installation of innovative intersection designs that will drastically improve intersection safety and operations. Findings will also be used with the new Intersection Control Evaluation (ICE) Policy and Procedure, and RCUT safety performance functions (SPFs) will be incorporated into the SPICE Tool.

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APPENDICES

Appendix A. Meta-analysis of the Literature

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Gross et al., 2010)	2010	A Guide to Developing Quality Crash Modification Factors	Report	-	Safety/ CMFs	Methods for developing CMFs	Review/ Forming a guide	Guides to develop accurate CMFs
(Wang et al., 2014)		A Systematic Approach for Hazardous Intersection Identification and Countermeasure Development	Paper	FL	Safety/ SPFs	To develop a method integrating hotspot identification and countermeasure based on intersection approach level SPFs	Statistical regression analysis	• Geometric design features of the intersection approaches were obtained from the high-resolution aerial and satellite imagery provided by software Google Earth • Hotspot identification based on crash totals tended to screen out approaches with high frequencies of rear-end and sideswipe crashes, rather than the ones with more serious crash types such as left-turn and right-angle. • Approach-level crash type models provide a powerful method for quantifying the effects of risk factors. • Countermeasures specific to the crash type were recommended at locations where there are overrepresentation of a particular crash type.
(Hughes et al., 2010)	2010	Alternative Intersections / Interchanges: Informational Report (AIIR)	Report		Design/ Geometry/ Operation/ Safety	To show advantages/ disadvantages of alternative junctions (RCUT) compared to traditional ones	Report/ Review/ Discussion	• Reduced vehicle-vehicle conflict points. • Less severe crashes • Require 2 signal phases rather than conventional 4 phase which translates to significant time savings leading to leads to reduced emissions and fuel consumption, increased productivity, and improved quality of life. • Improved progression of traffic platoons • May lead increased delay and inconvenience as well as exposure to traffic for pedestrians • Nontraditional vehicle movements are counter-intuitive to pedestrians with visual disabilities • Needed to balance pedestrian and vehicle safety and operational concerns • Disadvantageous at intersections with heavy through and left-turn volumes from the side street approaches • Drivers adapt well to RCUT intersections.

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
								• Median and lane width needed to accommodate large vehicles making U-turns at crossovers • Can adversely affect roadside businesses, particularly businesses not at median openings that attract left-turn pass-by trips.
(Hummer and Jagannathan, 2008)	2008	An Update on Superstreet Implementation and Research	Paper	NC MD	Safety	To present of the latest collision data from recent superstreet applications	Report/ Review/ Discussion	• More efficient and safer travel, at-grade, in an atmosphere of controlled speeds that welcomes pedestrians • The potential drawbacks, like heavy side street through volumes, wider medians, driver confusion, and lost business (possible to mitigate) • A considerable/huge (depending on location) reduction in collision frequency and rate after superstreet installation.
(Naghawi and Idewu, 2014)	2014	Analyzing delay and queue length using microscopic simulation for the unconventional intersection design Superstreet	Paper	-	Operation	The effect of superstreet implementation on traffic performance measures	Microscopic Simulation by CORSIM	• Superstreets consistently provide lower delay time and shorter queue length than conventional junctions • The greatest delay and queue length differences occurred when a high percentage of minor road left-turners (approximately 30%) coincided with a moderate amount of major road left-turners (above 15%) • An increased delay is experienced for motorist desiring to travel through and turn left from a minor street approach.
(Kharrazi and Thomson, 2008)	2008	Analysis of heavy truck accidents with regard to yaw and roll instability - Using LTCCS database	Paper	-	Safety	To determine common maneuvers causing loss of control of trucks	Statistical analysis	J-Turn maneuver lead to vehicle rollover more easily than other common maneuvers.
(Findley et al., 2012)	2012	Applying the Highway Safety Manual to Two-Lane Road Curves	Paper	NC	Safety	To evaluate the HSM crash prediction model using	Data collection/ Application of HSM	• Data collection for large number of sites which is necessary to develop an accurate model based on local conditions requires extensive manpower

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
						data on two-lane rural horizontal curves		• AADT, curve radius, and curve length of the segment are the most important variables for accuracy of the predicted crash value • To properly calibrate the predictive models to HSM standards, at least approximately 300 segments are required (for NC) • Randomly selected locations are preferred over high crash locations for calibration.
(Mehta and Lou, 2013)	2013	Calibration and Development of Safety Performance Functions for Alabama: Two-Lane, Two-Way Rural Roads and Four-Lane Divided Highways	Paper	AL	Safety/ CFs/ SPFs	To evaluate the applicability of HSM predictive methods, and to develop state-specific statistical models	Statistical regression analysis/ Application of HSM	• The best state-specific model includes a few variables that are not part of the HSM base SPF • HSM base SPFs may over- or underestimate the state-specific crash frequencies • State-specific SPFs outperform calibrated (by CFs) general SPFs • Effect (sign of coefficient) of variables in the SPF models may vary depending on the variable set used to model crash frequencies • Introduced a new approach to determine the CF, where the CF was considered as a constant term in the traditional negative binomial (NB) regression model fitting crash frequency data.
(Sun et al., 2013)	2013	Calibration of the Highway Safety Manual for Missouri	Report	MO	Safety/ CFs	To calibrate HSM crash prediction models for State of Missouri	Statistical analysis/ Report/ Review/ Discussion	• Calibration factors are generated for Missouri roadways based on HSM SPFs • The number of crashes at signalized intersections in Missouri was greater than the number of crashes predicted by the HSM • In calibration, some tradeoffs such as between segment homogeneity and minimum segment length may be required • For some site types (e.g., signalized intersections), significant differences between predicted and observed crashes can be found.

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Martinelli et al., 2009)	2009	Calibration of the Highway Safety Manual's Accident Prediction Model for Italian Secondary Road Network	Paper	Italy	Safety/ CFs	To calibrate HSM crash prediction models for Italy via HSM and other procedures	Statistical analysis/ Application of HSM	• A constant value of the calibration coefficient is not a suitable option for a valid model transferability • Calibration is absolutely necessary for the model transferability to avoid a considerable accuracy of expected crashes
(Xu et al., 2017)	2017	Computing the of Minimal U-turn Offset for an Un-Signalized Superstreet	Paper	MD	Design/ Geometry/ Safety	To develop a tool to determine minimum U-turn offset	Statistical Analysis/ Mathematical Model/ Microscopic simulation by SSAM	• A model to determine median U-turn offset was developed • Model is also capable of offering the criteria to decide when to apply signal conversion (to accommodate the growing volumes) • The safety performance of 1100 feet offset scenario is similar to the performance of 1500 feet offset scenario • The scenario of 700 feet offset significantly increases the potential lane-changing conflicts and the severity of collisions compared to 1100 and 1500 feet.
(Vogt, 1999)	1999	Crash models for rural intersections: Four-lane by two-lane stop-controlled and two-lane by two-lane signalized	Report	MI CA	Safety	To model rural intersection crashes	Statistical regression analysis	Data sets consist of 84 sites of the three-legged intersections, 72 sites of the four-legged intersections, and 49 sites of the signalized intersections. Major and minor road traffic, peak major and minor road left-turning percentage, number of driveways, channelization, median widths, vertical alignment, and the presence or absence of protected left-turn phases and peak truck percentage (for signalized intersections) were included in the models. From three-legged to four-legged to signalized intersections, major road ADT becomes less important while turning percentage measures become more important
(Olarte et al., 2011)	2011	Density models and safety analysis for rural unsignalized restricted crossing U-turn intersections	Paper	-	Operation/ Safety	To develop a model that assess RCUT applicable locations	Statistical regression analysis/ Microscopic simulation by VISSIM-SSAM	• A model that will aid planners was developed based on the calculated possible level of service of a RCUT implementation. • In terms of safety, volume ranges between 1605 pc/h/ln to 1708 pc/h/ln are found to be critical.

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Kweon and Lim, 2014)	2014	Development of Safety Performance Functions for Multilane Highway and Freeway Segments Maintained by the Virginia Department of Transportation	Report	VA	Safety/ SPFs	To develop SPFs for multilane highway and freeway segments of Virginia	Statistical regression analysis	• State-specific SPFs are developed • It was observed that model coefficients may found not statistically significant if the sample size is not large enough. Still, p values up to 0.2 is acceptable depending on the conditions • If there are regional differences within the state, regional specific SPFs (or modification of base SPFs) can also be produced (yet too much localization should be avoided)
(Srini-vasan and Carter, 2011)	2011	Development of Safety Performance Functions for North Carolina	Report	NC	Safety/ SPFs	To develop SPFs and CFs for 9 crash types for 16 roadway types in North Carolina	Statistical regression analysis/ Application of HSM	• State-specific SPFs are developed • Calibration factors are developed to adapt HSM predictive methods • To update SPFs in the future, new SPFs may be developed, or existing SPFs can be calibrated with new data following steps provided in HSM.
(Tegge et al., 2010)	2010	Development and application of safety performance functions for Illinois	Report	IL	Safety/ SPFs	To develop state specific SPFs and a software tool Illinois officials	Review/ Statistical regression analysis	• A level of significance of 0.10 typically is used for the development of SPFs • The SPFs were developed for a five-year crash data • Unaccounted variables such as weather conditions, demographic information may have large impact on the crash frequency
(Sun et al., 2016)	2016	Driving Simulator Study of J - Turn Acceleration / Deceleration Lane and U - Turn Spacing	Report	MO	Design/ Geometry/ Safety	To analyze the parameters of lane configuration, U-turn spacing, and signage	Driving simulator	• Lane configuration was found to be the most important parameter affecting J-turn safety based on speed-differentials. • Acceleration/Deceleration (1 length/1 length) lane configuration design is recommended over the Full Deceleration (2 length) lane configuration. Thus, when possible, acceleration lanes should be provided at J-turn sites. • Locations with high traffic demand should especially consider longer lane (A/D) lengths such as 2,000 feet. • A public educational campaign before J-turn deployment can help to improve driver understanding and to reduce the instances of missed U-turns.

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Edara et al., 2015)	2015	Empirical Evaluation of J-turn Intersection Performance – Analysis of Conflict Measures and Crashes	Paper	MO	Safety	To evaluate the effectiveness of unsignalized J-turn intersection in terms of safety	Field study by video/ Statistical analysis	• High reduction in total and fatal-injury crash frequency (31.2% and 63.8% reduction, respectively) after J-turn implementation • For minor road turning vehicles, time-to-collision conflict measure increased 4 times (increased safety) in J-turns compared to 2-way-stop controlled • While average travel time increases at J-turns, average wait time reduces compared to 2-way-stop controlled intersections
(Edara et al., 2013)	2013	Evaluation of J-turn Intersection Design Performance in Missouri Final Report	Report	PLEASE SEE ABOVE				
(Lubliner, Bornheimer, Schrock, Wang, and Fitzsimmons, 2014)	2014	Evaluation of Interactive Highway Safety Design Model Crash Prediction Tools for Two-Lane Rural Roads on Kansas Department of Transportation Projects	Report	KS	Safety/ SPFs	To evaluate suitability of crash prediction models in Kansas rural two-lane highways	Statistical analysis HSM Application	• Statewide calibration factor were developed for rural two-lane highways, and 3- and 4-leg stopped controlled intersections • A calibration function which account for animal crashes was developed for rural two-lane highway segments
(Giuffrè et al., 2014)	2014	Estimating the safety performance function for urban unsignalized four-legged one-way intersections in Palermo, Italy	Paper	Italy	Safety/ SPFs	To develop a SPFs for urban unsignalized intersections	Statistical regression analysis	• While 7 years crash data (644 crashes) was used, the sample consists of 92 unsignalized urban intersections in Palermo, Italy. • A radius of 20 meters from the center of the intersection is used to classify crashes as intersection-related • Sum of Annual Average Daily Traffic on major and minor-road (in power function form), and number of lanes on major road (in exponential function form) were found to be best variables for SPF development
(Ahmed, 2011)	2011	Evaluation of low cost technique "indirect right turn" to reduce congestion at urbanized	Paper	Pakistan	Operation/ Safety	To evaluate low cost “Indirect Right Turn Treatment” to	Filed study by GPS/ Microscopic simulation by VISSIM	• While the travel time reduced and traffic flow increased at most of the treatment locations, effect of treatment was contrary at some locations (mostly due to on street parking at U-turns)

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
		signalized intersection in developing countries				reduce conflicts and congestion at signalized intersections in urban areas		• Safety issues increases when U-turns are not properly designed and implemented.
(Inman et al., 2013)	2013	Evaluation of Restricted Crossing U-Turn Intersection as a Safety Treatment on Four-Lane Divided Highway	Paper	MD	Safety	To conduct crash analysis of RCUT intersections on two Maryland corridors	Statistical analysis	• RCUTs reduces all crashes by 44%. Among these, injury and fatality crashes were reduced by 9% • Particularly, angle type crashes highly reduced by RCUT conversion (with negligible increase in travel time) • Implementation of acceleration lanes help minimizing delays.
(Farid et al., 2016)	2016	Exploring the transferability of safety performance functions	Paper	FL OH CA	Safety/ SPFs	To examine transferability of HSM SPFs for rural divided multilane highway to local jurisdictions	Statistical regression analysis/ Index development	• Multi-state SPFs were developed using Negative Binomial regression with additional state parameters • Florida and California models are more transferable than Ohio models • Transferability is increasing when pooled data from multiple states is used • A modified empirical Bayes method is proposed instead of HSM procedure to develop calibration factors, which result in more successful results than obtained from HSM procedure
(Inman and Haas, 2012)	2012	Field Evaluation of a Restricted Crossing U-Turn Intersection	Report	MD	Safety/ Operation	To evaluate RCUT's safety and operations from a human factors perspective	Field study by video/ Statistical analysis	• The number and severity of conflicts at the conventional intersection suggests that the RCUT is a safer design • Induced weaving appears to be similar at RCUT and conventional intersections • both right-turn and U-turn acceleration lanes are a valuable part of the RCUT design and should be implemented in future RCUT deployments. • The RCUT design greatly reduces the probability of angle crashes at the cost of a minimal increase in travel time.

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Alluri, Saha, Liu, et al., 2014)	2014	Improved Processes for Meeting the Data Requirements for Implementing the Highway Safety Manual (HSM) and SafetyAnalyst in Florida	Report	FL	Safety/ SPFs/ CFs	To explore influential calibration variables for data collection and determine the minimum sample sizes to estimate reliable calibration factors.	Statistical analysis	• The minimum sample size of 30-50 sites with at least 100 crashes per year (HSM recommendation) is insufficient to achieve the desired accuracy of CFs. • A software program that converts the crash and roadway data for Florida's state roads to "import" files used by SafetyAnalyst was developed. • SPFs for unsignalized intersections were developed • For segments and intersections, crash predicting variables were ranked based on their influence • Sample size for CFs are recommended to be 50 and 80 for urban 3-legged signalized and urban 4-legged signalized intersections, respectively
(Maze et al., 2010)	2010	Median Intersection Design for Rural High-Speed Divided Highways APPENDIX B : Complete Literature Review	Report	-	Design/ Geometry/ Safety/ Operation	To present a comprehensive review on the RCUTs	Review	• Consideration of major and minor roadway traffic volumes as separate independent variables leads to better estimation of crash frequency in a SPF for intersection • Crash frequency is more sensitive to the minor roadway volume than the major roadway volume
(Alluri, Saha, and Gan, 2014)	2014	Minimum Sample Sizes for Estimating Reliable Highway Safety Manual (HSM) Calibration Factors	Paper	FL	Safety/ CFs	To estimate minimum sample size for deriving accurate CFs	Statistical analysis	• The HSM recommendation, 30-50 sites, is insufficient for accurate CFs • The generalized one-size-fits-all approach of using a sample size of 30 to 50 sites is not appropriate as different facility types • Different minimum number of sites and crashes depending on facility type are recommended to produce reliable CFs (~200 sites, 150 crashes approximately) • A major effort of HSM CF procedure is to collect data on missing variables (total of 36) for the entire road network statewide.
(Savo-lainen et al., 2015)	2015	Michigan Urban Trunkline Intersections Safety Performance Functions (SPFs) Development and Support	Report	MI	Safety/ SPFs	To develop state-specific SPFs for urban signalized and stop-controlled	Statistical analysis/ Statistical regression analysis	• Total sample size is comprised of 353 3ST, 350 4ST, 210 3SG, and 349 4SG, whereas 50 sites were used for region CFs on average. • Fatality and Incapacitating injury crashes are combined for analysis

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
						intersections along arterials		• Two types of SPF were produced: simple SPFs including only AADT (minor and major), complex SPFs including other variables in addition to AADTs • Google Earth was implemented to verify and assure/ control quality of the data
(National Highway Traffic Safety Administration (NHTSA), 2012)	2012	MMUCC Guideline: Model Minimum Uniform Crash Criteria	Report	-	Safety	To generate uniform crash database to aid in crash safety studies	Forming a guide	Creates guidelines for establishing a common type of crash database.
(J. Kim et al., 2015)	2015	Modeling Safety Performance Functions for Alabama's Urban and Suburban Arterials	Paper	AL	Safety/ CFs/SPFs	To develop CFs and SPFs for urban and suburban arterials	Statistical regression analysis/ Application of HSM	• The required sample sizes (ranging 130-600) for accurate CFs are significantly higher than HSM requirement (30-50) • It is found to be too difficult to apply directly the HSM process because of lack of data and different format of data • Sufficient sample size was evaluated based on HSM calibration study of Maryland DOT • AADT was found to be well fitted on the predictive models than log-transformed AADT in the Alabama
(Yang, Liu, Zhang, and Ragland, 2016)	2016	Multi-objective analysis of using U-turns as alternatives to direct left-turns at two-way stop-controlled intersections	Paper	-	Operation/ Environment/ Safety/ SPFs/ CMFs	To evaluate economic benefit of converting to a right turn followed by U-turn (RTUT) intersection	Microscopic simulation by VISSIM/ Application of HSM/ Statistical analysis	• The net present value associated with the RTUT treatment increased with an increase in the proportion of left-turn traffic from the major street • RTUTs are highly beneficial even for a single objective yet alone contributions in other aspects • It is recommended to install RTUT at the traditional intersections with a large proportion of left-turn traffic from the major street
(T. Kim et al., 2007)	2007	Operational and Safety Performance of a Nontraditional Intersection Design: The Superstreet	Paper	-	Operation/ Safety	To compare superstreets with conventional intersections	Microscopic simulation by VISSIM-SSAM/	• Superstreets are better alternative than comparable conventional intersection under high traffic volumes in terms of throughput, travel time, and delay • The superstreet design with one U-turn lane is safer than the comparable conventional design

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Haley et al., 2011)	2011	Operational Effects of Signalized Superstreets in North Carolina	Paper	NC	Operation	To determine the operational effects of the super- street treatment on existing signalized arterials	Microscopic simulation by VISSIM	• The superstreet outperformed the conventional design at each location studied and reduced the overall average travel time per vehicle traveling through the intersection. • The superstreet provided more capacity than what the conventional intersection could provide when it reached high demand levels • The more superstreet intersections that are back-to-back along a corridor, the better the progression will be relative to a conventional corridor.
(Hauer, 2001)	2001	Overdispersion in modelling accidents on road sections and in Empirical Bayes estimation	Paper	-	Safety	To examine the change introduced by modeling overdispersion per unit length of roadway	Statistical analysis	• The value of the overdispersion parameter is estimated along with all other unknown model parameters. • The use of same overdispersion regardless of roadway length may result in inconsistent estimations • Modelling overdispersion per unit length may increase the accuracy, but future study is needed to reach firm conclusions
(Hummer, Holzem, et al., 2014)	2014	Pedestrian and Bicycle Accommodations on Superstreets	Report	NC	Design/ Geometry/ Operation	To assess the challenges for pedestrians and bicyclists at RCUTs and recommend crossing alternatives	Microscopic simulation by VISSIM	• The two-stage Barnes Dance crossing produced the lowest values for average stopped delay, average number of stops, and average travel time for pedestrians when there is high volume of pedestrians. • A combination of the diagonal cross with the midblock cross is recommended if pedestrian volume is not high • The bicycle direct cross had the lowest average number of stops and the lowest average travel time for bicyclists
(Abdel-Aty et al., 2009)	2009	Reducing Fatalities and Severe Injuries on Florida ’ s High-Speed Multi-Lane Arterial Corridors	Report	FL	Safety	To examine the safety effects of the corridor level and intersection improvements made on multi-lane arterials by	Statistical analysis Statistical regression analysis	• Wide variations in terms of resultant safety benefits were observed following the corridor level improvement • Except resurfacing projects, improvements were observed to be effective in reducing total number of crashes as well as severe crashes. • FDOT was evaluated to be successful in selection of treatment sites and improving safety.

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
						before-after analysis		
(Donnell et al., 2016)	2016	Regionalized Safety Performance Functions	Report	PA	Safety/ SPFs	To develop state-specific regionalized SPFs	Statistical regression analysis	• Sample size used to estimate SPFs: Intersections, at least 50; segments, at least 30 miles per county per year; crashes at least 100 crashes per year in total. • District-level SPFs, with county adjustment factors, outperformed other regional or statewide models based on the predictive power of the models • Statewide models, with district-level adjustment factors, were recommended to account for geographic differences in the state when sufficient sample size to estimate regional SPFs is not available • Google Earth® satellite imagery was used to collect horizontal curve data.
(Ott et al., 2015)	2015	Resident, Commuter, and Business Perceptions of New Superstreets	Paper	NC	User perception	To evaluate residential, commuter, and business owner opinions and perception of superstreets	Survey	• Residents indicated that the RCUTs improve safety, but they perceive more travel time (ones near signalized RCUTs) and more stopped vehicles at the intersection. • Commuters perceived enhanced safety and more difficulty in navigating as well as savings in travel time and reductions in number of stopped vehicles. • Business owners/managers perceived negative impact due to RCUTs in business growth and operations as well as issues related to customer access and confusion problems • Improvements in traffic flow and safety were also noted.
(Hummer, Ray, et al., 2014)	2014	Restricted Crossing U-turn Informational Guide	Report	NC MO	Design/ Geometry/ Safety/ Planning and policy/ Construction / Economic	To provide information and guidance on RCUT intersections	Report/ Review	• RCUTs provide substantial decrease in conflict point which implies enhanced safety • Operation type of RCUTs is consistent with driver expectations in terms of lane change behavior while approaching to intersection • All types of crashes are significantly reduced by the RCUT implementation except side-swipe and rear-end

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
								• Side-swipe and rear-end crashes are reduced by a much lower rate or even slightly increased in some cases.
(Bared, 2009)	2009	Restricted Crossing U-Turn Intersection	Report	-	Design/ Geometry/ Operation/ Safety/	To provide a brief informational guide on RCUTs	Report/ Review	• RCUT intersections have 18 conflict points com- pared to 32 at conventional intersections. • The RCUT intersection appears to offer substantial safety advantages over conventional intersections.
(Liu et al., 2008)	2008	Safety effects of the separation distances between driveway exits and downstream U-turn locations	Paper	FL	Safety	To evaluate the effects of driveway on safety of downstream U-turns (RTUT)	Statistical regression analysis	• The longer the distance between driveway/minor road and U-turn (separation distance), the lower the number of crashes • At signalized intersections, longer separation distance is recommended, if U-turns are allowed.
(Ott et al., 2012)	2012	Safety effects of unsignalized superstreets in North Carolina	Paper	NC	Safety	To determine the safety effects of the unsignalized superstreets	Statistical analysis/ Application of HSM	• Superstreets are very effective in reducing crashes at unsignalized intersections on rural divided four-lane arterials • RCUTs are appropriate at locations where low-volume, two-lane roads intersect high-volume, divided, four-lane arterials • Use of the comparison group, C-G method to analyze the safety of superstreets is recommended as Regression-to-mean did not have an important impact on the results • If demand for minor street left-turn and through movements is high, superstreets may not be the optimum design choice.

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Russo et al., 2016)	2016	Safety performance functions for crash severity on undivided rural roads	Paper	Italy	Safety	To develop and calibrate SPFs predicting the frequency per year of injuries and fatalities on homogeneous road segments	Statistical regression analysis/ Application of HSM	• AADT, lane width, curvature change rate, length, and vertical grade are important variables in explaining the severity of crashes • CF is found to be greater in the HSM procedure than the SPFs calculated in the study.
(Srinivasan and Bauer, 2013)	2013	Safety Performance Function Development Guide: Developing Jurisdiction-Specific SPFs	Report	-	Safety/ SPFs	To create a guide that covers developing jurisdiction-specific SPFs	Report/ Review/ Forming a guide/ Statistical analysis	A comprehensive step-by-step guide that helps understanding and developing SPFs.
(Srinivasan et al., 2013)	2013	Safety Performance Function Decision Guide: SPF Calibration versus SPF Development	Report	NC	Safety/ SPFs/ CFs	To provide a guide on selection of developing SPFs or calibrating available SPFs by CFs	Forming a guide	• Provide a guide on how to develop SPFs and CFs • Provide a guide on when and how to select whether developing a new SPF or calculating CFs to calibrate already available SPFs.
(Hummer et al., 2010)	2010	Superstreet Benefits and Capacities	Report	NC	Operation/ Safety/ User perception	To evaluate operational, safety, and perceived effects of superstreets and develop an approach to estimate level of service	Microscopic simulation by VISSIM-SSAM/ Statistical analysis/ Survey	• A significant reduction in total, angle and right turn, and left-turn collisions at unsignalized superstreets • A significant reduction in fatal and injury collisions was observed • At various volumes, the superstreet outperformed the conventional intersection in terms of average travel time • Residents have positive perception of RCUTs • Commuters have positive to moderate perception of RCUTs • Business owners/managers have negative perception of RCUTs

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
(Mississippi Department of Transportation (MDOT), 2010)	2010	Synthesis of J-Turn Design Standards And Criteria	Report	MS	Design/ Geometry/ Safety/ Economic	To provide guidelines for J-Turn implementation	Review/ Report/ Forming a guide	• For J-Turns the recommended design speed is 65 mph • The typical maximum superelevation rate is 10% • A clear zone distance of 30 ft is recommended • Median widths greater than or equal to 64 ft are recommended • Pedestrian crossings at a J-Turn intersection are discouraged
(Edara et al., 2016)	2016	System-wide Safety Treatments and Design Guidance for J-Turns	Report	MO	Design/ Operation/ Safety/ Economic	To synthesize the literature and state of the practice to assess effectiveness of RCUTs and to provide guidance on J-Turn design	Review/ Report/ Forming a guide/ Microscopic simulation by VISSIM-SSAM	• Most of the major road sideswipe and rear-end crashes occurred while vehicles were merging with traffic or changing lanes to enter the U-turn. • Higher speed differentials between merging and major road vehicles and driver inattention were common factors in most crashes that occurred at the J-turn facilities. • Sideswipe and rear-end crashes decreased with an increase in the spacing between the minor road and the U-turn. • J-turns with a spacing of 1,500 ft or greater experienced the lowest crash rates
(Hummer et al., 2012)	2012	Taking advantage of the flexibility offered by unconventional arterial designs	Paper	NC	Operation	To evaluate ability of alternative intersections to maintain highway service for major road while accommodating site traffic	Report/ Review	• Superstreets work well when major road traffic volume is twice as large or larger than the traffic volume of minor road • Flexibility of superstreets create room for deviations from typical superstreet design
(Hummer and Reid, 2000)	2000	Unconventional left-turn alternatives for urban and suburban arterials - An Update	Paper	-	Operation	to review five unconventional intersection alternatives	Review	Superstreets: • Impose fewer threats on crossing pedestrians • Reduce and separated conflict points • Confuse drivers and pedestrians • Increase delay, stops, and travel distance for crossing minor road traffic Superstreets, for through arterial traffic :

Author(s)	Dt	Title	Ty	St	Subject	Focus	Methods	Key Finding(s)
								- Reduce delay - Reduce stops - Provide “Perfect” two-way progression at all times with any signal spacing
(Lu, Liu, and Lu, 2009)	2009	Understanding Factors Affecting Safety Effects of Indirect Driveway Left-Turn Treatments	Paper	FL	Safety	To identify and quantify the impacts of the factors that affect the safety of right turns followed by U-turns (RTUT)	Statistical regression analysis	- U-turn crashes only account for a very small percentage of RTUT crashes - U-turn crashes occur very infrequently at median openings and signalized intersections - Majority of crashes related with RTUT occur at the section between driveways and downstream U-turn locations - The major street ADT, the location of U-turn deceleration lane, and the separation distances between driveway exits and downstream U-turn locations are the most important factors affecting RTUT safety

Appendix B. Copy of the Questionnaire Used to Collect the Data

May 8th, 2017

ATTN: XXX Contact Person / Title
XXX Department of Transportation
XXX Department of Transportation Address

Subject: Survey for the "Development of Safety Performance Functions for Restricted Crossing U-Turn (RCUT) Intersections" project funded by Florida Department of Transportation - BDV30 TWO 977-19.

Dear XXX,
Florida A&M University-Florida State University College of Engineering is conducting a survey for the Florida Department of Transportation (FDOT) as part of the "Development of Safety Performance Functions for Restricted Crossing U-Turn (RCUT) Intersections" project (Project Manager: Mr. Alan El-Urfali, FDOT Traffic Operations Office). Your agency has been identified as an important contributor to this project, and your cooperation in completing this survey will ensure the success of this effort. Please note that the results of this survey and findings of the study will be shared with you and your agency.

This survey is intended to gather information on the RCUT implementations (also referred to as J-Turns, superstreets, reduced conflict intersections, and synchronized street intersections) in your state. As defined by the Federal Highway Administration, the RCUT is characterized by the prohibition of left-turn and through movements from side street approaches as permitted in conventional designs. ***Please see the Appendix on Page 12 for more information on RCUTs***.

This questionnaire has a total of 17 questions; however, it is possible that far fewer will require answers since each individual's responses will vary. You will be asked to kindly complete these questions based on your agency' experience with the RCUT intersections. You will also be asked to provide information on the availability and access of geometric, traffic and crash data for the RCUT intersections in your states. The research team will also collect these data from the states that already have RCUT implementations.

If you are not the appropriate person within your office or department to complete this survey, please forward it to the correct person, or provide us with the contact information for this person. If you know other people who can contribute (such as local transportation agencies – city, county and MPO representatives), please pass this survey onto others who could add value to this effort.

Please send your responses to Eren Erman Ozguven electronically by 05/26/2017 at:
E-mail: eozguven@fsu.edu
Phone: (850) 410-6146 (Office), (908) 239-0116 (Cell)
Address:
Assistant Professor of Civil and Environmental Engineering,
FAMU-FSU College of Engineering,
2525 Pottsdamer Street,
Tallahassee, FL, 32310.

If you prefer to mail your answers to the survey questions, you may use the above address. Please also note that the research team may follow up with a phone call to address any questions agencies may have and confirm point of contact. Please note again that the results of this survey and findings of the study will be shared with you and your agency.

Thank you for your time and participation.
If you have any questions, please feel free to contact the principal investigator (Eren Erman Ozguven) at (850) 410-6146 or eozguven@fsu.edu, or alternatively, the project manager (Alan El-Urfali) at (850) 410-5416 or alan.el-urfali@dot.state.fl.us.

Sincerely Yours,

Eren Erman Ozguven, Ph.D.
Assistant Professor,
Department of Civil and Environmental Engineering
FAMU-FSU College of Engineering
2525 Pottsdamer Street, Room B313,
Tallahassee, FL 32310
Email: eozguven@fsu.edu,
Phone: (850) 410-6146

Florida Department of Transportation
RCUTs Project (BDV30 TWO 977-19) Expert Survey

<u>Part 1: Contact Information</u>

Q1. Please identify yourself:

Name	
Agency	
Department/Office	
Title	
Address	
Telephone	
E-mail	
Website	

Q2. What category best describes the main function of your office? Please feel free to mark two choices as needed.

[ ]	Construction
[ ]	Design
[ ]	Maintenance
[ ]	Planning and Development
[ ]	Safety
[ ]	Traffic Operations
[ ]	Transportation Statistics
[ ]	Research
[ ]	Other (please specify):

<u>Part 2: RCUT Intersections in Your State</u>

Q3. Does your state have RCUT intersections, whether they are under the state DOT jurisdiction or not? If your answer is no, you do not have to fill the table, please proceed with Question 14.

[ ]	No
[ ]	Yes: Please fill in the table below (Add more rows if necessary).

Intersection (Major and minor street)	**Location (City, State)**	**Type (Signal, Stop or Merge)**	**Year Built**	**Urban or Rural?**

Q4. The research team would also like to gather some data for these RCUT locations. Can you provide information on how to gather these data (offline or online availability, shapefiles)?

Data Availability

The following three data sets are <u>definitely</u> needed and therefore critical to gather in order to create the safety performance functions:

- ***Crash data (5 years before and after the implementation – if possible, more than 5 year data after the implementation)***
- ***Traffic data (AADT) – same years with the crash data, both before and after the implementation***
- ***Geometric data (merging and transition lengths, median and shoulder widths, number of lanes for both directions, etc.)***

The following two data sets would also be very helpful, but not critical for the creation of the safety performance functions:

- ***Signal timing data (for signalized RCUTs only)***
- ***Construction, operation and maintenance costs***

Part 3: General Perspectives and Planning

Q5. Based on your experience with the RCUTs, what are the most important geometric design parameters that should be considered while designing a new RCUT (lengths of merging/offset/transition, median and shoulder widths, number of lanes, etc.)? How did these parameters affect the operations after the construction?

Q6. In your state, what is the ratio of the minor roadway traffic volume over the total intersection volume (or major roadway traffic volume) for the selected RCUT locations?

Q7. Have you performed a benefit-cost (BC) analysis for the RCUTs? If yes, what types of safety benefits have you assessed (crash frequency and severity reduction, etc.) What was the result of the before and after BC analysis?

Part 4: Traffic Safety and Operations

Q8. What are the types of crashes RCUTs have reduced? Are there any type of crashes that occurred more than before the implementation?

Q9. How are pedestrians and bicyclists affected from the RCUT design based on your experience with the RCUTs in your state, in terms of traffic safety, signalization, operations and others?

Q10. Have you utilized the micro-simulation models prior to the RCUT implementation (i.e., a micro-simulation model for the intersection that can identify the traffic conflict points)? If yes, which software and what significant results have you obtained?

Q11. Are you relying on the CMFs (such as those listed in the FHWA CMF Clearinghouse) for the RCUTs? If yes, what do you think about the usability of the CMFs for your current RCUT intersections?

Q12. Have you created regression equations (safety performance functions – SPFs) for state use only? Based on your experience, what should be the most important factors that should be used to create the SPFs for RCUTs?

Q13. How did the residents and businesses perceive the new RCUT design and operations? Please provide information on both negative and positive perceptions.

<u>Part 5: Prospective RCUT Implementations in Your State</u>

Q14. Do you have any ongoing or planned deployment of RCUTs in your state?

[ ]	No
[ ]	Yes (please specify the locations and types):

Q15. In terms of planning and policy making, what is the reasoning behind the selection of RCUTs among other alternatives for future improvement?

Q16. Are there any other RCUT intersections in your state not under the jurisdiction of the Department of Transportation? If yes, can you provide the RCUT location and a contact person that can provide more information on that RCUT?

Q17. Are there other experts (such as city, county or MPO officials) you think it would be helpful for us to send this survey?

Name/Title:

Organization/Mail address:

E-mail address/Phone:

Name/Title:

Organization/Mail address:

E-mail address/Phone:

Name/Title:

Organization/Mail address:

E-mail address/Phone:

Name/Title:

Organization/Mail address:

E-mail address/Phone:

End of Survey

The survey is now complete. Thank you for your willingness to participate in this survey for our Florida Department of Transportation-funded project. Your response is very important to us.

Please send your responses to Eren Erman Ozguven electronically by 05/26/2017 at:
E-mail: eozguven@fsu.edu
Phone: (850) 410-6146 (Office), (908) 239-0116 (Cell)
Address:
Assistant Professor of Civil and Environmental Engineering,
FAMU-FSU College of Engineering,
2525 Pottsdamer Street,
Tallahassee, FL, 32310.

If you prefer to mail your answers to the survey questions, you may use the above address. Please note that the results of this survey and findings of the study will be shared with you and your agency.

Please also note that the research team may follow up with a phone call to address any questions agencies may have and confirm point of contact.

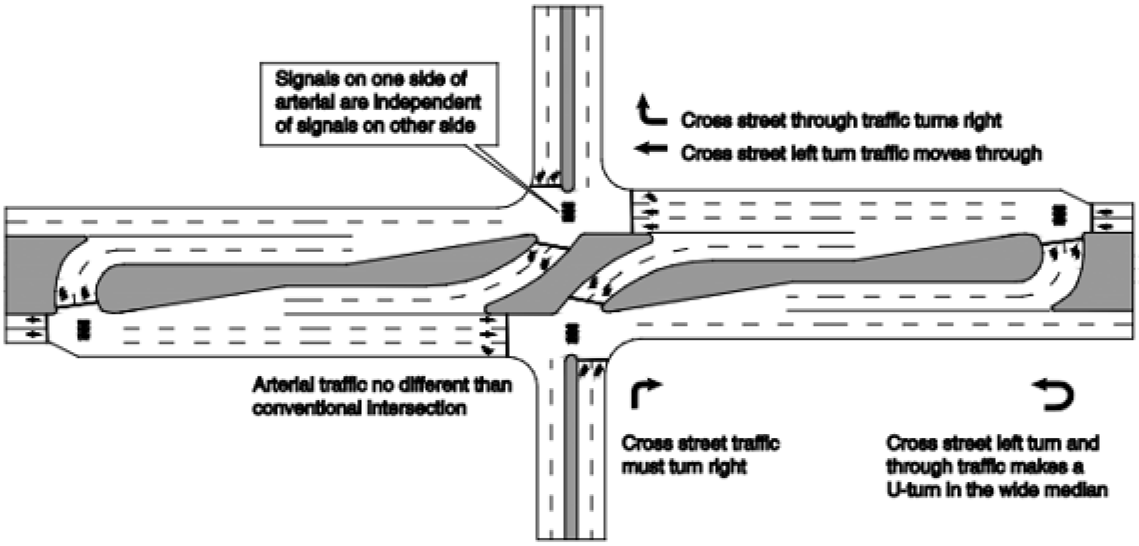
Survey Appendix

Project Background

Conventional intersection designs are known to be problematic and unreliable while handling the complexity associated with the heavy traffic volume and travel demand on today's roadways. Therefore, transportation agencies have been searching for more innovative and safer intersection design solutions in order to address these complex problems. One such alternative intersection design is the restricted crossing U-turn (RCUT) intersections. As defined by the Federal Highway Administration, the RCUT, also referred to as the superstreet intersection or J-turn intersection, is characterized by the prohibition of left-turn and through movements from side street approaches as permitted in conventional designs. Instead, the RCUT intersection accommodates these movements by requiring drivers to turn right onto the main road and then make a U-turn maneuver at a one-way median opening after the intersection. Left-turns from the main road approaches are executed in a manner similar to left-turns at conventional intersections and are unchanged in this design. Left-turn movements from the major road could also be removed at primarily rural unsignalized RCUT designs. RCUTs have been constructed in several States following the introduction of the concept in the early 1980s.

Following figures illustrate the three types of RCUT intersections: signalized, stop controlled and with merges.

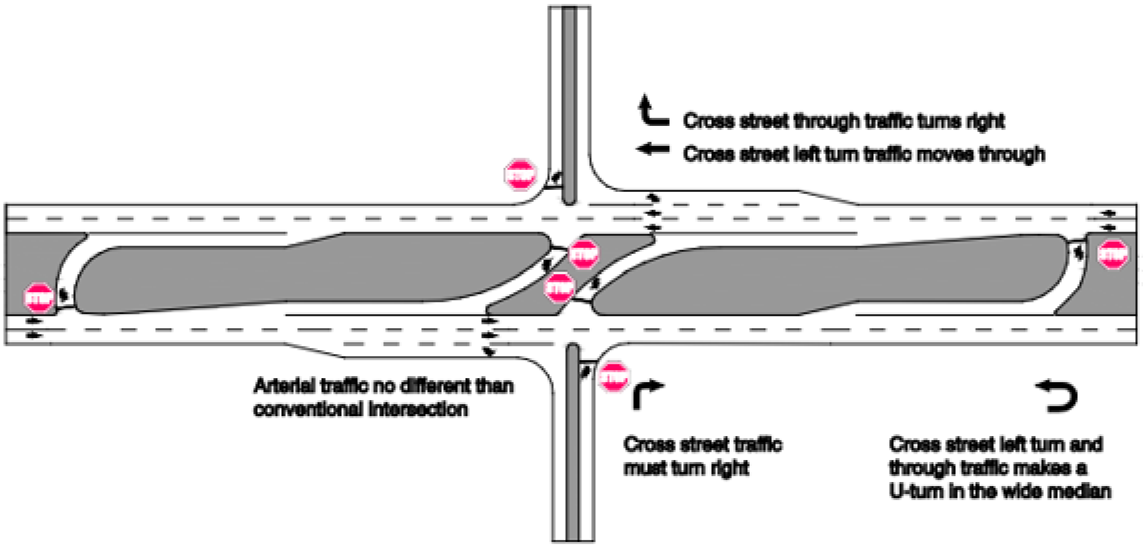
A Signalized RCUT intersection



Schematic diagram of a signalized RCUT intersection

Signalized RCUT intersection in operation near San Antonio, TX showing a pedestrian "Z" crossing.

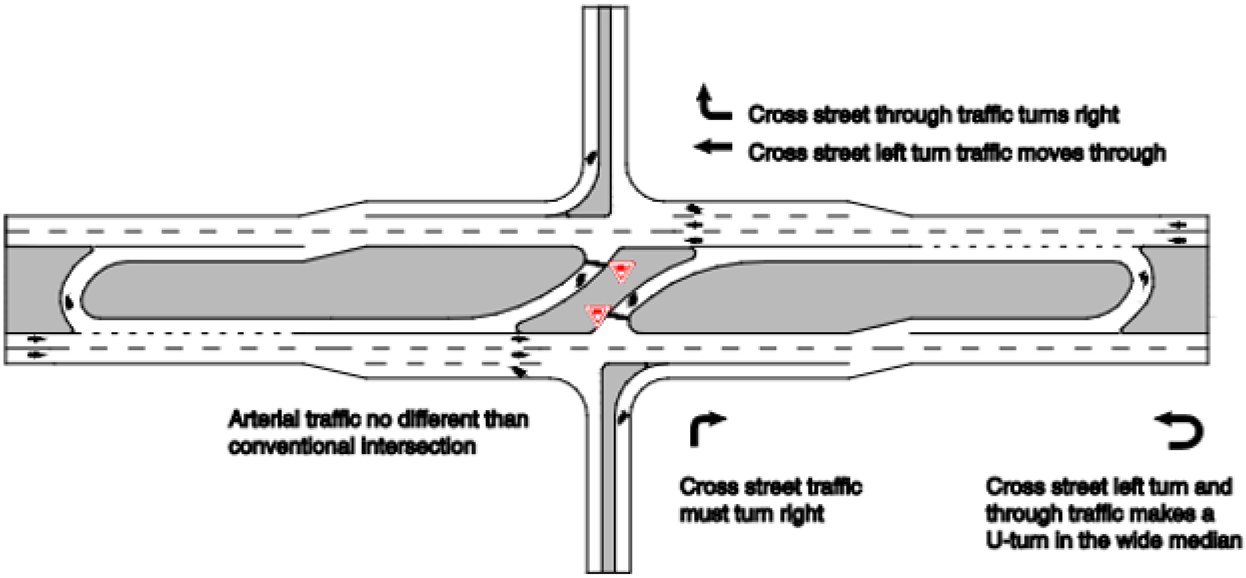
A Stop-controlled RCUT intersection



Schematic diagram of a stop-controlled RCUT intersection

Stop-controlled RCUT intersection on US-1 near Southern Pines, NC.

A RCUT intersection with merges



Schematic diagram of a RCUT intersection with merges

Merge-controlled RCUT intersection on US-15 in Emmitsburg, MD.

Appendix C. List of RCUTs as Provided by FHWA in 2014

State	Intersection	Location	Type	Built
Alabama	Plum Road & US 231	Dothan, AL	Signal	2009
Alabama	Retail Drive & US 231	Dothan, AL	Signal	2009
Alabama	Northwest of Plum Road & US 231	Dothan, AL	Stop	2009
Alabama	Rock Bridge Road & US 231	Dothan, AL	Stop	2009
Alabama	Buyers Drive & US 231	Dothan, AL	Stop	2009
Louisiana	Veterans Boulevard Corridor	Kenner, LA	Stop or Merge	2005
Louisiana	US 61 & Leblanc's Food Store	Gonzales, LA	Stop or Merge	2007
Louisiana	LA-8/LA-28 & LA-117	Leesville, LA	Stop or merge	2011
Louisiana	Loyola Drive & 31st Street	Kenner, LA	Stop or Merge	
Maryland	US-15 north of Frederick	Maryland	Merge	
Maryland	US-301 west of Delaware	Maryland	Merge	
Michigan	Big Beaver & Lakeview Drive	Troy, MI	Signal	1990s
Michigan	Long Lake & Corporate/Investment Drive	Troy, MI	Signal	1990s
Minnesota	County Road 24	Willmar, MN	Stop	
Minnesota	US 169 & County Road 3	Belle Plaine, MN	Stop	
Minnesota	Highway 36 and Keats Avenue	Lake Elmo, MN	Merge	
Minnesota	US 10 and County Road 8	Becker, MN	Stop	
Minnesota	US 169 and 173rd Street	Jordan, MN	Stop	
Minnesota	US 212 and Highway 284	Cologne, MN	Stop	
Minnesota	Highway 65 and 169th Avenue	Ham Lake, MN	Stop	
Minnesota	US 53 and County Road 52	Cotton, MN	Stop	
Minnesota	US 52 and County Road 66	Vermillion, MN	Stop	2014
Minnesota	US 169 and Highway 22	St. Peter, MN	Stop	2014
Minnesota	US 169 and St. Julien Street	St. Peter, MN	Stop	2014
Missouri	US-63 at Deer Park Road	Jefferson City, MO	Stop	
Missouri	US-54 at Honey Creek Road	Jefferson City, MO	Stop	
Missouri	US-54 at Route-E	Jefferson City, MO	Stop	
Missouri	MO-13 at Old MO-13	Jefferson City, MO	Stop	
Missouri	Route-M at Lemay Ferry Road	Jefferson City, MO	Stop	
North Carolina	US 17 & Lanvale Road	Leland, NC	Signal	2007
North Carolina	US 17 & Brunswick Forest Parkway	Leland, NC	Signal	2007
North Carolina	US 17 & Grandiflora Drive/Gate Drive	Leland, NC	Signal	2007

North Carolina	US 17 & Gregory Road	Leland, NC	Signal	2007
North Carolina	US 17 & Waterford Way/Ploof Road	Leland, NC	Signal	2007
North Carolina	US 17 & Hospital Drive	Supply, NC	Signal	
North Carolina	US 17 & Old Ocean Highway	Supply, NC	Signal	
North Carolina	US 17 & Medical Center Drive	Supply, NC	Stop	
North Carolina	US 17 & Mt Pisgah Road	Supply, NC	Stop	
North Carolina	Carolina Beach Road (US 421) & Retail Center	Wilmington, NC	Signal	
North Carolina	US 15/501	Chapel Hill, NC	Signal	
North Carolina	NC 55 & West Holly Springs Road	Holly Springs, NC	Signal	2013
North Carolina	NC 55 & Green Oaks Parkway	Holly Springs, NC	Signal	2013
North Carolina	NC 55 & New Hill Road	Holly Springs, NC	Signal	2013
Ohio	Ohio 4 & Symmes Road	Hamilton, OH	Signal	
Ohio	Ohio 4 & Tylersville Road	Hamilton, OH	Signal	
Ohio	Ohio 4 & Hamilton Mason Road	Hamilton, OH	Signal	
Texas	US-281 & Evans Road	San Antonio, TX	Signal	2010
Texas	Stone Oak Parkway/TPC Parkway	San Antonio, TX	Signal	2010
Texas	North Northwind Drive/Marshall Road	San Antonio, TX	Signal	2011
Texas	Loop-1604 & New Guilbeau/Shaenfield	San Antonio, TX	Signal	2011
Texas	TX-71 at FM-973/Fallwell Lane	Austin, TX	Signal	2014

Appendix D. List of RCUTs as Provided in This Project

State	Location	Location	Type	Built
Alabama	US-72 & Capital Park at 72 West	Huntsville	Signal	1990
Alabama	Carl T. Jones Drive @ Valley Bend	Huntsville	Signal	2000
Alabama	US-231 & Plum Road	Dothan	Signal	2009
Alabama	US-231 & Retail Drive	Dothan	Signal	2009
Alabama	US-231 & Hospitality Lane	Dothan	Stop	2009
Alabama	US-231 & Rock Bridge Road	Dothan	Stop	2009
Alabama	US-231 & Buyers Drive	Dothan	Stop	2010
Alabama	US-82 & SR-219	Centreville	Stop	2017
Alabama	US-280 & Meadow Lake Dr.	Birmingham	Stop	
Alabama	US-280 & Resource Center Pkwy	Birmingham	Stop	
Alabama	US-280 & Brook Manor Dr.	Birmingham	Signal	2014
Alabama	SR-182 @ Cotton Bayou Boat Launch	Orange Beach	Signal	2017
Georgia	SR 1/US 27 @ Kierbow Rd	Bremen	Stop	2016
Georgia	SR 20 @ Simpson Mill Rd	McDonough	Stop	2015
Georgia	SR 3/US 19 @ Lucky St	Griffin	Stop	2016
Georgia	SR 92 @ N Griffin Square Shopping Center	Griffin	Stop	2016
Georgia	SR 74 @ Sandy Creek Rd	Tyrone	Merge	2016
Georgia	SR 7/US 41 @ Grove St	Barnesville	Stop	2016
Georgia	SR 57 @ Ridge Rd/Henderson Rd	Macon	Stop	2017
Georgia	SR 96 @ Houston County High School	Warner Robins	Merge	2016
Georgia	SR 243/Fall Line Freeway @ College St	Gordon	Stop	2013
Georgia	SR 10/Thomson Bypass @ Morgan-Watson Rd	Thomson	Stop	2011
Georgia	SR 10/US 78 @ Glenn Club Dr./Sharp Trail SW	Stone Mountain	Merge	2009
Georgia	SR 10/US 78 @ Stone Dr. SW	Stone Mountain	Stop	2009
Georgia	SR 10/US 78 @ Lake Lucerne Dr. SW	Stone Mountain	Stop	2009
Georgia	SR 10/US 78 @ Jessica Daron Ct	Stone Mountain	Stop	2009
Georgia	SR 10/US 78 @ Paxton Ln	Snellville	Stop	2009
Georgia	SR 10/US 78 @ Killian Hill Village Shopping Center	Snellville	Stop	2012
Georgia	SR 10/US 78 @ VW Dealership Driveway	Snellville	Stop	2009
Georgia	SR 10/US 78 @ Georgia Ln	Snellville	Stop	2009
Georgia	SR 10/US 78 @ Britt Dr.	Snellville	Merge	2009
Georgia	SR 3/US 41/Tara Blvd @ N Main St	Jonesboro	Merge	1999
Georgia	SR 3/US 41/Tara Blvd @ Valley Hill Rd SE	Jonesboro	Stop	1999
Georgia	SR 144 @ Richmond Way/Carter St	Richmond Hill	Stop	2008
Georgia	SR 204 @ Lewis St	Savannah	Stop	2005

Illinois	US 67 & 200/Harlem Avenue	Monmouth	Stop	2007
Indiana	US 41 & State Road 114	Morocco	Stop	2015
Indiana	US 231 & State Road 62 (south junction, Washington Street)	Dale	Stop	2016
Indiana	US 231 & State Road 68 (SR 62 north junction, Medcalf Street)	Dale	Stop	2016
Louisiana	Veterans Boulevard Corridor	Kenner	Stop	2005
Louisiana	US-61 & Shopping mall entrance (600 feet southwest of E. Cornerview St.)	Gonzales	Stop	
Louisiana	LA-8/LA-28 & LA-117 at Kurthwood Rd.	Leesville	Stop	
Louisiana	Loyola Dr. & 31st Street	Kenner	Stop	
Louisiana	US 90 & N. Girouad St.	Lafayette	Stop	
Maryland	MD 3 & Waugh Chapel Rd., Odenton	Anne Arundel	Signal	2011
Maryland	US 15 & Hayward Rd.	Frederick	Stop	
Maryland	US 15 & Willow Rd.	Frederick	Stop	
Maryland	US 15 & Biggs Ford Rd.	Frederick	Stop	
Maryland	US 15 & Sundays Ln.	Frederick	Stop	
Maryland	US 15 & College Ln.	Emmitsburg	Stop	
Maryland	US 15 & Old Frederick Rd.	Emmitsburg	Stop	
Maryland	US 301 & Main St.	Queenstown	Stop	
Maryland	US 301 & Del Rhodes Ave.	Queenstown	Stop	
Maryland	US 301 & Ruthsburg Rd.	Centreville	Stop	
Maryland	US 301 & Sudlersville Rd.	Sudlersville	Stop	
Maryland	US 301 & McGinnes Rd.	Millington	Stop	
Maryland	US 301 & Galena Rd.	Galena	Stop	
Maryland	MD 228 & Bunker Hill Rd	Waldorf	Stop	
Maryland	MD 5 & Sandstone St., Waldorf	Waldorf	Stop	
Michigan	Michigan Ave at Clippert St	Lansing	Stop	
Michigan	Big beaver and Lake drive	Troy	Signal	1990
Michigan	Long Lake and Corporate drive	Troy	Signal	1990
Minnesota	Old Highway 71 and County Road 24	Willmar	Stop	2010
Minnesota	US 53 and CSAH 52	Cotton	Stop	2012
Minnesota	US 212 and MNTH 284/CSAH 53	Cologne	Stop	2012
Minnesota	MNTH 65 and 169th Avenue	Ham Lake	Stop	2012
Minnesota	US 52 and CSAH 66	Vermillion	Stop	2014
Minnesota	MNTH 36 and Demontreville Trail	Lake Elmo	Stop	2013
Minnesota	US 169 and Julien Street	St Peter	Stop	2014
Minnesota	US 169 and Dodd Street	St Peter	Stop	2014
Minnesota	US 14 and CSAH 17	Eagle Lake	Stop	2016
Minnesota	US 61 and Gilmore Street	Winona	Stop	2016
Minnesota	MNTH 23 and Saratoga Street	Marshall	Stop	2016

Minnesota	MNTH 371 (two locations)	Pequot Lakes	Stop	2016
Mississippi	US Highway 98 at Old Highway 63 North	Lucedale	Merge	2012
Mississippi	US 84 at Ferguson Mill Road	Monticello	Merge	2013
Mississippi	US Highway 84 at State Route 184/Magnolia Road	Cleo Community	Merge	2013
Mississippi	US Highway 45 at Clarke County Road 212	Shubuta	Merge	2014
Mississippi	US Highway 84 at State Route 35	Lone Star Community	Merge	2016
Mississippi	State Route 67 at Big John Road	D’Iberville	Merge	2015
Mississippi	State Route 67 at Tradition Parkway	Tradition	Merge	2016
Mississippi	US Highway 45 at Tarlton Road	Crawford	Merge	2017
Missouri	US 63 and Rt M	Macon County	Stop	2014
Missouri	US 63 and Rt B	Randolph County	Stop	2014
Missouri	US 50 and MO 58	Johnson County	Stop	2014
Missouri	MO 30 before and after Upper Byrnes Mills	Jefferson County	Stop	2012
Missouri	US 54 and Heritage Hwy/Buffalo Road	Cole County	Stop	2012
Missouri	US 54 and Honey Creek	Cole County	Stop	2011
Missouri	US 54 and Route E	Cole County	Stop	2011
Missouri	US 54 and Route CC	Cole County	Stop	2012
Missouri	US 63 and Hinton/Calvert Hill	Boone County	Stop	2014
Missouri	US 63 and Route AB	Boone County	Stop	2012
Missouri	US 63 and Bonne Femme	Boone County	Stop	2012
Missouri	US 63 and Liberty/Peterson Ln	Boone County	Stop	2014
Missouri	MO 13 and Old MO 13/CRD 364	St. Clair County	Stop	2009
Missouri	US 65 @ Rochester	Taney County	Stop	2012
Missouri	US 65 @ County Rd 65	Dallas County	Stop	2009
Missouri	US 65 @ MO 38/MO TT	Dallas County	Stop	2009
Missouri	US 65 @ MO 215	Dallas County	Stop	2009
Missouri	US 65 @ RT AA	Dallas County	Stop	2009
Missouri	Rt M by Old Lemay Ferry Rd	Jefferson County	Stop	2007
North Carolina	US 70 at Cannon Blvd - Intersection 1	Carteret	Stop	2007
North Carolina	US 70 at western intersection with SR 1247 (Chatham St)	Carteret	Stop	2009
North Carolina	US 70 at SR 2362 (Triplett Road)	Iredell	Stop	2011
North Carolina	US 70 at SR 1731 (Piney Grove Rd)	Wayne	Stop	2003
North Carolina	US 52 Byp at SR 1772 (Old Buck Shoals Rd)	Surry	Stop	2009
North Carolina	SR 4315 (South Main St) at Century Park Blvd *SEE NOTE	Forsyth	Stop	2000
North Carolina	US 74 Byp at Crossover 0.77 miles east of NC 226/Earl Rd	Cleveland	Stop	2003
North Carolina	SR 3466 (West Millbrook Rd) at Davis Circle	Wake	Stop	2008
North Carolina	SR 3100 (Brier Creek Pkwy) and Skyland Ridge Pkwy	Wake	Stop	2008
North Carolina	US 1 at Tramway Crossing Shopping Center	Lee	Stop	2012

North Carolina	US 70 near Holiday Inn - SS 02-00-208,9 Location 2	Craven	Stop	2001
North Carolina	US 70 at Grantham Rd - Treatment 1	Craven	Stop	2008
North Carolina	SR 1223 (Dickerson Blvd) at Monroe Mall - Intersection 1	Union	Stop	2002
North Carolina	US 70 at the Newport River Shoppes - Intersection 1	Carteret	Stop	2007
North Carolina	US 23-74 at Balsam Rest Area - SS 14-97-018 Location 4	Haywood	Stop	2001
North Carolina	US 70 at SR 1291 (Bayberry St) - Intersection 2	Carteret	Stop	2007
North Carolina	US 70 near El Cerro Grande Restaurant - SS 02-00-208,9 Location 1	Craven	Stop	2001
North Carolina	SR 2911 (New Bern Ave) at Lord Ashley Rd - Intersection 1	Wake	Stop	2004
North Carolina	SR 2911 (New Bern Ave) at Lord Berkley Rd - Intersection 2	Wake	Stop	2004
North Carolina	US 70 (E. Main St) at Webb Blvd - Intersection 2	Craven	Stop	2007
North Carolina	US 23-74 at SR 1527 (Steeple Dr)/SR 1449 (Cope Creek Rd)	Jackson	Stop	1998
North Carolina	US 70 (E. Main St) at Shepard St - Intersection 4	Craven	Stop	2007
North Carolina	SR 3073 (NW Maynard Rd) at Waterford Center/Maynard Crossing	Wake	Stop	2005
North Carolina	SR 3109 (Brier Creek Pkwy) at Little Brier Creek Ln/Arco Corporate Dr	Wake	Stop	2006
North Carolina	US 70 near Stratford Rd - SS 02-00-208,9 Location 3	Craven	Stop	2001
North Carolina	NC 132 (College Road) at Greenbriar Rd/United Advent Ch - W-5104 Location 4	New Hanover	Stop	2011
North Carolina	NC 132 (College Road) at Hidden Valley Rd - W-5104 Location 5	New Hanover	Stop	2011
North Carolina	NC 132 (College Road) at Wedgefield Dr/Abaco Ln - W-5104 Location 6	New Hanover	Stop	2011
North Carolina	NC 132 (College Road) at Wickslow Dr - W-5104 Location 20	New Hanover	Stop	2011
North Carolina	NC 132 (College Road) at Greenhowe Dr Location 22	New Hanover	Stop	2011
North Carolina	US 17 at Parkwood Dr/Western Shopping Plaza	Onslow	Stop	1998
North Carolina	US 29-70/I-85 Bus at SR 1774 (Mendenhall St)	Davidson	Stop	2002
North Carolina	US 74 @ SR 2090, Location 1	Cleveland	Stop	2011
North Carolina	NC 24 (W.T. Harris Blvd) at SR 2458 (David Cox Rd)	Mecklenburg	Stop	2005
North Carolina	US 29 (N. Tryon St) at Grove Lake Dr	Mecklenburg	Stop	2004
North Carolina	US 521 (Johnston Rd) at SR 3635 (Marvin Rd)	Mecklenburg	Stop	2008
North Carolina	US 70 near Earthworks Garden Center - SS 02-00-208,9 Location 4	Craven	Stop	2001
North Carolina	US 74 at SR 1152 / SR 1319 (Old Wire Rd)	Scotland	Stop	2007
North Carolina	US 321 (Hickory Blvd) at SR 1796 (Victoria Ct)/Clover Dr	Caldwell	Stop	2001
North Carolina	US 23-74 at SR 1158/SR 1243 (Old Balsam Rd) - SS 14-97-018 Location 8	Haywood	Stop	2001
North Carolina	US 64 at Shepherds Vineyard Dr	Wake	Stop	2012
North Carolina	US 17 (Ocean Highway) and the entrance to Brunswick Community Hospital.	Brunswick	Stop	2012
North Carolina	US 29 and SR 1432 (Concord Farms Road) in Concord.	Cabarrus	Stop	2012
North Carolina	NC 24 and SR 1230 (Haw Branch Rd)	Onslow	Stop	2007
North Carolina	NC 87 at SR 2235/SR 2261 (Grays Creek Ch Rd/Alderman Rd) - Intersection 1	Cumberland	Stop	2009
North Carolina	US 23/441 @ NC 116/ SR 1368	Jackson	Stop	2004
North Carolina	US 64 at SR 1163 (Kelly Rd)	Wake	Stop	2002
North Carolina	US-17 / NC-210 at SR 1561 (Sloop Point Rd) / SR 1726 (Machine Gun Rd)	Pender	Stop	2012

North Carolina	US 17 (Ocean Blvd) at SR 1130 (Mt. Pisgah Rd)	Brunswick	Stop	2008
North Carolina	US 64 Business at SR 2234/SR 2500 (Marks Creek Rd)	Wake	Stop	2001
North Carolina	US 70 (Arendell St) at SR 1149 (Sam Garner Rd)	Carteret	Stop	2005
North Carolina	US 321 (Blowing Rock Blvd) at NC 268/SR 1346 (Warrior Rd)	Caldwell	Stop	2011
North Carolina	US 17 and SR 1184 (Ocean Isle Beach Rd)	Brunswick	Stop	2008
North Carolina	US 74-76 (Andrew Jackson Hwy) at SR 1800 (Bolton)	Columbus	Stop	2006
North Carolina	US 17 at SR 1221 (Rocky Run Rd)/Pirates Rd	Craven	Stop	2010
North Carolina	US 74 at SR 1321 (Elmore Rd/Laurel Hill Church Rd)	Scotland	Stop	2008
North Carolina	US 401 at SR 1409 (Lake Park Rd) and SR 1303 (Scull Rd)	Hoke	Stop	2008
North Carolina	US 276 at SR 1394 (Hall Dr)/Russell Cove Rd	Haywood	Stop	2010
North Carolina	NC 87 at SR 2233 (Butler Nursery Rd) - Intersection 2	Cumberland	Stop	2009
North Carolina	US 74 @ SR 2089 - Location 3	Cleveland	Stop	2011
North Carolina	NC-87 Byp at SR 1150 (Peanut Plant Rd)	Bladen	Stop	2006
North Carolina	NC-87 Byp at SR 1700 (Mercer Mill Rd) - Intersection 1	Bladen	Stop	2009
North Carolina	NC-87 Byp at SR 1145 (Martin Luther King Dr) - Intersection 2	Bladen	Stop	2009
North Carolina	US 70 at SR 1129 (Tom Mann Rd)	Carteret	Stop	2003
North Carolina	US 70 at SR 1148 (Carl Garner Rd)/SR 1252 (Training Ground Rd)	Carteret	Stop	2003
North Carolina	US 23-74 at SR 1157 (Walker Rd)/SR 1155 (Red Banks Rd) - SS 14-97-018	Haywood	Stop	2001
North Carolina	US 401/421-NC 27/210 (Main St) at SR 1319 (Duncan St/10th St)	Harnett	Stop	2010
North Carolina	US 70 at SR 1127 (Mason Town Rd)	Carteret	Stop	2007
North Carolina	US 117 at SR 1141 (Main Street).	Wayne	Stop	2012
North Carolina	NC 67 (Silas Creek Pkwy) at Forsyth Technical College	Forsyth	Stop	2000
North Carolina	NC 132 (North College Rd) at SR 1378 (Spring View Dr)	New Hanover	Stop	2004
North Carolina	NC 132 (College Road) at Lowes Foods Entrance - W-5104 Location 1	New Hanover	Stop	2011
North Carolina	NC 132 (College Road) at Lansdowne Rd/Andrews Mortuary - W-5104 Location 12	New Hanover	Stop	2011
North Carolina	NC 132 (College Road) at Ace Hardware - W-5104 Location 18	New Hanover	Stop	2011
North Carolina	US 264 at SR 1523 (Whichard Rd)	Pitt	Stop	1999
North Carolina	US 70 at SR 1719 (Beston Rd)	Wayne	Stop	2007
North Carolina	US 74 Bus/SR 1001 at WB ramps to US 74 Byp	Cleveland	Stop	2003
North Carolina	US 401 (Raeford Rd) at SR 1546 (Little Drive)/Falcon Village Shopping Center	Cumberland	Stop	1997
North Carolina	NC 132 at SR 2003 (Kings Grant Rd)/Grace Church Children's Academy	New Hanover	Stop	1998
North Carolina	NC 150 (Peters Creek Pkwy) at Franciscan Dr and Ethel Dr	Forsyth	Stop	2011
North Carolina	US 19/23 (Smokey Park Hwy) at the Shoneys/McDonalds’ Driveway	Buncombe	Stop	1998
North Carolina	NC 24/NC 27 at SR 1503 (Mill Street)	Montgomery	Stop	2011
North Carolina	US 158 (Stratford Rd) and Burke Mill Rd	Forsyth	Stop	1999
North Carolina	US 64 and SR 2229 (Treatment Plant Road)/SR 1363 (Pearlman Teague Road)	Chatham	Stop	2011
North Carolina	SR 1403 (Reilly Rd) at SR 1583 (Baldoon Dr)	Cumberland	Stop	2006
North Carolina	US 401 (Ramsey St) at Tallstone Dr - W-5000 Location 12	Cumberland	Stop	2011

North Carolina	US 401 (Ramsey St) at London Ct - W-5000 Location 15	Cumberland	Stop	2011
North Carolina	US 401 (Ramsey St) at Lofton Dr - W-5000 Location 16	Cumberland	Stop	2011
North Carolina	US 401 (Ramsey St) at Kings Creek Dr/Cape Fear Ortho - W-5000 Location 17	Cumberland	Stop	2011
North Carolina	US 401 (Ramsey St) at Carver Falls Rd/Cedar Falls Ch - W-5000 Location 19	Cumberland	Stop	2011
North Carolina	US 401 (Ramsey St) at Farmers Rd/Ft Bragg CU - W-5000 Location 20	Cumberland	Stop	2011
North Carolina	US 221 at SR 1149 (Mt. Jefferson Rd)	Ashe	Stop	2007
North Carolina	NC 73 and SR 2428 (Mayes Road/Black Farm Road).	Mecklenburg	Stop	2012
North Carolina	US-17 (Wilmington Hwy / Ocean Hwy) at SR 1107 (Dawson Cabin Road)	Onslow	Signal	2011
North Carolina	NC 87 at H. M. Cagle Dr./Food Lion Entrance/Linden Oak	Harnett	Signal	2011
North Carolina	NC 132 (College Road) at Mohican Trl/Jasmine Cove Way - W-5104 Location 7	New Hanover	Signal	2011
North Carolina	Poplar Tent at I-85 SB	Kannapolis	Signal	2014
North Carolina	NC-24/87 at HM Cagle Drive / Linden Oaks Parkway	Spout Springs	Signal	2012
North Carolina	NC 132 (S. College Rd) from Lowes Foods Entrance North to Bentley Drive	Wilmington	Signal	2011
North Carolina	US-17 at Grandiflora/Westgate	Leland	Signal	2006
North Carolina	US-17 at Gregory/Ocean Gate Plaza	Leland	Signal	2006
North Carolina	US-17 at Olde Waterford/Ploof	Leland	Signal	2006
North Carolina	US-17 at Old Ocean Hwy	Bolivia	Signal	2012
North Carolina	US17 at Hospital Drive	Bolivia	Signal	2012
North Carolina	US17 at Scotts Hill Loop N	Wilmington	Signal	2012
North Carolina	US17 at Sidbury Rd	Wilmington	Signal	2012
North Carolina	US17 at Scotts Hill Loop S	Wilmington	Signal	2012
North Carolina	US17 at Futch Creek	Wilmington	Signal	2012
North Carolina	NC-55 at Vinewood Pl	Holy Springs	Signal	2013
North Carolina	NC-55 at Holy Springs Rd	Holy Springs	Signal	2013
North Carolina	NC-55 at Green Oaks Pkwy	Holy Springs	Signal	2013
North Carolina	US 15-501 (Fordham Blvd) at SR 1734 (Erwin Rd)/Europa Dr	Chapel Hill	Signal	2008
North Carolina	Carolina Beach Road (US 421) @ SR 2501/Home Depot Shopping Center	Wilmington	Signal	2009
North Carolina	US-401 at Business Intersection South (US-401 Bus)	Rolesville	Signal	2015
North Carolina	US-401 at Jonesville Rd.	Rolesville	Signal	2015
North Carolina	US-401 at SR 1003 (Young St)	Rolesville	Signal	2015
North Carolina	US-401 at Pulley Town Rd	Rolesville	Signal	2015
North Carolina	US 401 Business Intersection North (US-401 Bus)	Rolesville	Signal	2015
Ohio	OH-4 Bypass Symmes Rd (39.343840, -84.502066)	Fairfield	Signal	2011
Ohio	OH-4 Bypass at Tylersville Rd (39.362811, -84.504166)	Fairfield	Signal	2011
Ohio	OH-4 Bypass at Hamilton Mason Rd (39.378711, -84.506846)	Hamilton	Signal	2011
South Carolina	US 52 and S-50 (Oakley Rd)	Moncks Corner	Merge	2013
South Carolina	US 176 (Furman L Fendley Hwy) and S-407 (New Hope Church Rd)	Jonesville	Merge	2014
South Carolina	SC 9 BYP and S-66	Loris	Stop	2011

Tennessee	State Route 6 at Canaan Road	Maury County	Stop	2013
Tennessee	State Route 6 at South Cross Bridges Road	Maury County	Stop	2013
Tennessee	State Route 33 at the intersection of the Wal-Mart entrance	Monroe County	Stop	2013
Tennessee	State Route 20 at the intersection of Egg Hill Road	Crockett County	Stop	2013
Texas	US-281 & Evans Rd	San Antonio, TX	Signal	2010
Texas	Stone Oak Parkway & TPC Parkway	San Antonio, TX	Signal	2010
Texas	North Northwind Drive & Marshall Road	San Antonio, TX	Signal	2011
Texas	Loop-1604 & New Guilbeau / Shaenfield	San Antonio, TX	Signal	2011
Texas	TX-71 at FM-973 / Fallwell Lane	Austin, TX	Signal	2014
Wisconsin	US 53 & CTH B	Hawthorne	Stop	2011
Wisconsin	STH 29/32 & CTH VV	Hobart	Stop	2013
Wisconsin	STH 23 & CTH M	Sheboygan Falls	Stop	2013
Wisconsin	USH 53 & CTH B	Beaverbrook	Stop	2015
Wisconsin	US 141 & CTH E	Abrams	Stop	2014
Wisconsin	STH 54 & CTH U	Village Biron	Stop	2016
Wisconsin	STH 57 & CTH C	Brussels	Stop	2015

Appendix E. List of RCUT Types

Signalized RCUTs

4L-2U: 4-legged with 2 U-turns
4L-1U: 4-legged with 1 U-turns
3L-2U: 3-legged with 2 U-turns
3L-1U: 3-legged with 1 U-turns
4-3L-0U: 4- or 3-legged without a U-turn

State	Location	Location	Type	Built
Alabama	Carl T. Jones Drive @ Valley Bend	Huntsville	4-3L-0U	
Alabama	US-231 & Plum Road	Dothan	4L-2U	2009
Alabama	US-231 & Retail Drive	Dothan	4L-2U	2009
Maryland	MD 3 & Waugh Chapel Rd., Odenton	Anne Arundel	4L-2U	2011
Michigan	Big beaver and Lake drive	Troy	4L-2U	1990
Michigan	Long Lake and Corporate drive	Troy	4L-2U	1990
North Carolina	US-17 (Wilmington Hwy / Ocean Hwy) at SR 1107 (Dawson Cabin Road)	Onslow	4L-2U	2011
North Carolina	NC 87 at H. M. Cagle Dr./Food Lion Entrance/Linden Oak	Harnett	4L-2U	2011
North Carolina	NC 132 (College Road) at Mohican Trail	New Hanover	4L-1U	2011
North Carolina	Poplar Tent at I-85 SB	Kannapolis	3L-1U	2014
North Carolina	NC-24/87 at HM Cagle Drive / Linden Oaks Parkway	Spout Springs	4L-2U	2012
North Carolina	US-17 at Grandiflora/Westgate	Leland	4L-2U	2006
North Carolina	US-17 at Gregory/Ocean Gate Plaza	Leland	4L-2U	2006
North Carolina	US-17 at Olde Waterford/Ploof	Leland	4L-2U	2006
North Carolina	US-17 at Old Ocean Hwy	Bolivia	3L-1U	2012
North Carolina	US17 at Hospital Drive	Bolivia	3L-2U	2012
North Carolina	US17 at Scotts Hill Loop N	Wilmington	3L-1U	2012
North Carolina	US17 at Sidbury Rd	Wilmington	4-3L-0U	2012
North Carolina	US17 at Scotts Hill Loop S	Wilmington	4-3L-0U	2012
North Carolina	US17 at Futch Creek	Wilmington	4L-1U	2012
North Carolina	NC-55 at Vinewood Pl	Holy Springs	3L-1U	2013
North Carolina	NC-55 at Holy Springs Rd	Holy Springs	4L-2U	2013
North Carolina	NC-55 at Green Oaks Pkwy	Holy Springs	4L-2U	2013
North Carolina	Carolina Beach Road (US 421) @ SR 2501/Home Depot Shopping Center	Wilmington	4L-2U	2009
North Carolina	US-401 at Business Intersection South (US-401 Bus)	Rolesville	3L-1U	2015
North Carolina	US-401 at Jonesville Rd.	Rolesville	4L-2U	2015
North Carolina	US-401 at SR 1003 (Young St)	Rolesville	4L-2U	2015

North Carolina	US 401 Business Intersection North (US-401 Bus)	Rolesville	3L-1U	2015
Ohio	OH-4 Bypass Symmes Rd (39.343840, -84.502066)	Fairfield	4L-2U	2011
Ohio	OH-4 Bypass at Tylersville Rd (39.362811, -84.504166)	Fairfield	4L-2U	2011
Ohio	OH-4 Bypass at Hamilton Mason Rd (39.378711, -84.506846)	Hamilton	4L-2U	2011
Texas	US-281 & Evans Rd	San Antonio, TX	4L-2U	2010
Texas	Stone Oak Parkway & TPC Parkway	San Antonio, TX	4L-2U	2010
Texas	North Northwind Drive & Marshall Road	San Antonio, TX	4L-2U	2011
Texas	Loop-1604 & New Shaenfield	San Antonio, TX	3L-2U	2011
Texas	Loop-1604 & New Guilbeau	San Antonio, TX	3L-1U	2011
Texas	TX-71 at FM-973 / Fallwell Lane	Austin, TX	4L-1U	2014
Texas	TX-71 at FM-973 / Alice Ave	Austin, TX	3L-1U	2014

Unsignalized RCUTs

State	Location	City	Type	Built
Alabama	US-72 & Capital Park at 72 West	Huntsville	4L-1U	1990
Alabama	US-231 & Hospitality Lane	Dothan	3L – 2U	2009
Alabama	US-231 & Rock Bridge Road	Dothan	4L – 2U	2009
Alabama	US-231 & Executive Park Dr.	Dothan	3L – 1U	2010
Alabama	US-82 & SR-219	Centreville	4L – 2U	2017
Alabama	US-280 & Meadow Lake Dr.	Birmingham	4L – 2U	
Alabama	US-280 & Resource Center Pkwy	Birmingham	4L – 2U	
Alabama	US-280 & Brook Manor Dr.	Birmingham	4L – 1U	2014
Alabama	SR-182 @ Cotton Bayou Boat Launch	Orange Beach	4L – 1U	2017
Alabama	US 82 & Timberlane Rd.	Centreville	4L – 1U	2017
Georgia	SR 1/US 27 @ Kierbow Rd	Bremen	N/A	2016
Georgia	SR 20 @ Simpson Mill Rd	McDonough	4L – 2U	2015
Georgia	SR 3/US 19 @ Lucky St	Griffin	4L – 2U	2016
Georgia	SR 92 @ N Griffin Square Shopping Center	Griffin	4L – 2U	2016
Georgia	SR 74 @ Sandy Creek Rd	Tyrone	4L – 2U	2016
Georgia	SR 7/US 41 @ Grove St	Barnesville	4L – 2U	2016
Georgia	SR 57 @ Ridge Rd/Henderson Rd	Macon	4L – 2U	2017
Georgia	SR 96 @ Houston County High School	Warner Robins	N/A	2016
Georgia	SR 243/Fall Line Freeway @ College St	Gordon	4L – 1U	2013
Georgia	SR 10/Thomson Bypass @ Morgan-Watson Rd	Thomson	4-3L-0U	2011
Georgia	SR 10/US 78 @ Glenn Club Dr./Sharp Trail SW	Stone Mountain	4L – 2U	2009
Georgia	SR 10/US 78 @ Stone Dr. SW	Stone Mountain	4L – 2U	2009
Georgia	SR 10/US 78 @ Lake Lucerne Dr. SW	Stone Mountain	N/A	2009

Georgia	SR 10/US 78 @ Jessica Daron Ct	Stone Mountain	4-3L-0U	2009
Georgia	SR 10/US 78 @ Paxton Ln	Snellville	3L – 1U	2009
Georgia	SR 10/US 78 @ Killian Hill Village Shopping Center	Snellville	4-3L-0U	2012
Georgia	SR 10/US 78 @ VW Dealership Driveway	Snellville	4L – 2U	2009
Georgia	SR 10/US 78 @ Georgia Ln	Snellville	3L – 1U	2009
Georgia	SR 10/US 78 @ Britt Dr.	Snellville	3L – 2U	2009
Georgia	SR 3/US 41/Tara Blvd @ N Main St	Jonesboro	N/A	1999
Georgia	SR 3/US 41/Tara Blvd @ Valley Hill Rd SE	Jonesboro	3L – 2U	1999
Georgia	SR 144 @ Richmond Way/Carter St	Richmond Hill	4L – 2U	2008
Georgia	SR 204 @ Lewis St	Savannah	3L – 1U	2005
Illinois	US 67 & 200/Harlem Avenue	Monmouth	N/A	2007
Indiana	US 41 & State Road 114	Morocco	4L – 2U	2015
Indiana	US 231 & State Road 62 (south junction, Washington Street)	Dale	N/A	2016
Indiana	US 231 & State Road 68 (SR 62 north junction, Medcalf Street)	Dale	N/A	2016
Louisiana	Veterans Boulevard Corridor	Kenner	N/A	2005
Louisiana	US-61 & Leblanc's Food Store	Gonzales	4L – 1U	
Louisiana	LA-8/LA-28 & LA-117	Leesville	4L – 2U	
Louisiana	Loyola Dr. & 31st Street	Kenner	4L – 2U	
Louisiana	US 90 & N. Girouad St.	Lafayette	4L – 1U	
Maryland	US 15 & Hayward Rd., Frederick		3L – 1U	
Maryland	US 15 & Monacacy Rd., Frederick		3L – 0U	
Maryland	US 15 & Biggs Ford Rd., Frederick		4L – 1U	
Maryland	US 15 & Sundays Ln., Frederick		3L – 2U	
Maryland	US 15 & College Ln., Emmitsburg		4L – 2U	
Maryland	US 15 & Old Frederick Rd., Emmitsburg		4L – 2U	
Maryland	US 301 & Main St. Queenstown		4L – 1U	
Maryland	US 301 & Del Rhodes Ave., Queenstown		4L – 2U	
Maryland	US 301 & Ruthsburg Rd., Centreville		4L – 2U	
Maryland	US 301 & Sudlersville Rd., Sudlersville		4L – 2U	
Maryland	US 301 & McGinnes Rd., Millington		4L – 2U	
Maryland	US 301 & Galena Rd., Galena		4L – 2U	
Maryland	MD 228 & Bunker Hill Rd, Waldorf		4L – 2U	
Maryland	MD 5 & Sandstone St., Waldorf		4L – 2U	
Michigan	Michigan Ave at Clippert St	Lansing	4L – 2U	
Minnesota	Old Highway 71 and County Road 24	Willmar	4L	2010
Minnesota	US 53 and CSAH 52	Cotton	4L – 2U	2012
Minnesota	US 212 and MNTH 284/CSAH 53	Cologne	4L – 2U	2012
Minnesota	MNTH 65 and 169th Avenue	Ham Lake	4L – 2U	2012

Minnesota	US 52 and CSAH 66	Vermillion	4L – 2U	2014
Minnesota	MNTH 36 and Demontreville Trail	Lake Elmo	4L – 1U	2013
Minnesota	US 169 and Julien Street	St Peter	3L – 1U	2014
Minnesota	US 169 and Dodd Street	St Peter	4L – 2U	2014
Minnesota	US 14 and CSAH 17	Eagle Lake	4L – 2U	2016
Minnesota	US 61 and Gilmore Street	Winona	N/A	2016
Minnesota	MNTH 23 and Saratoga Street	Marshall	N/A	2016
Minnesota	MNTH 371 (two locations)	Pequot Lakes	N/A	2016
Mississippi	US Highway 98 at Old Highway 63 North	Lucedale	4L – 2U	2012
Mississippi	US 84 at Ferguson Mill Road	Monticello	4L – 2U	2013
Mississippi	US Highway 84 at State Route 184/Magnolia Road	Cleo Community	4L – 2U	2013
Mississippi	US Highway 45 at Clarke County Road 212	Shubuta	4L – 2U	2014
Mississippi	US Highway 84 at State Route 35	Lone Star Community	N/A	2016
Mississippi	State Route 67 at Big John Road	D'Iberville	4L – 2U	2015
Mississippi	State Route 67 at Tradition Parkway	Tradition	4L – 2U	2016
Mississippi	US Highway 45 at Tarlton Road	Crawford	4L – 2U	2017
Missouri	US 63 and Rt M	Macon County	4L – 2U	2014
Missouri	US 63 and Rt B	Randolph County	4L – 2U	2014
Missouri	US 50 and MO 58	Johnson County	4L – 2U	2014
Missouri	MO 30 before and after Upper Byrnes Mills	Jefferson County	4L – 2U	2012
Missouri	US 54 and Heritage Hwy/Buffalo Road	Cole County	4L – 2U	2012
Missouri	US 54 and Honey Creek	Cole County	4L – 2U	2011
Missouri	US 54 and Route E	Cole County	3L – 2U	2011
Missouri	US 54 and Route CC	Cole County	N/A	2012
Missouri	US 63 and Hinton/Calvert Hill	Boone County	4L – 2U	2014
Missouri	US 63 and Route AB	Boone County	N/A	2012
Missouri	US 63 and Bonne Femme	Boone County	N/A	2012
Missouri	US 63 and Liberty/Peterson Ln	Boone County	4L – 1U	2014
Missouri	MO 13 and Old MO 13/CRD 364	St. Clair County	4L – 2U	2009
Missouri	US 65 @ Rochester	Taney County	4L – 2U	2012
Missouri	US 65 @ County Rd 65	Dallas County	N/A	2009
Missouri	US 65 @ MO 38/MO TT	Dallas County	N/A	2009
Missouri	US 65 @ MO 215	Dallas County	N/A	2009
Missouri	US 65 @ RT AA	Dallas County	N/A	2009
Missouri	Rt M by Old Lemay Ferry Rd	Jefferson County	N/A	2007
North Carolina	US 64 and SR 2229 (Treatment Plant Road)/SR 1363 (Pearlman Teague Road)	Chatham	4L – 2U	2011
North Carolina	NC 150 (Peters Creek Pkwy) at Franciscan Dr and Ethel Dr	Forsyth	4-3L-0U	2011
North Carolina	US 401/421-NC 27/210 (Main St) at SR 1319 (Duncan St/10th St)	Harnett	4L – 1U	2010

North Carolina	US 17 at SR 1221 (Rocky Run Rd)/Pirates Rd	Craven	4L – 2U	2010
North Carolina	US 70 at Grantham Rd - Treatment 1	Craven	4-3L-0U	2008
North Carolina	US 70 near Holiday Inn - SS 02-00-208,9 Location 2	Craven	4-3L-0U	2001
North Carolina	US 70 near El Cerro Grande Restaurant - SS 02-00-208,9 Location 1	Craven	4-3L-0U	2001
North Carolina	US 70 near Stratford Rd - SS 02-00-208,9 Location 3	Craven	4-3L-0U	2001
North Carolina	US 70 near Earthworks Garden Center - SS 02-00-208,9 Location 4	Craven	4-3L-0U	2001
North Carolina	NC 132 (College Road) at Greenbriar Rd/United Advent Ch - W-5104 Location 4	New Hanover	4-3L-0U	2011
North Carolina	NC 132 (College Road) at Hidden Valley Rd - W-5104 Location 5	New Hanover	4-3L-0U	2011
North Carolina	NC 132 (College Road) at Wedgefield Dr/Abaco Ln - W-5104 Location 6	New Hanover	4-3L-0U	2011
North Carolina	NC 132 (College Road) at Wickslow Dr - W-5104 Location 20	New Hanover	4-3L-0U	2011
North Carolina	NC 132 (College Road) at Greenhowe Dr Location 22	New Hanover	4-3L-0U	2011
North Carolina	NC 132 (College Road) at Lowes Foods Entrance - W-5104 Location 1	New Hanover	4-3L-0U	2011
North Carolina	NC 132 (College Road) at Lansdowne Rd/Andrews Mortuary-W-5104 Location 12	New Hanover	4-3L-0U	2011
North Carolina	NC 132 (College Road) at Ace Hardware - W-5104 Location 18	New Hanover	4-3L-0U	2011
North Carolina	US 29 and SR 1432 (Concord Farms Road) in Concord	Cabarrus	3L – 2U	2012
North Carolina	US 117 at SR 1141 (Main Street)	Wayne	4-3L-0U	2012
North Carolina	NC 73 and SR 2428 (Mayes Road/Black Farm Road)	Mecklenburg	4-3L-0U	2012
North Carolina	NC 24/NC 27 at SR 1503 (Mill Street)	Montgomery	4-3L-0U	2012
North Carolina	US 1 at Tramway Crossing Shopping Center	Lee	4-3L-0U	2012
North Carolina	US 64 at Shepherds Vineyard Dr	Wake	4-3L-0U	2012
North Carolina	US 17 (Ocean Highway) and the entrance to Brunswick Community Hospital	Brunswick	3L – 2U	2012
North Carolina	US 401 (Ramsey St) at Tallstone Dr - W-5000 Location 12	Cumberland	4-3L-0U	2011
North Carolina	US 401 (Ramsey St) at London Ct - W-5000 Location 15	Cumberland	4-3L-0U	2011
North Carolina	US 401 (Ramsey St) at Lofton Dr - W-5000 Location 16	Cumberland	4-3L-0U	2011
North Carolina	US 401 (Ramsey St) at Kings Creek Dr/Cape Fear Ortho - W-5000 Location 17	Cumberland	4-3L-0U	2011
North Carolina	US 401 (Ramsey St) at Carver Falls Rd/Cedar Falls Ch - W-5000 Location 19	Cumberland	4-3L-0U	2011
North Carolina	US 401 (Ramsey St) at Farmers Rd/Ft Bragg CU - W-5000 Location 20	Cumberland	4-3L-0U	2011
North Carolina	US 74 @ SR 2090, Location 1	Cleveland	4-3L-0U	2011
North Carolina	US 74 @ SR 2089 - Location 3	Cleveland	3L – 1U	2011
North Carolina	US-17 / NC-210 at SR 1561 (Sloop Point Rd) / SR 1726 (Machine Gun Rd)	Pender	4L – 2U	2012
North Carolina	US 70 at SR 2362 (Triplett Road)	Iredell	4-3L-0U	2011
North Carolina	US 321 (Blowing Rock Blvd) at NC 268/SR 1346 (Warrior Rd)	Caldwell	4L – 1U	2011
North Carolina	NC-87 Byp at SR 1700 (Mercer Mill Rd) - Intersection 1	Bladen	4-3L-0U	2009
North Carolina	C-87 Byp at SR 1145 (Martin Luther King Dr) - Intersection 2	Bladen	4-3L-0U	2009
North Carolina	US 52 Byp at SR 1772 (Old Buck Shoals Rd)	Surry	4L – 0U	2009
North Carolina	US 276 at SR 1394 (Hall Dr)/Russell Cove Rd	Haywood	4-3L-0U	2010
North Carolina	US 70 at western intersection with SR 1247 (Chatham St)	Carteret	N/A	2009
North Carolina	SR 3466 (West Millbrook Rd) at Davis Circle	Wake	4-3L-0U	2008

North Carolina	US 17 (Ocean Blvd) at SR 1130 (Mt. Pisgah Rd)	Brunswick	4L – 2U	2008
North Carolina	US 401 at SR 1409 (Lake Park Rd) and SR 1303 (Scull Rd)	Hoke	4L – 1U	2008
North Carolina	SR 3100 (Brier Creek Pkwy) and Skyland Ridge Pkwy	Wake	4-3L-0U	2008
North Carolina	US 521 (Johnston Rd) at SR 3635 (Marvin Rd)	Mecklenburg	4L – 1U	2008
North Carolina	US 74 at SR 1321 (Elmore Rd/Laurel Hill Church Rd)	Scotland	4L – 1U	2008
North Carolina	US 17 and SR 1184 (Ocean Isle Beach Rd)	Brunswick	4L – 2U	2008
North Carolina	NC 87 at SR 2235/SR 2261 (Grays Creek Ch Rd/Alderman Rd) - Intersection 1	Cumberland	4L – 2U	2009
North Carolina	NC 87 at SR 2233 (Butler Nursery Rd) - Intersection 2	Cumberland	4L – 1U	2009
North Carolina	US 221 at SR 1149 (Mt. Jefferson Rd)	Ashe	4-3L-0U	2007
North Carolina	NC 24 and SR 1230 (Haw Branch Rd)	Onslow	4L – 2U	2007
North Carolina	US 74 at SR 1152 / SR 1319 (Old Wire Rd)	Scotland	4L – 1U	2007
North Carolina	US 70 at the Newport River Shoppes - Intersection 1	Carteret	4-3L-0U	2007
North Carolina	US 70 at Cannon Blvd - Intersection 1	Carteret	4-3L-0U	2007
North Carolina	US 70 at SR 1291 (Bayberry St) - Intersection 2	Carteret	4-3L-0U	2007
North Carolina	US 70 at SR 1719 (Beston Rd)	Wayne	4L – 1U	2007
North Carolina	US 70 at SR 1127 (Mason Town Rd)	Carteret	4-3L-0U	2007
North Carolina	US 70 (E. Main St) at Webb Blvd - Intersection 2	Craven	4-3L-0U	2007
North Carolina	US 70 (E. Main St) at Shepard St - Intersection 4	Craven	4-3L-0U	2007
North Carolina	SR 3109 (Brier Creek Pkwy) at Little Brier Creek Ln/Arco Corporate D	Wake	4-3L-0U	2006
North Carolina	US 74-76 (Andrew Jackson Hwy) at SR 1800 (Bolton)	Columbus	4L – 2U	2006
North Carolina	SR 1403 (Reilly Rd) at SR 1583 (Baldoon Dr)	Cumberland	4-3L-0U	2006
North Carolina	US 70 (Arendell St) at SR 1149 (Sam Garner Rd)	Carteret	4L – 1U	2005
North Carolina	SR 3073 (NW Maynard Rd) at Waterford Center/Maynard Crossing	Wake	4-3L-0U	2005
North Carolina	NC 24 (W.T. Harris Blvd) at SR 2458 (David Cox Rd)	Mecklenburg	4-3L-0U	2005
North Carolina	SR 2911 (New Bern Ave) at Lord Ashley Rd - Intersection 1	Wake	4-3L-0U	2004
North Carolina	SR 2911 (New Bern Ave) at Lord Berkley Rd - Intersection 2	Wake	4-3L-0U	2004
North Carolina	US 29 (N. Tryon St) at Grove Lake Dr	Mecklenburg	N/A	2004
North Carolina	NC 132 (North College Rd) at SR 1378 (Spring View Dr)	New Hanover	4-3L-0U	2004
North Carolina	NC-87 Byp at SR 1150 (Peanut Plant Rd)	Bladen	4-3L-0U	2006
North Carolina	US 23/441 @ NC 116/ SR 1368	Jackson	3L – 2U	2004
North Carolina	US 70 at SR 1731 (Piney Grove Rd)	Wayne	N/A	2003
North Carolina	US 74 Bus/SR 1001 at WB ramps to US 74 Byp	Cleveland	N/A	2003
North Carolina	US 74 Byp at Crossover 0.77 miles east of NC 226/Earl Rd	Cleveland	4-3L-0U	2003
North Carolina	US 70 at SR 1148 (Carl Garner Rd)/SR 1252 (Training Ground Rd)	Carteret	N/A	2003
North Carolina	US 70 at SR 1129 (Tom Mann Rd)	Carteret	N/A	2003
North Carolina	US 29-70/I-85 Bus at SR 1774 (Mendenhall St)	Davidson	4-3L-0U	2002
North Carolina	SR 1223 (Dickerson Blvd) at Monroe Mall - Intersection 1	Union	4L – 0U	2002
North Carolina	US 64 at SR 1163 (Kelly Rd)	Wake	4L – 2U	2002

North Carolina	US 19/23 (Smokey Park Hwy) at the Shoneys/McDonalds’ Driveway	Buncombe	N/A	1998
North Carolina	US 158 (Stratford Rd) and Burke Mill Rd	Forsyth	N/A	1999
North Carolina	US 321 (Hickory Blvd) at SR 1796 (Victoria Ct)/Clover Dr	Caldwell	4L – 0U	2001
North Carolina	US 64 Business at SR 2234/SR 2500 (Marks Creek Rd)	Wake	4L – 1U	2001
North Carolina	US 23-74 at Balsam Rest Area - SS 14-97-018 Location 4	Haywood	4-3L-0U	2001
North Carolina	US 23-74 at SR 1158/SR 1243 (Old Balsam Rd) - SS 14-97-018 Location 8	Haywood	4L – 2U	2001
North Carolina	US 23-74 at SR 1157 (Walker Rd)/SR 1155 (Red Banks Rd) - SS 14-97-018	Haywood	4L – 2U	2001
North Carolina	SR 4315 (South Main St) at Century Park Blvd	Forsyth	4-3L-0U	2000
North Carolina	US 401 (Raeford Rd) at SR 1546 (Little Drive)/Falcon Village Shopping Center	Cumberland	4-3L-0U	1997
North Carolina	US 264 at SR 1523 (Whichard Rd)	Pitt	N/A	1999
North Carolina	US 23-74 at SR 1527 (Steeple Dr)/SR 1449 (Cope Creek Rd)	Jackson	4L – 0U	1998
North Carolina	NC 132 at SR 2003 (Kings Grant Rd)/Grace Church Children's Academy	New Hanover	4-3L-0U	1998
North Carolina	US 17 at Parkwood Dr/Western Shopping Plaza	Onslow	4-3L-0U	1998
North Carolina	NC 67 (Silas Creek Pkwy) at Forsyth Technical College	Forsyth	4-3L-0U	2000
North Carolina	US64 at Knollwood Dr	Wake	N/A	2016
South Carolina	US 52 and S-50 (Oakley Rd)	Moncks Corner	4L-2U	2013
South Carolina	US 176 (Furman L Fendley Hwy) and S-407 (New Hope Church Rd)	Jonesville	4L-2U	2014
South Carolina	SC 9 BYP and S-66	Loris	N/A	2011
Tennessee	State Route 6 at Canaan Road	Maury County	4L – 2U	2013
Tennessee	State Route 6 at South Cross Bridges Road	Maury County	4L – 2U	2013
Tennessee	State Route 33 at the intersection of the Wal-Mart entrance	Monroe County	4L – 1U	2013
Tennessee	State Route 20 at the intersection of Egg Hill Road	Crockett County	N/A	2013
Wisconsin	US 53 & CTH B	Hawthorne	4L – 2U	2011
Wisconsin	STH 29/32 & CTH VV	Hobart	4L – 2U	2013
Wisconsin	STH 23 & CTH M	Sheboygan Falls	4L – 2U	2013
Wisconsin	USH 53 & CTH B	Beaverbrook	4L – 2U	2015
Wisconsin	US 141 & CTH E	Abrams	3L – 1U	2014
Wisconsin	STH 54 & CTH U	Grand Rapids	N/A	2016
Wisconsin	STH 57 & CTH C	Brussels	4L – 0U	2015

N/A: Not a RCUT intersection.

Appendix F. List of Variables Documented for RCUTs

Signalized and unsignalized RCUT variables

Crashes

- total number of crashes
- number of possible injury crashes
- number of non-incapacitating injury crashes
- number of incapacitating injury crashes
- number of fatality crashes

Traffic

- major roadway AADT in the first direction
- major roadway AADT in the second direction
- minor roadway AADT in the first direction
- minor roadway AADT in the second direction
- major roadway speed limit
- minor roadway speed limit

Geometric design

- number of legs
- number of U-turns
- number of lanes on major roadway first direction
- number of lanes on major roadway second direction
- number of lanes on minor roadway first direction
- number of lanes on minor roadway second direction
- lane width of major roadway
- shoulder type of major roadway
- shoulder width of major roadway
- offset distance of major roadway first direction
- offset distance of major roadway second direction
- presence of acceleration lane on major roadway first direction
- presence of acceleration lane on major roadway second direction
- acceleration lane length on major roadway first direction
- acceleration lane length on major roadway second direction
- presence of deceleration lane on major roadway first direction
- presence of deceleration lane on major roadway second direction
- deceleration lane length on major roadway first direction
- deceleration lane length on major roadway second direction
- weaving length on major roadway first direction
- weaving length on major roadway second direction
- median width of major roadway first direction
- median width of major roadway second direction
- number of U-turn lanes on first U-turn
- number of U-turn lanes on second U-turn
- median width of first U-turn
- median width of second U-turn

number of right turn lanes on major roadway first direction
number of right turn lanes on major roadway second direction
number of left-turn lanes on major roadway first direction
number of left-turn lanes on major roadway second direction
presence of concrete channelization
Environment
urbanization
presence of lighting
number of driveways
presence of business
presence of residence
presence of pedestrian crossing

Appendix G. SPF Models for Signalized RCUTs

All Crashes

Model 1

The first model (Model 1) is also called the full model. Model 1 consists of eight variables including traffic-, geometric design-, and environment-related factors. The model analysis results are given below.

Variables	β	S.E.	p	p < 0.1
Intercept	-13.50	1.384	0.00	✓
Ln(Maximum Major AADT)	0.986	0.131	0.00	✓
Ln(Maximum Minor AADT)	0.503	0.083	0.00	✓
Number of U-turns	0.705	0.150	0.00	✓
Number of Major Lanes	0.364	0.116	0.00	✓
Number of Minor Lanes	-0.279	0.128	0.03	✓
Total Median Width	-5.08e-3	2.08e-3	0.01	✓
Maximum Offset Distance	3.54e-4	1.89e-4	0.06	✓
Number of Driveways	0.042	0.021	0.04	✓
θ	6.03	1.17		
Log-likelihood	-797.5			
AIC	817.5			
Null Deviance vs. residual deviance	508.8 vs. 124.4			

Number of observations: 114, Number of variables: 8

Abbreviations β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion

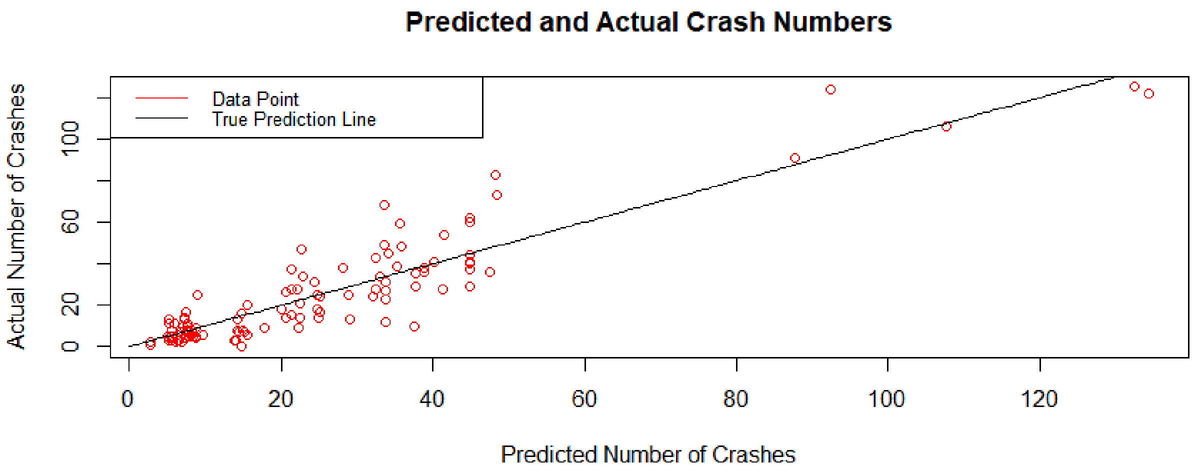


Figure 68. Predicted and actual crash numbers for signalized RCUTs Model 1 (All crashes)

Model 2

The second model (Model 2) consists of seven variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-15.00	1.232	0.00	✓
Ln(Maximum Major AADT)	1.145	0.110	0.00	✓
Ln(Maximum Minor AADT)	0.468	0.083	0.00	✓
Number of U-turns	0.831	0.144	0.00	✓
Number of Major Lanes	0.392	0.119	0.00	✓
Number of Minor Lanes	-0.305	0.131	0.02	✓
Total Median Width	-4.09e-3	2.09-e3	0.05	✓
Maximum Offset Distance	3.67e-4	1.94e-4	0.05	✓
θ	5.58	1.04		
Log-likelihood	-801.4			
AIC	819.4			
Null Deviance vs. residual deviance	479.9 vs. 121.9			
Number of observations: 114, Number of variables: 7				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

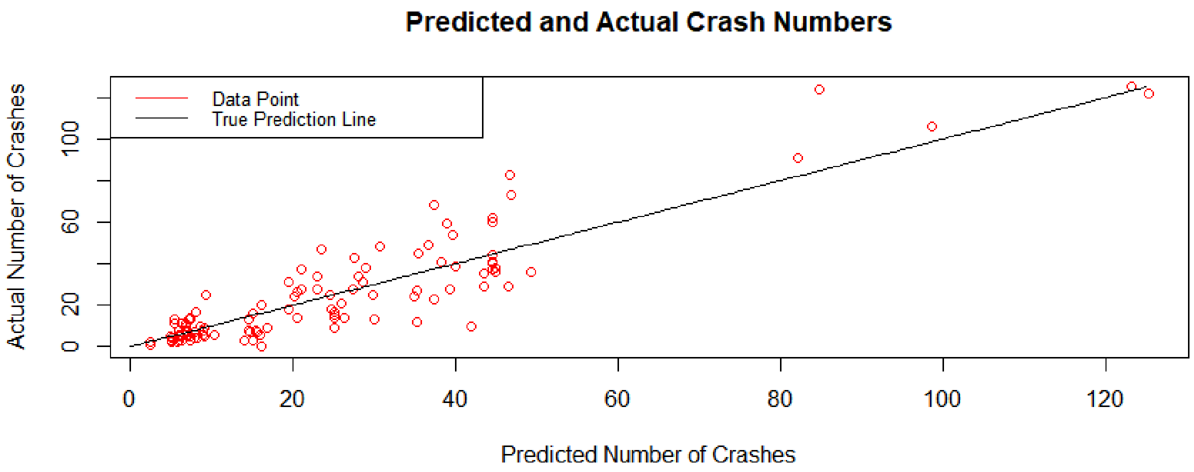


Figure 69. Predicted and actual crash numbers for signalized RCUTs Model 2 (All crashes)

Model 3

The third model (Model 3) consists of six variables including traffic- and geometric-related design factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-15.14	1.253	0.00	✓
Ln(Maximum Major AADT)	1.213	0.106	0.00	✓
Ln(Maximum Minor AADT)	0.470	0.085	0.00	✓
Number of U-turns	0.738	0.138	0.00	✓
Number of Major Lanes	0.324	0.116	0.01	✓
Number of Minor Lanes	-0.261	0.132	0.05	✓
Total Median Width	-3.62e-3	2.13e-3	0.09	✓
θ	5.28	0.96		
Log-likelihood	-804.9			
AIC	820.9			
Null Deviance vs. residual deviance	459.7 vs. 120.8			
Number of observations: 114, Number of variables: 6				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

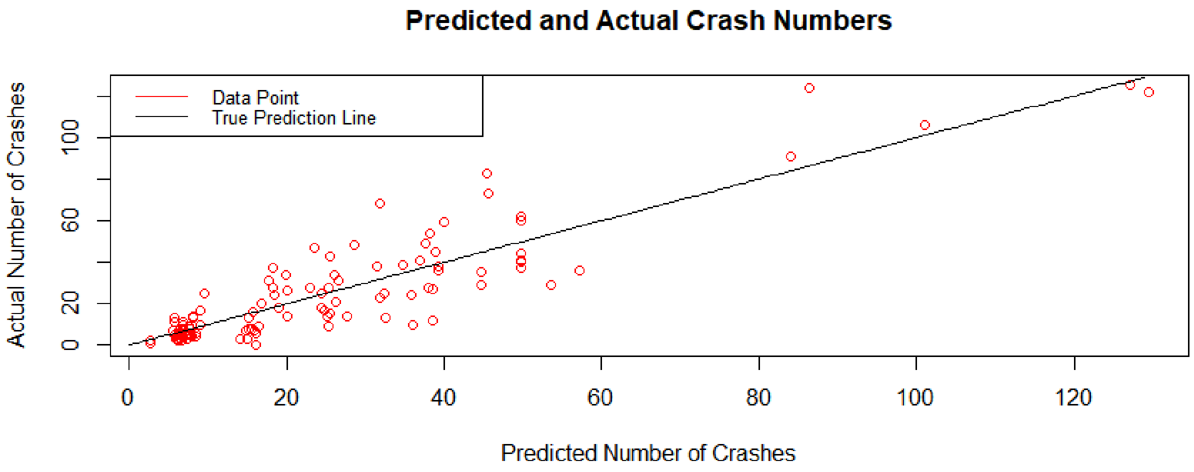


Figure 70. Predicted and actual crash numbers for signalized RCUTs Model 3 (All crashes)

Model 4

The fourth model (Model 4) consists of five variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-13.60	1.103	0.00	✓
Ln(Maximum Major AADT)	1.089	0.110	0.00	✓
Ln(Maximum Minor AADT)	0.359	0.070	0.00	✓
Number of U-turns	0.651	0.121	0.00	✓
Number of Major Lanes	0.272	0.111	0.01	✓
Maximum Offset Distance	2.84e-4	1.97e-4	0.15	x
θ	5.14	0.92		
Log-likelihood	-806.7			
AIC	820.7			
Null Deviance vs. residual deviance	450.8 vs. 120.5			
Number of observations: 114, Number of variables: 5				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

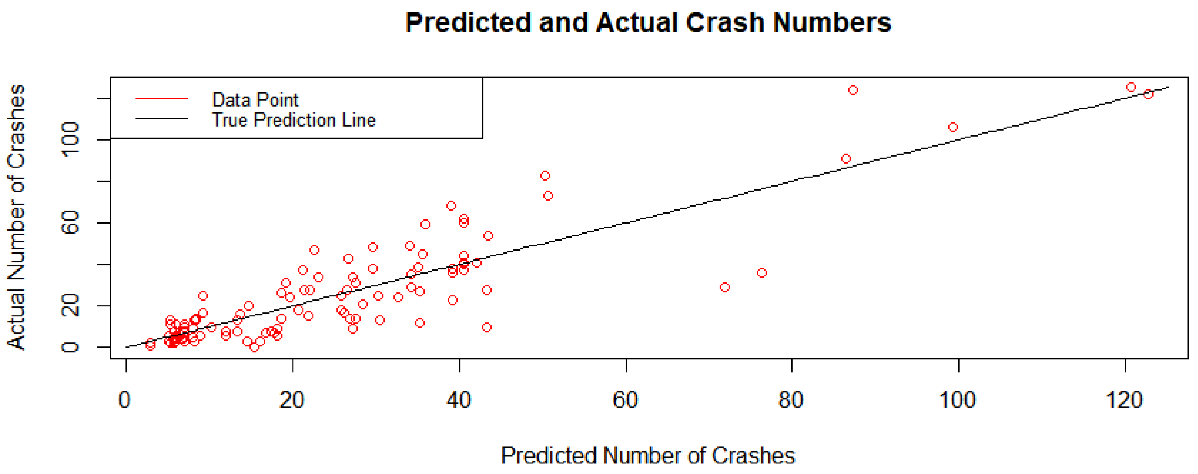


Figure 71. Predicted and actual crash numbers for signalized RCUTs Model 4 (All crashes)

Model 5

The fifth model (Model 5) consists of four variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-13.88	1.106	0.00	✓
Ln(Maximum Major AADT)	1.149	0.104	0.00	✓
Ln(Maximum Minor AADT)	0.374	0.071	0.00	✓
Number of U-turns	0.596	0.118	0.00	✓
Number of Major Lanes	0.229	0.108	0.03	✓
θ	4.99	0.88		
Log-likelihood	-808.8			
AIC	820.8			
Null Deviance vs. residual deviance	440.4 vs. 120.8			
Number of observations: 114, Number of variables: 4				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

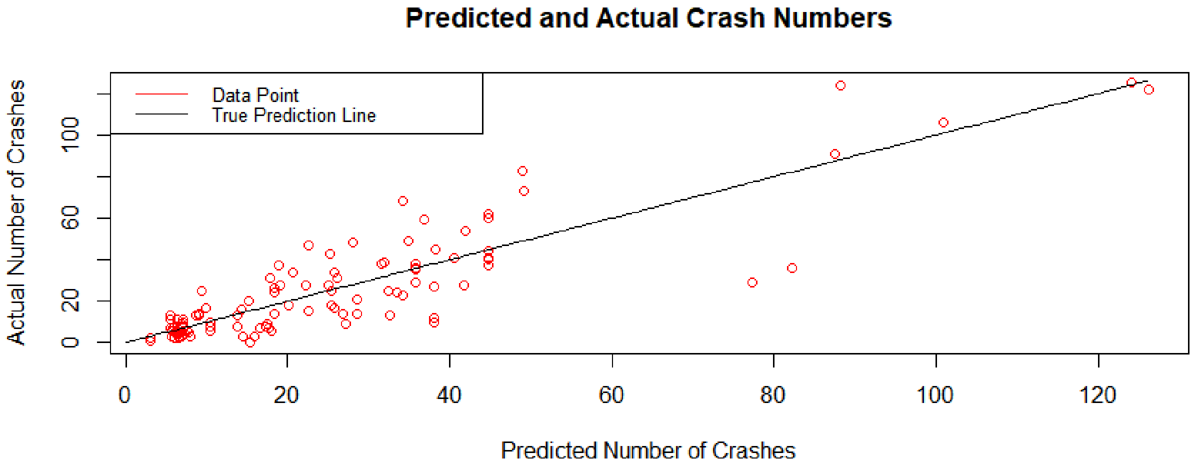


Figure 72. Predicted and actual crash numbers for signalized RCUTs Model 5 (All crashes)

Model 6

The sixth model (Model 6) consists of three variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-13.96	1.127	0.00	✓
Ln(Maximum Major AADT)	1.152	0.106	0.00	✓
Ln(Maximum Minor AADT)	0.443	0.070	0.00	✓
Number of U-turns	0.600	0.120	0.00	✓
θ	4.77	0.83		
Log-likelihood	-813.0			
AIC	823.0			
Null Deviance vs. residual deviance	425.1 vs. 120.4			
Number of observations: 114, Number of variables: 3				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

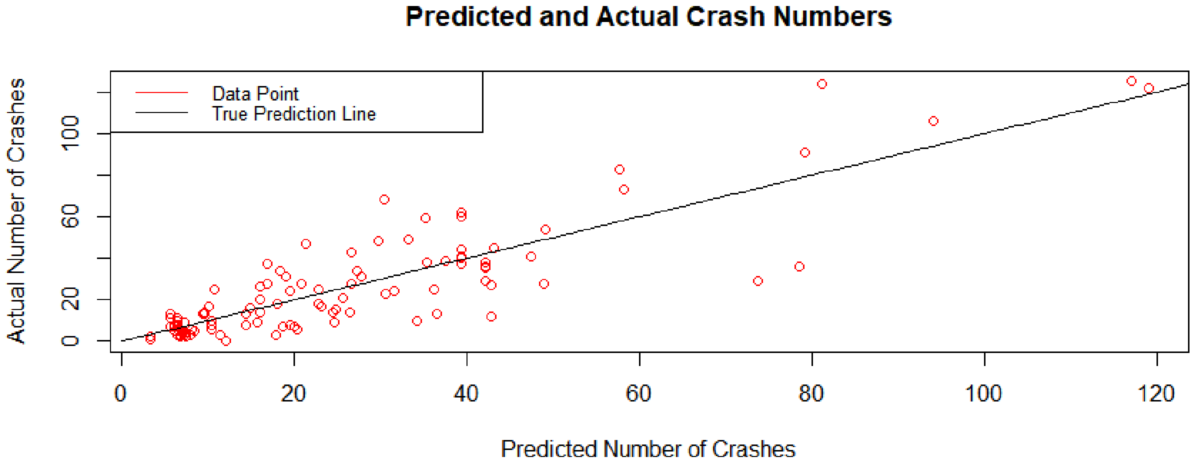


Figure 73. Predicted and actual crash numbers for signalized RCUTs Model 6 (All crashes)

Model 6WO (Without outliers)

The final model (Model 6WO) consists of three variables including traffic- and geometric design-related factors after the removal of the outliers. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-14.54	1.139	0.00	✓
Ln(Maximum Major AADT)	1.186	0.105	0.00	✓
Ln(Maximum Minor AADT)	0.478	0.068	0.00	✓
Number of U-turns	0.572	0.120	0.00	✓
θ	5.05	0.92		
Log-likelihood	-785.4			
AIC	795.4			
Null Deviance vs. residual deviance	442.6 vs. 118.3			
Number of observations: 111, Number of variables: 3				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

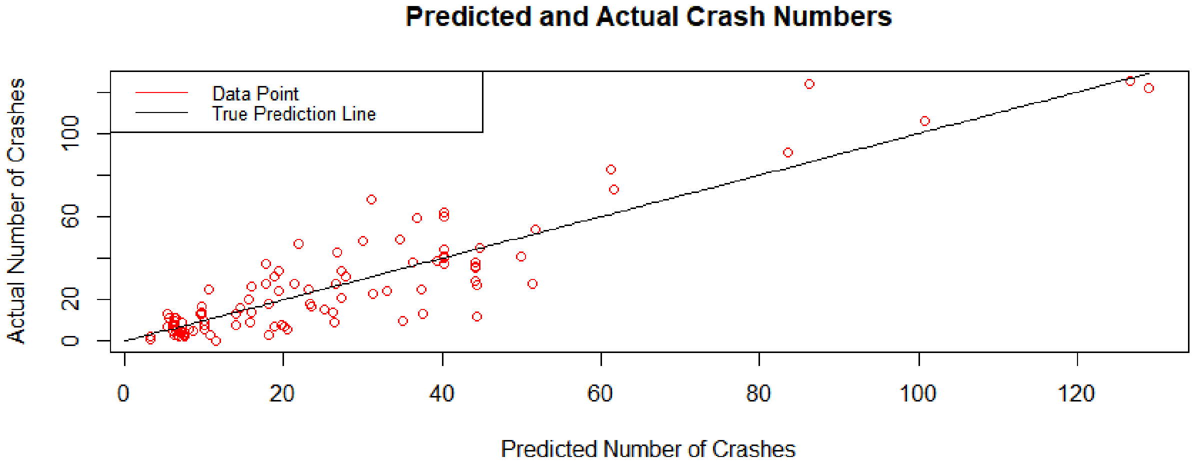


Figure 74. Predicted and actual crash numbers for signalized RCUTs Model 6WO (All crashes)

Outlier Data Points

Outlier Observations	**Total Crash**	**Fatal and Injury Crash**	**AADT$_{major}$**	**AADT$_{minor}$**	AADT Ratio
MD 3 & Waugh Chapel Rd., Odenton	29	7	62062	17953	3.46
MD 3 & Waugh Chapel Rd., Odenton	36	14	65490	17953	3.65

This RCUT has exceptionally low number of crashes compared to its major and minor approach AADTs. Therefore, it presents an outlier pattern.

Fatal and Injury Crashes

Model 1

The first model (Model 1) is also called the full model. Model 1 consists of six variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-18.301	1.688	0.00	✓
Ln(Maximum Major AADT)	1.154	0.130	0.00	✓
Ln(Maximum Minor AADT)	0.547	0.080	0.00	✓
Number of U-turns	0.357	0.141	0.01	✓
Number of Major Lanes	0.311	0.117	0.01	✓
Total Median Width	-5.55e-3	2.08e-3	0.01	✓
Ln(Maximum Offset Distance)	0.300	0.218	0.17	x
θ	9.46	3.45		
Log-likelihood	-555.9			
AIC	571.9			
Null Deviance vs. residual deviance	480.9 vs. 131.2			
Number of observations: 114, Number of variables: 6				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

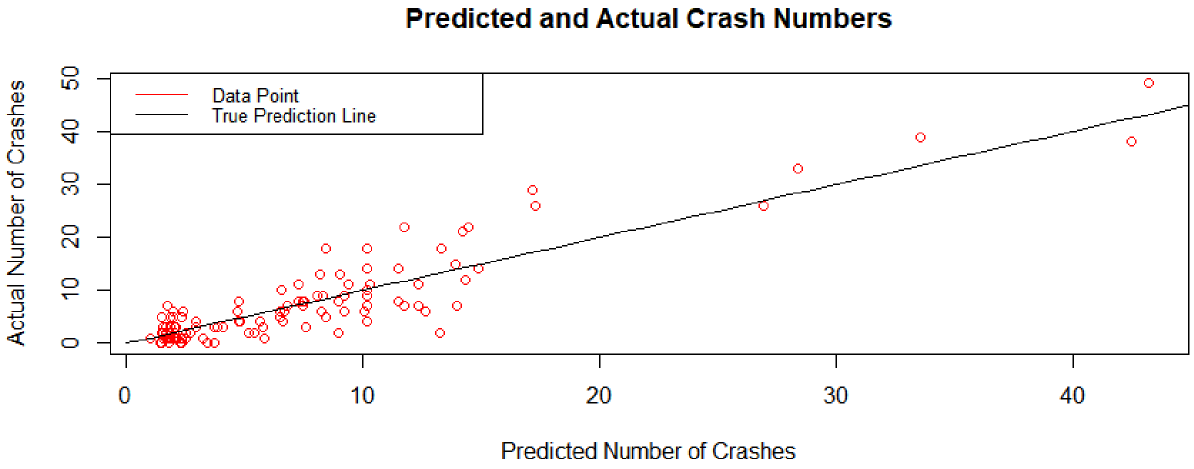


Figure 75. Predicted and actual crash numbers for signalized RCUTs Model 1 (Fatal and injury crashes)

Model 2

The second model (Model 2) consists of four variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-16.091	1.294	0.00	✓
Ln(Maximum Major AADT)	1.142	0.123	0.00	✓
Ln(Maximum Minor AADT)	0.555	0.085	0.00	✓
Number of U-turns	0.341	0.142	0.02	✓
Number of Major Lanes	0.202	0.119	0.09	✓
θ	6.60	1.87		
Log-likelihood	-563.8			
AIC	575.8			
Null Deviance vs. residual deviance	409.4 vs. 123.2			
Number of observations: 114, Number of variables: 4				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

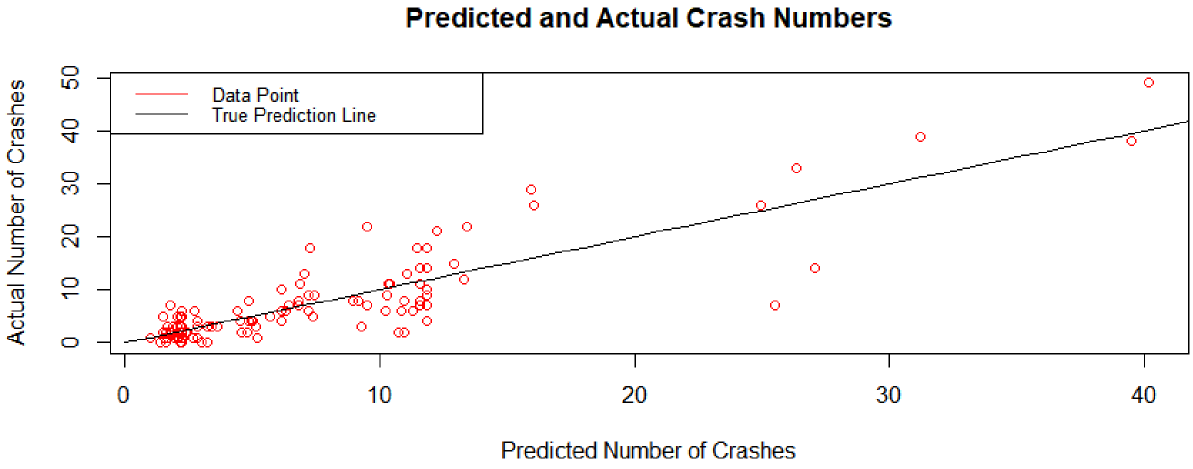


Figure 76. Predicted and actual crash numbers for signalized RCUTs Model 2 (Fatal and injury crashes)

Model 3

The third model (Model 3) consists of three variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-16.21	1.316	0.00	✓
Ln(Maximum Major AADT)	1.160	0.125	0.00	✓
Ln(Maximum Minor AADT)	0.604	0.082	0.00	✓
Number of U-turns	0.336	0.144	0.02	✓
θ	6.26	1.75		
Log-likelihood	-566.6			
AIC	576.6			
Null Deviance vs. residual deviance	399.2 vs. 123.5			
Number of observations: 114, Number of variables: 3				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

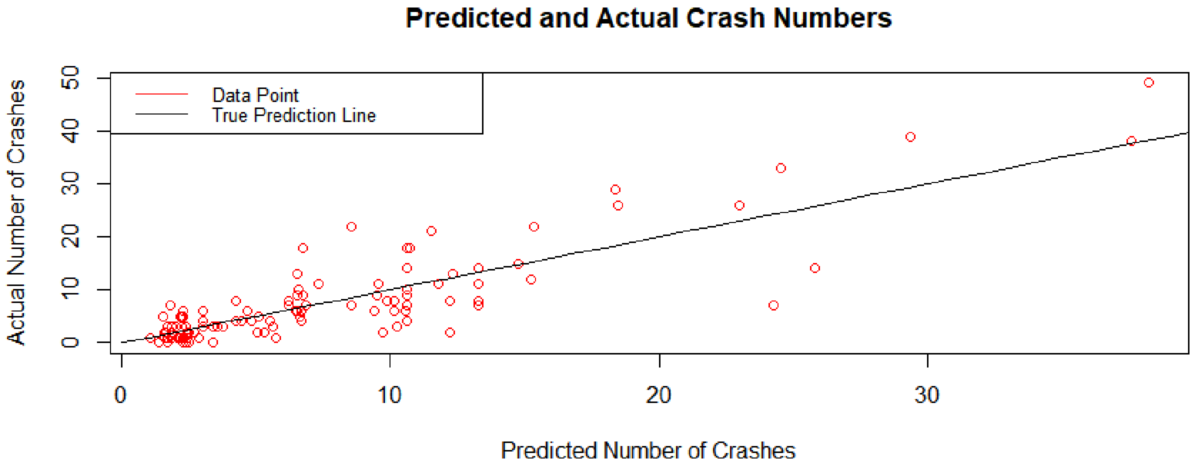


Figure 77. Predicted and actual crash numbers for signalized RCUTs Model 3 (Fatal and injury crashes)

Model 3WO (Without Outliers)

The final model (Model 3WO) consists of three variables including traffic- and geometric design-related factors after the removal of outliers. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-16.93	1.298	0.00	✓
Ln(Maximum Major AADT)	1.197	0.121	0.00	✓
Ln(Maximum Minor AADT)	0.652	0.082	0.00	✓
Number of U-turns	0.299	0.143	0.04	✓
θ	7.61	2.50		
Log-likelihood	-543.9			
AIC	553.9			
Null Deviance vs. residual deviance	435.4 vs. 124.2			
Number of observations: 114, Number of variables: 3				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

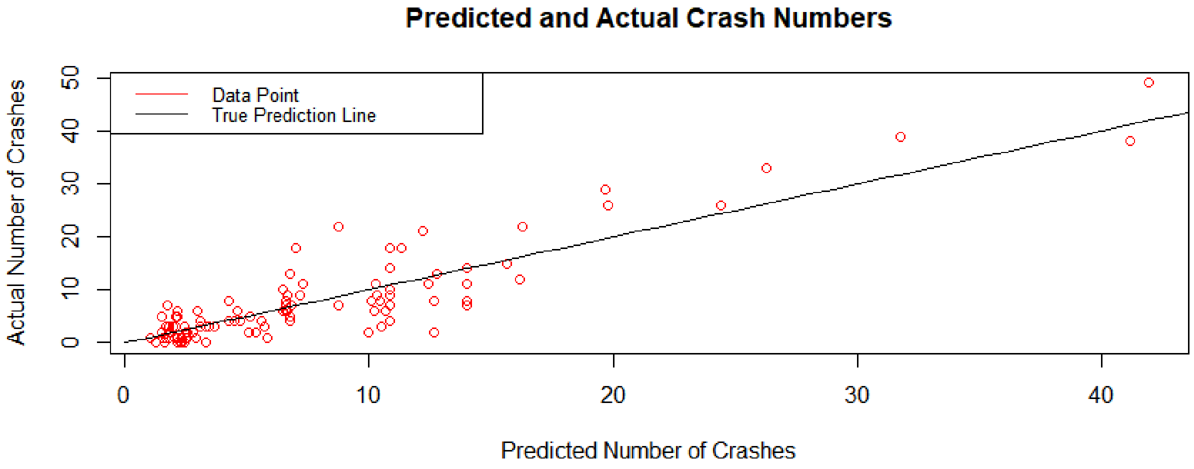


Figure 78. Predicted and actual crash numbers for signalized RCUTs Model 3WO (Fatal and injury crashes)

Appendix H. SPF Models for Unsignalized RCUTs

All Crashes

Model 1

The first model (Model 1) is also called the full model. Model 1 consists of six variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-4.884	1.226	0.00	✓
Maximum Major AADT	1.63e-5	6.01e-6	0.01	✓
Ln(Maximum Minor AADT)	0.433	0.075	0.00	✓
Ln(Total Offset Distance)	0.368	0.139	0.01	✓
Ln(Total Deceleration Lane Length)	-0.091	0.041	0.03	✓
Ln(Maximum Median Width)	-0.126	0.085	0.14	x
Number of Left-Turn Lanes on Major	0.623	0.369	0.09	✓
θ	3.54	0.74		
Log-likelihood	-982.7			
AIC	998.7			
Null Deviance vs. residual deviance	331.4 vs. 249.7			
Number of observations: 224, Number of variables: 6				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

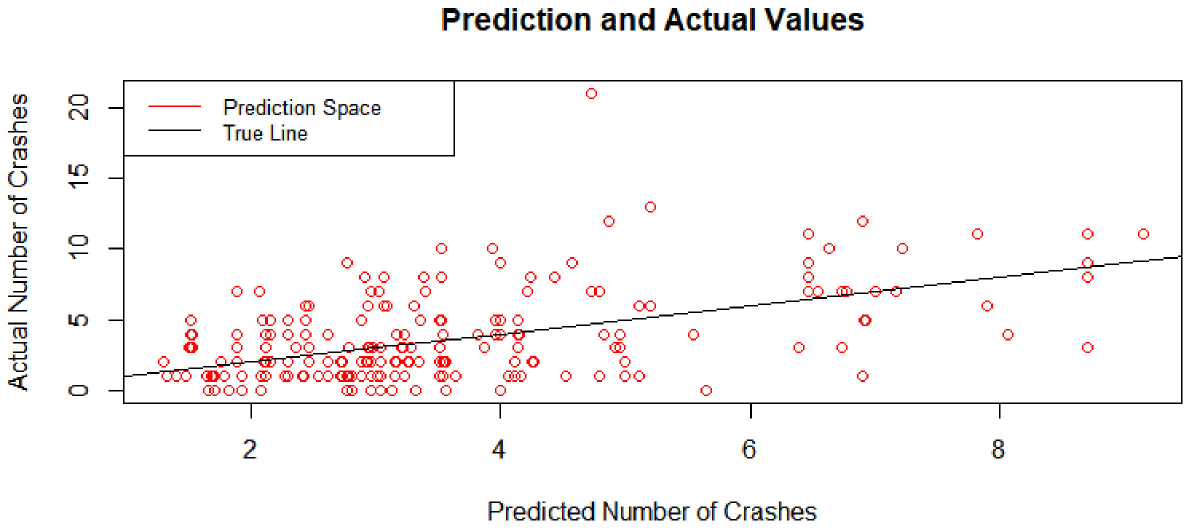


Figure 79. Predicted and actual crash numbers for unsignalized RCUTs Model 1 (All crashes)

Model 2

The second model (Model 2) consists of seven variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-4.283	1.170	0.00	✓
Maximum Major AADT	1.77e-5	5.96e-6	0.00	✓
Ln(Maximum Minor AADT)	0.394	0.071	0.00	✓
Ln(Total Offset Distance)	0.259	0.118	0.03	✓
Ln(Total Deceleration Lane Length)	-0.085	0.041	0.04	✓
Number of Left-Turn Lanes on Major	0.667	0.368	0.07	✓
θ	3.49	0.73		
Log-likelihood	-985.0			
AIC	999.0			
Null Deviance vs. residual deviance	329.5 vs. 250.6			
Number of observations: 224, Number of variables: 5				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

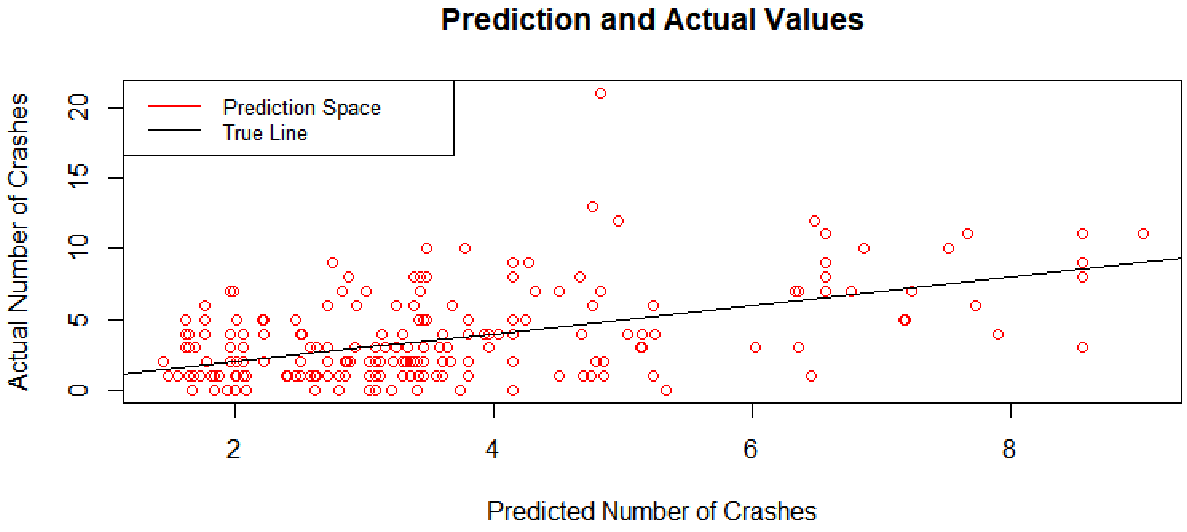


Figure 80. Predicted and actual crash numbers for unsignalized RCUTs Model 2 (All crashes)

Model 3

The third model (Model 3) consists of six variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-3.662	1.127	0.00	✓
Maximum Major AADT	1.78e-5	6.04e-6	0.00	✓
Ln(Maximum Minor AADT)	0.391	0.072	0.00	✓
Ln(Total Offset Distance)	0.263	0.118	0.03	✓
Ln(Total Deceleration Lane Length)	-0.081	0.042	0.05	✓
θ	3.37	0.69		
Log-likelihood	-988.4			
AIC	1000.4			
Null Deviance vs. residual deviance	324.7 vs. 250.6			
Number of observations: 224, Number of variables: 4				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

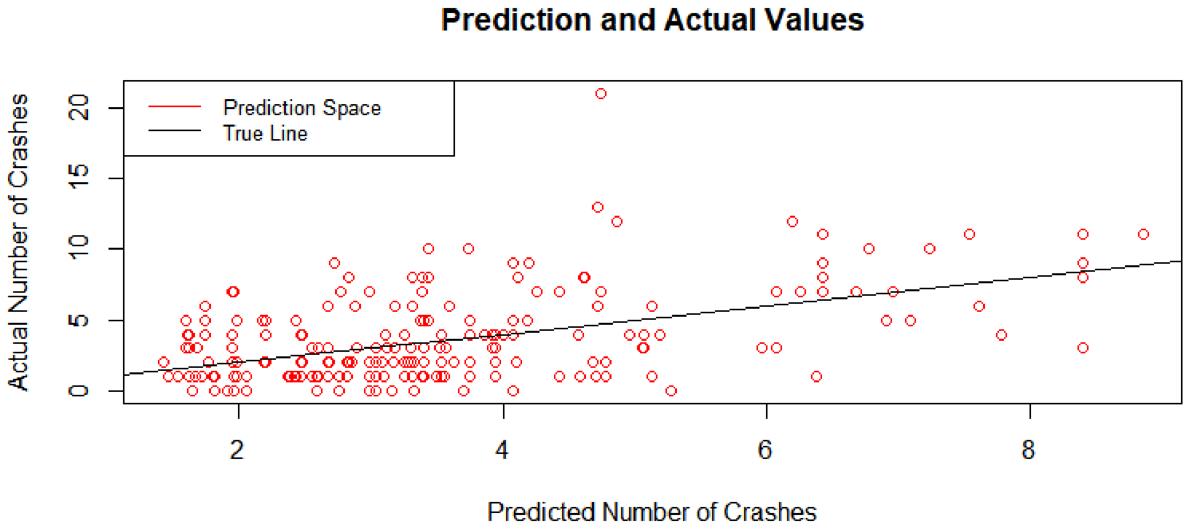


Figure 81. Predicted and actual crash numbers for unsignalized RCUTs Model 3 (All crashes)

Model 4

The fourth model (Model 4) consists of five variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-4.037	1.122	0.00	✓
Maximum Major AADT	2.13e-5	5.89e-6	0.00	✓
Ln(Maximum Minor AADT)	0.365	0.071	0.00	✓
Ln(Total Offset Distance)	0.264	0.120	0.03	✓
θ	3.19	0.63		
Log-likelihood	-992.5			
AIC	1002.5			
Null Deviance vs. residual deviance	317.2 vs. 249.2			
Number of observations: 224, Number of variables: 3				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

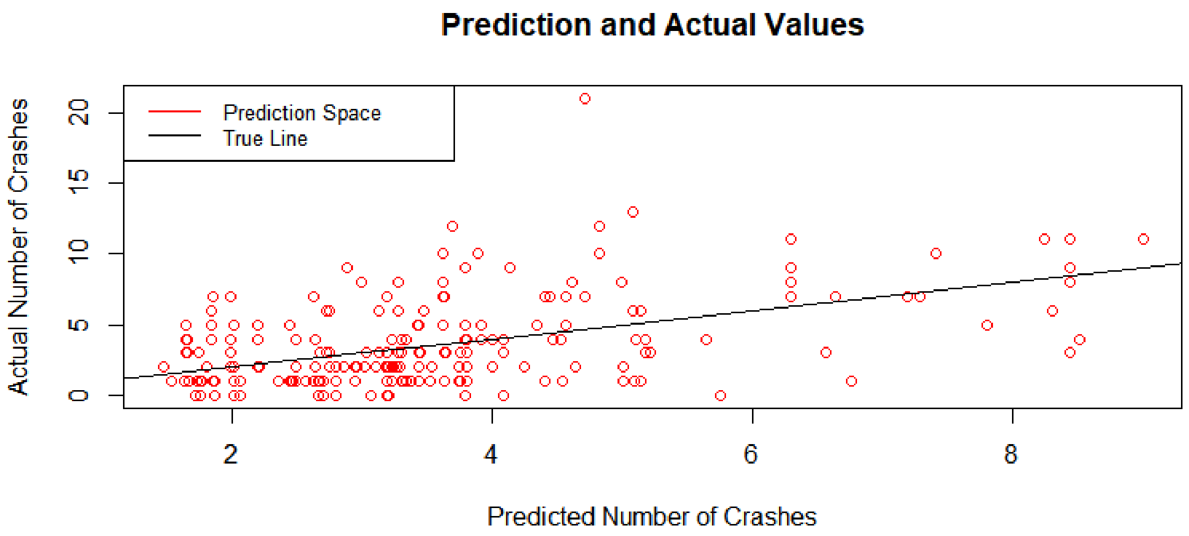


Figure 82. Predicted and actual crash numbers for unsignalized RCUTs Model 4 (All crashes)

Model 5

The fifth and last model (Model 5) consists of two variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-1.852	0.517	0.00	✓
Maximum Major AADT	2.09e-5	5.97e-6	0.00	✓
Ln(Maximum Minor AADT)	0.350	0.071	0.00	✓
θ	3.03	0.58		
Log-likelihood	-997.0			
AIC	1005.0			
Null Deviance vs. residual deviance	309.9 vs. 248.3			
Number of observations: 224, Number of variables: 3				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

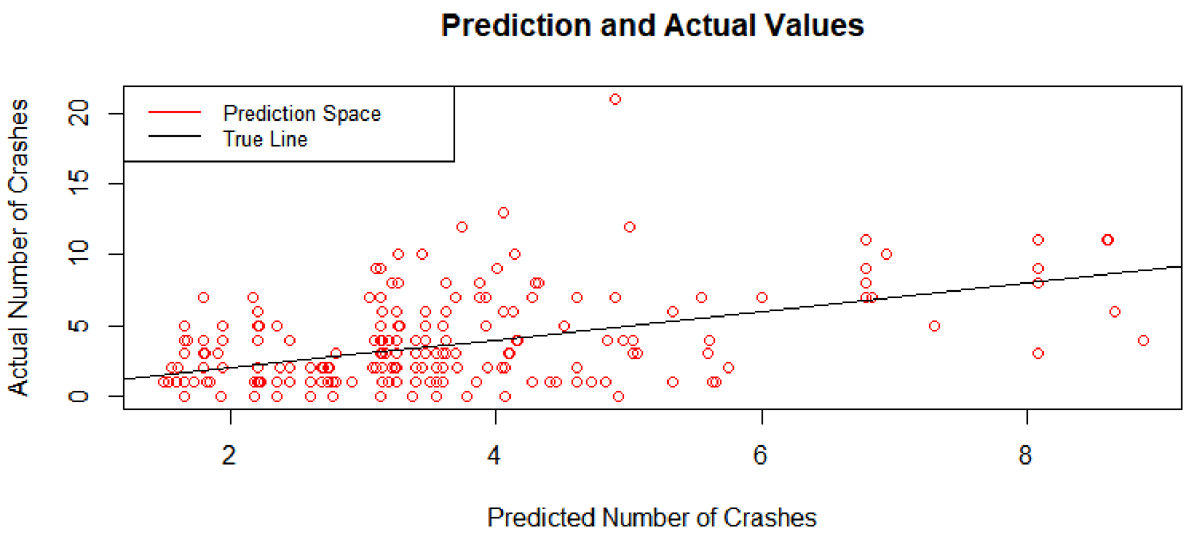


Figure 83. Predicted and actual crash numbers for unsignalized RCUTs Model 5 (All crashes)

Fatal and Injury Crashes

Model 1

The first model (Model 1) is also called the full model. Model 1 consists of eight variables including traffic-, geometric design-, and environment-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-9.234	2.141	0.00	✓
Ln(Maximum Major AADT)	0.501	0.157	0.00	✓
Ln(Maximum Minor AADT)	0.265	0.103	0.01	✓
Ln(Total Offset Distance)	0.506	0.194	0.01	✓
Ln(Total Deceleration Lane Length)	-0.133	0.050	0.01	✓
Ln(Maximum Median Width)	-0.197	0.112	0.08	✓
θ	3.53	1.42		
Log-likelihood	-624.8			
AIC	638.8			
Null Deviance vs. residual deviance	285.2 vs. 240.3			
Number of observations: 224, Number of variables: 5				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

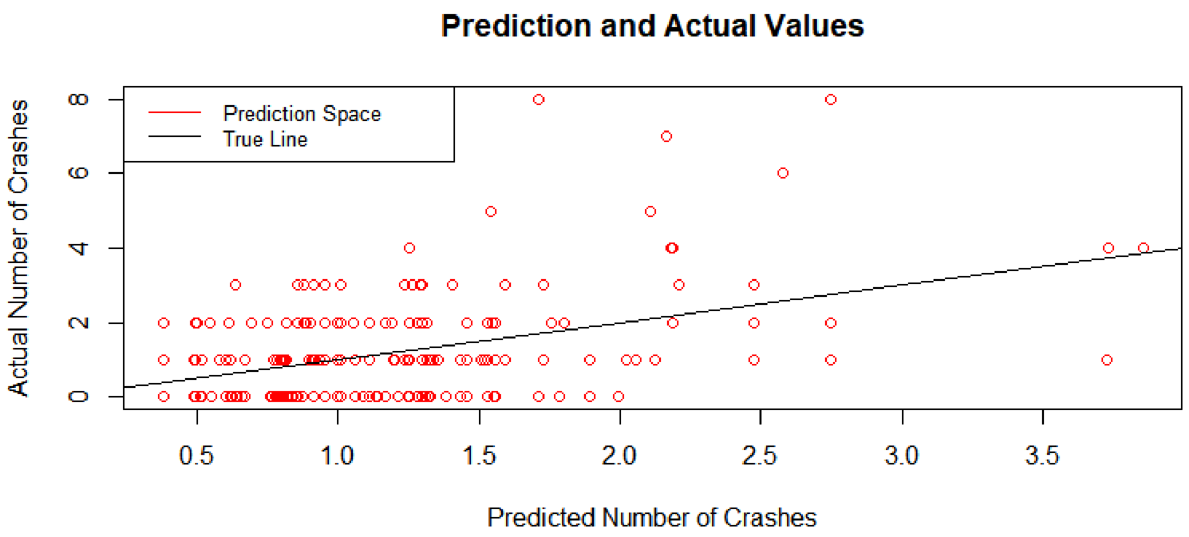


Figure 84. Predicted and actual crash numbers for unsignalized RCUTs Model 1 (Fatal and injury crashes)

Model 2

The second model (Model 2) consists of seven variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	p < 0.1
Intercept	-8.648	2.129	0.00	✓
Ln(Maximum Major AADT)	0.543	0.155	0.00	✓
Ln(Maximum Minor AADT)	0.205	0.097	0.03	✓
Ln(Total Offset Distance)	0.343	0.167	0.04	✓
Ln(Total Deceleration Lane Length)	-0.125	0.051	0.01	✓
θ	3.28	1.25		
Log-likelihood	-627.9			
AIC	639.9			
Null Deviance vs. residual deviance	280.7 vs. 239.8			
Number of observations: 224, Number of variables: 4				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

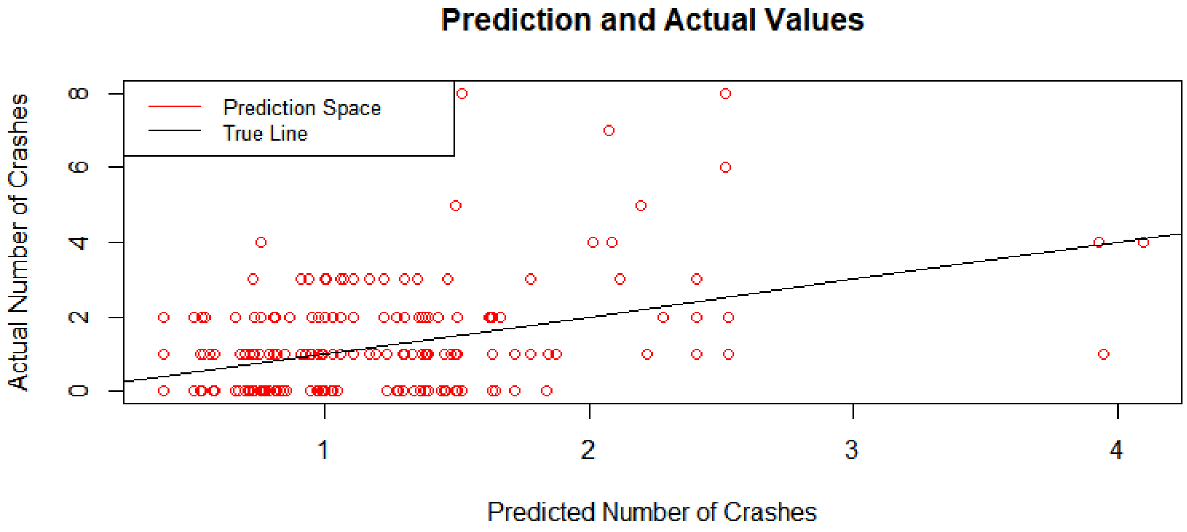


Figure 85. Predicted and actual crash numbers for unsignalized RCUTs Model 2 (Fatal and injury crashes)

Model 3

The third model (Model 3) consists of six variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-5.570	1.523	0.00	✓
Ln(Maximum Major AADT)	0.515	0.156	0.00	✓
Ln(Maximum Minor AADT)	0.191	0.096	0.05	✓
Ln(Total Deceleration Lane Length)	-0.129	0.053	0.01	✓
θ	3.05	1.12		
Log-likelihood	-632.0			
AIC	642.0			
Null Deviance vs. residual deviance	276.3 vs. 240.2			
Number of observations: 224, Number of variables: 3				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

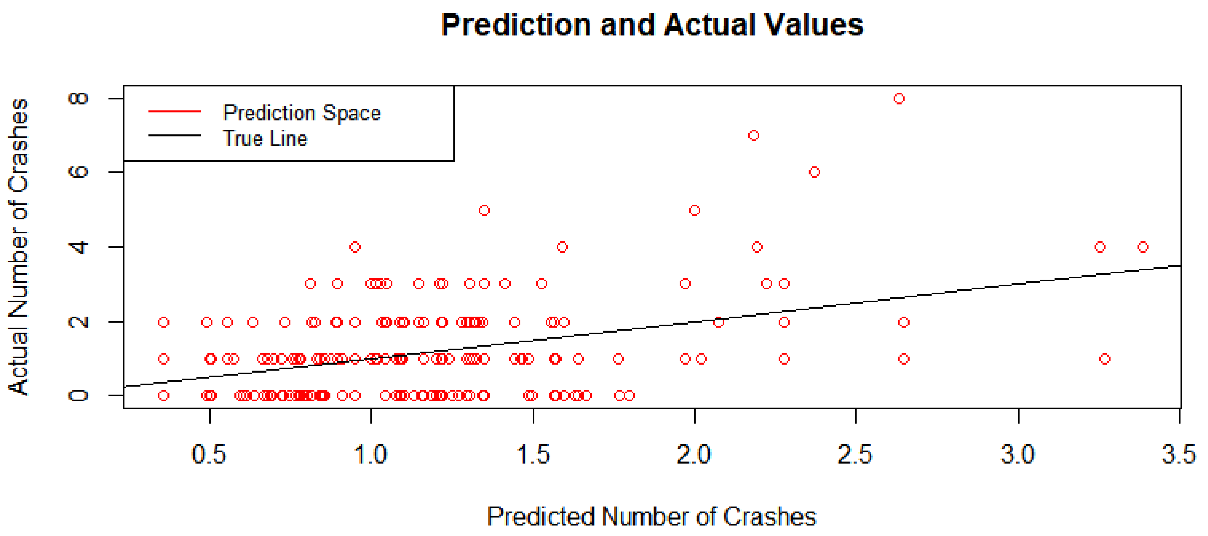


Figure 86. Predicted and actual crash numbers for unsignalized RCUTs Model 3 (Fatal and injury crashes)

Model 4

The fourth model (Model 4) consists of five variables including traffic- and geometric design-related factors. The model analysis results are given below.

Variables	β	S.E.	p	$p < 0.1$
Intercept	-6.886	1.435	0.00	✓
Ln(Maximum Major AADT)	0.599	0.154	0.00	✓
Ln(Maximum Minor AADT)	0.153	0.096	0.10	✓
θ	2.66	0.90		
Log-likelihood	-638.1			
AIC	646.1			
Null Deviance vs. residual deviance	267.5 vs. 239.0			
Number of observations: 224, Number of variables: 2				
Abbreviations	β: estimated coefficient mean, S.E. Standard Error, p: p value, θ: over-dispersion parameter, AIC: Akaike's Information Criterion			

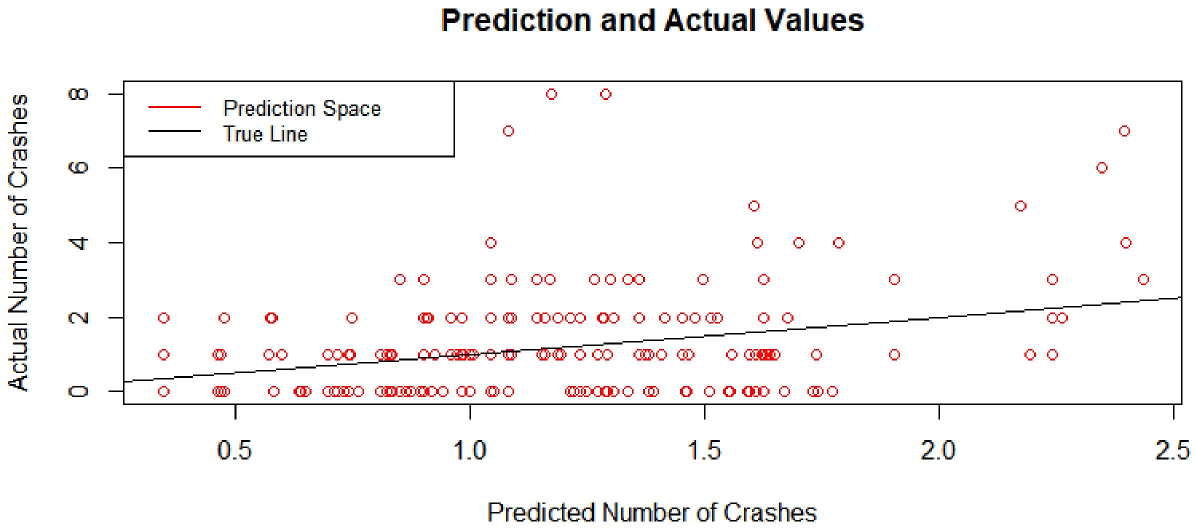


Figure 87. Predicted and actual crash numbers for unsignalized RCUTs Model 4 (Fatal and injury crashes)

Appendix I. Crashes and AADTs of Signalized and Unsignalized RCUTs

Signalized RCUT Crashes and AADTs

Location	Year	K	A	B	C	O	KABC	PDO	Total	Major AADT	Minor AADT	AADT Ratio
AL3	2012						4	10	14	27,000	5,000	5.4
AL3	2013						8	18	26	27,000	5,000	5.4
AL4	2012						0	0	0	39,000	1,000	39.0
AL4	2013						1	2	3	37,000	1,000	37.0
MD1	2015		5	2		22	7	22	29	62,062	17,953	3.5
MD1	2016		9	5		22	14	22	36	65,490	17,953	3.6
MI2	2011			2	16	42	18	42	60	57,000	5,400	10.6
MI2	2012		1	5	8	48	14	48	62	57,000	5,400	10.6
MI2	2013				7	34	7	34	41	57,000	5,400	10.6
MI2	2014			5	5	34	10	34	44	57,000	5,400	10.6
MI2	2015		1	2	6	31	9	31	40	57,000	5,400	10.6
MI2	2016				4	33	4	33	37	57,000	5,400	10.6
MI3	2011			1	1	8	2	8	10	9,700	9,000	1.1
MI3	2012		1			6	1	6	7	9,700	9,000	1.1
MI3	2013			1	1	5	2	5	7	9,700	9,000	1.1
MI3	2014				1	9	1	9	10	9,700	9,000	1.1
MI3	2015			1	2	5	3	5	8	9,700	9,000	1.1
MI3	2016			2	1	8	3	8	11	9,700	9,000	1.1
NC100	2007				1	7	1	7	8	30,000	1,438	20.9
NC100	2008					6	0	6	6	30,000	1,438	20.9
NC101	2007			1	5	4	6	4	10	30,000	1,438	20.9
NC101	2008			2	3	5	5	5	10	30,000	1,438	20.9
NC102	2007			2	3	12	5	12	17	28,000	1,566	17.9
NC102	2008			1	2	14	3	14	17	28,000	1,566	17.9
NC103	2013				1	4	1	4	5	23,500	4,100	5.7
NC103	2014			2	1	1	3	1	4	23,500	4,400	5.3
NC103	2015				1	2	1	2	3	23,500	4,500	5.2
NC103	2016				1	4	1	4	5	27,100	4,500	6.0
NC104	2015					3	0	3	3	23,500	1,000	23.5
NC104	2016			1	1	1	2	1	3	27,100	1,000	27.1
NC105	2007			1	1	4	2	4	6	32,000	2,600	12.3
NC105	2008				1	6	1	6	7	28,000	1,571	17.8
NC105	2009				2	5	2	5	7	27,000	2,200	12.3
NC105	2010			2	3	4	5	4	9	31,000	2,200	14.1
NC105	2011			1		4	1	4	5	31,000	2,200	14.1
NC108	2007			1	6	4	7	4	11	34,100	1,350	25.3
NC108	2008				2	9	2	9	11	29,500	1,400	21.1
NC108	2009			2	3	8	5	8	13	29,400	1,400	21.0

NC108	2010				1	4	1	4	5	32,000	1,400	22.9
NC108	2011			1	2	5	3	5	8	32,000	1,400	22.9
NC109	2014				4	9	4	9	13	32,500	3,500	9.3
NC109	2015				3	11	3	11	14	35,000	3,000	11.7
NC109	2016				4	9	4	9	13	35,000	3,000	11.7
NC110	2014	1		2	8	28	11	28	39	38,000	14,000	2.7
NC110	2015				8	30	8	30	38	42,000	14,000	3.0
NC110	2016	1		3	10	22	14	22	36	42,000	14,000	3.0
NC111	2014				4	11	4	11	15	38,000	5,500	6.9
NC111	2015			1	10	18	11	18	29	42,000	14,000	3.0
NC111	2016			2	5	28	7	28	35	42,000	14,000	3.0
NC113	2010			1	5	25	6	25	31	37,000	3,190	11.6
NC113	2011			1	3	20	4	20	24	38,000	3,190	11.9
NC113	2012			1	5	28	6	28	34	52,000	3,007	17.3
NC113	2013			2	4	22	6	22	28	50,500	3,052	16.5
NC113	2014			3	4	24	7	24	31	51,500	3,190	16.1
NC113	2015			4	6	33	10	33	43	51,000	3,007	17.0
NC113	2016			2	9	37	11	37	48	55,800	3,052	18.3
NC114	2015				2	4	2	4	6	16,000	9,500	1.7
NC114	2016				1	2	1	2	3	16,000	9,500	1.7
NC115	2016					4	0	4	4	16,000	3,000	5.3
NC115	2017					4	0	4	4	16,000	3,000	5.3
NC116	2016			1	5	19	6	19	25	16,000	7,700	2.1
NC118	2015				1	1	1	1	2	13,000	3,600	3.6
NC118	2016			1			1	0	1	13,000	3,600	3.6
NC95	2012					8	0	8	8	32,000	2,500	12.8
NC95	2013				3	10	3	10	13	32,000	2,500	12.8
NC95	2014				3	17	3	17	20	35,000	2,500	14.0
NC95	2015				3	13	3	13	16	33,000	2,500	13.2
NC96	2012				1	5	1	5	6	28,000	2,450	11.4
NC96	2013			2	1	2	3	2	5	28,000	2,300	12.2
NC96	2014			1		4	1	4	5	29,500	2,350	12.6
NC96	2015					4	0	4	4	31,000	2,400	12.9
NC97	2014					2	0	2	2	19,000	6,600	2.9
NC97	2015			2			2	0	2	20,000	7,250	2.8
OH1	2012			5	8	15	13	15	28	22,400	14,500	1.5
OH1	2013			7	11	29	18	29	47	22,400	15,300	1.5
OH1	2014		1	3	2	18	6	18	24	31,000	16,100	1.9
OH1	2015		1	6	11	31	18	31	49	31,600	17,042	1.9
OH1	2016			14	7	38	21	38	59	32,412	18,218	1.8
OH2	2012			1	4	13	5	13	18	25,500	7,500	3.4
OH2	2013			3	1	5	4	5	9	22,400	7,650	2.9

OH2	2014			2	4	19	6	19	25	31,000	7,700	4.0
OH2	2015			4	5	9	9	9	18	31,000	7,750	4.0
OH2	2016			1	4	12	5	12	17	31,000	8,000	3.9
OH3	2012			1	1	1	2	1	3	25,500	7,400	3.4
OH3	2013			2		5	2	5	7	26,500	7,400	3.6
OH3	2014				4	4	4	4	8	27,500	7,400	3.7
OH3	2015			2	1	4	3	4	7	28,000	7,400	3.8
OH3	2016				1	5	1	5	6	28,426	7,400	3.8
TX1	2012			5	21	65	26	65	91	89,180	8,200	10.9
TX1	2013		1	10	22	91	33	91	124	82,906	10,496	7.9
TX1	2014		1	8	30	67	39	67	106	87,314	12,800	6.8
TX1	2015			10	28	87	38	87	125	98,947	15,130	6.5
TX1	2016		2	13	34	73	49	73	122	100,467	15,130	6.6
TX2	2012			2	10	16	12	16	28	49,000	13,100	3.7
TX2	2013		1	8	13	32	22	32	54	49,104	13,200	3.7
TX2	2014	1		4	10	26	15	26	41	48,036	12,900	3.7
TX2	2015		1	1	24	47	26	47	73	54,533	14,669	3.7
TX2	2016	1	1	11	16	54	29	54	83	54,251	14,669	3.7
TX3	2012			1	7	17	8	17	25	48,860	6,732	7.3
TX3	2013			2	1	10	3	10	13	49,104	6,766	7.3
TX3	2014			3	5	30	8	30	38	48,036	6,619	7.3
TX3	2015			1	12	32	13	32	45	54,533	7,514	7.3
TX3	2016			1	7	19	8	19	27	54,251	7,475	7.3
TX3	2017				2	10	2	10	12	54,251	7,475	7.3
TX4	2012				2	8	2	8	10	44,610	7,435	6.0
TX4	2013			2	5	16	7	16	23	41,564	6,927	6.0
TX4	2014	1	2	5	14	46	22	46	68	41,522	6,920	6.0
TX7	2012			2	7	25	9	25	34	44,610	7,076	6.3
TX7	2013		1	1	5	21	7	21	28	41,564	7,076	5.9
TX7	2014			4	4	29	8	29	37	41,522	7,076	5.9
TX5	2013			6	3	5	9	5	14	50,279	9,969	5.0
TX5	2014			2	4	3	6	3	9	52,744	8,935	5.9
TX5	2015		1	8	2	10	11	10	21	57,567	7,724	7.5
TX6	2013	1	1	2	2	8	6	8	14	50,279	11,800	4.3
TX6	2014			5	2	2	7	2	9	52,744	12,729	4.1
TX6	2015	1	1	3	1	10	6	10	16	57,567	13,765	4.2

Unsignalized RCUT Crashes and AADTs

Code	Year	K	A	B	C	O	KABC	PDO	Total	Major AADT	Minor AADT	Rate
NC18	2013				2	7	2	7	9	23,000	5,100	4.5
NC18	2014					1	0	1	1	23,500	5,100	4.6
NC18	2015				1	6	1	6	7	24,000	5,100	4.7
NC24	2013					2	0	2	2	29,000	1,000	29.0
NC3	2011					1	0	1	1	23,000	4,400	5.2
NC3	2012					1	0	1	1	24,000	4,900	4.9
NC32	2014					1	0	1	1	33,000	2,000	16.5
NC32	2014					1	0	1	1	33,000	2,000	16.5
NC33	2012		1	1	1	1	3	1	4	26,000	2,500	10.4
NC33	2013			1	2	4	3	4	7	29,000	2,800	10.4
NC33	2014					5	0	5	5	28,000	2,800	10.0
NC38	2010			1		1	1	1	2	12,000	350	34.3
NC38	2011					1	0	1	1	13,000	350	37.1
NC38	2012					1	0	1	1	13,000	310	41.9
NC38	2013				1		1	0	1	13,000	310	41.9
NC38	2014					1	0	1	1	13,000	290	44.8
NC39	2011						0	0	0	16,000	500	32.0
NC39	2012						0	0	0	16,000	500	32.0
NC39	2013						0	0	0	16,000	500	32.0
NC39	2014						0	0	0	16,000	500	32.0
NC4	2010				2	1	2	1	3	20,000	380	52.6
NC4	2011					1	0	1	1	18,000	380	47.4
NC4	2013	1	1		1		3	0	3	16,000	420	38.1
NC4	2014				1	1	1	1	2	16,000	300	53.3
NC42	2009				2	1	2	1	3	26,000	4,300	6.0
NC42	2010					4	0	4	4	26,000	4,300	6.0
NC42	2011				1	3	1	3	4	26,000	4,300	6.0
NC42	2012				2	1	2	1	3	28,000	3,900	7.2
NC42	2013				1	3	1	3	4	27,000	3,900	6.9
NC43	2009				1	3	1	3	4	23,000	1,400	16.4
NC43	2010				1		1	0	1	23,000	1,400	16.4
NC43	2011					4	0	4	4	23,000	1,400	16.4
NC43	2012			2	1	2	3	2	5	22,000	1,600	13.8
NC43	2013				1	1	1	1	2	20,000	1,600	12.5
NC45	2008				1	8	1	8	9	37,000	8,700	4.3
NC45	2009			1	2	6	3	6	9	37,000	8,700	4.3
NC45	2010				1	2	1	2	3	37,000	8,700	4.3
NC45	2011				3	8	3	8	11	37,000	8,700	4.3
NC45	2012				2	6	2	6	8	37,000	8,700	4.3
NC45	2013			1	5	5	6	5	11	40,000	9,500	4.2

NC46	2009			1			1	0	1	23,000	290	79.3
NC46	2010					1	0	1	1	23,000	290	79.3
NC46	2011					1	0	1	1	23,000	290	79.3
NC46	2013					1	0	1	1	20,000	290	69.0
NC47	2009				1	11	1	11	12	20,000	6,100	3.3
NC47	2010			1	1	19	2	19	21	20,000	5,700	3.5
NC47	2011				1	6	1	6	7	20,000	5,700	3.5
NC47	2012			1		5	1	5	6	23,000	6,100	3.8
NC47	2013					1	0	1	1	23,000	6,100	3.8
NC48	2010			1	1	3	2	3	5	9,700	1,300	7.5
NC48	2011					2	0	2	2	10,000	1,300	7.7
NC49	2010					1	0	1	1	9,700	1,100	8.8
NC49	2011				1		1	0	1	10,000	1,100	9.1
NC49	2009					1	0	1	1	9,700	1,100	8.8
NC51	2008					1	0	1	1	9,200	1,500	6.1
NC51	2009				1	3	1	3	4	9,200	1,500	6.1
NC51	2010					2	0	2	2	9,200	1,500	6.1
NC52	2008				1	1	1	1	2	18,000	2,000	9.0
NC52	2009				2	2	2	2	4	18,000	2,000	9.0
NC52	2010				1		1	0	1	18,000	2,000	9.0
NC56	2007					1	0	1	1	20,000	2,000	10.0
NC56	2008				2	2	2	2	4	20,000	2,000	10.0
NC56	2009					2	0	2	2	20,000	2,000	10.0
NC56	2010				1	2	1	2	3	20,000	2,000	10.0
NC61	2007						0	0	0	8,400	420	20.0
NC61	2008						0	0	0	8,400	420	20.0
NC61	2009						0	0	0	8,400	420	20.0
NC61	2010						0	0	0	8,400	420	20.0
NC63	2004				3	3	3	3	6	28,000	1,000	28.0
NC63	2005			1	1	1	2	1	3	28,000	1,000	28.0
NC63	2006		1			2	1	2	3	28,000	1,000	28.0
NC63	2007				1	1	1	1	2	28,000	1,000	28.0
NC63	2009				1	2	1	2	3	28,000	1,000	28.0
NC63	2010	1		1		1	2	1	3	28,000	1,000	28.0
NC71	2005		1		1	1	2	1	3	14,000	3,400	4.1
NC71	2006				1	4	1	4	5	14,000	3,400	4.1
NC71	2007					2	0	2	2	14,000	3,400	4.1
NC71	2008					1	0	1	1	14,000	3,400	4.1
NC71	2009				2		2	0	2	14,000	3,400	4.1
NC79	2003				3	5	3	5	8	28,000	9,000	3.1
NC79	2004				3	8	3	8	11	28,000	9,000	3.1
NC79	2005				1	6	1	6	7	28,000	9,000	3.1

NC79	2006				1	8	1	8	9	28,000	9,000	3.1
NC82	2002					2	0	2	2	20,000	2,000	10.0
NC82	2003			1	1		2	0	2	20,000	2,000	10.0
NC82	2005			1			1	0	1	20,000	2,000	10.0
NC83	2002				1	1	1	1	2	17,000	480	35.4
NC83	2003				2	2	2	2	4	17,000	480	35.4
NC83	2004		1		2	2	3	2	5	17,000	480	35.4
NC85	2002	1	1		1	2	3	2	5	21,000	550	38.2
NC85	2003				1		1	0	1	21,000	550	38.2
NC85	2004				1	1	1	1	2	21,000	550	38.2
NC86	2002					4	0	4	4	21,000	550	38.2
NC86	2003			1	3	2	4	2	6	21,000	550	38.2
NC86	2004				2	3	2	3	5	21,000	550	38.2
MD2	2015		1	5	1	4	7	4	11	43,863	6,880	6.4
MD2	2016			1	3	2	4	2	6	43,766	7,061	6.2
MD2	2017		2	1		1	3	1	4	44,598	7,202	6.2
MD3	2015		4	1		2	5	2	7	45,069	11,300	4.0
MD3	2016			1		9	1	9	10	45,565	11,300	4.0
MD3	2017			2		3	2	3	5	47,722	11,500	4.1
MD6	2015					3	0	3	3	27,180	1,250	21.7
MD6	2016		1	1		2	2	2	4	23,020	1,300	17.7
MD6	2017						0	0	0	23,531	1,300	18.1
MD7	2015		4			3	4	3	7	27,180	6660	4.1
MD7	2016		1			6	1	6	7	23,020	6,821	3.4
MD7	2017		1				1	0	1	23,531	6,972	3.4
MD9	2015					2	0	2	2	27,351	974	28.1
MD9	2016			3		1	3	1	4	27,382	975	28.1
MD9	2017		1			2	1	2	3	28,550	990	28.8
MD10	2015		1			7	1	7	8	20,251	3,940	5.1
MD10	2016					8	0	8	8	20,232	3,941	5.1
MD10	2017			1			1	0	1	20,723	4,042	5.1
MD11	2015			1		6	1	6	7	13,051	2,212	5.9
MD11	2016			1			1	0	1	13,042	2,430	5.4
MD11	2017		1			3	1	3	4	12,340	2,531	4.9
MD12	2015					2	0	2	2	9,920	1,992	5.0
MD13	2015		2			1	2	1	3	11,102	2,740	4.1
MD13	2016					2	0	2	2	9,830	2,811	3.5
MD13	2017					3	0	3	3	10,051	2,872	3.5
MD15	2015					1	0	1	1	27,370	5,474	5.0
MD15	2016		1			3	1	3	4	27,291	5,458.2	5.0
MD15	2017					2	0	2	2	28,002	5,600.4	5.0
MN1	2012					1	0	1	1	9,400	2,450	3.8
MN1	2013					1	0	1	1	10,100	1,850	5.5

MN1	2014				1		1	0	1	10,100	1,850	5.5
MN2	2012				1	2	1	2	3	7,800	530	14.7
MN2	2013			1		4	1	4	5	7,800	530	14.7
MN2	2014			1	1	2	2	2	4	7,900	530	14.9
MN2	2015				1	3	1	3	4	8,400	530	15.8
MN3	2012					3	0	3	3	10,400	3,150	3.3
MN3	2013			1	1	7	2	7	9	11,200	2,600	4.3
MN3	2014				1	7	1	7	8	11,200	2,900	3.9
MN3	2015					2	0	2	2	11,600	2,900	4.0
MN4	2012			2			2	0	2	29,000	1,500	19.3
MN4	2013						0	0	0	30,000	1,500	20.0
MN4	2014					1	0	1	1	30,000	1,200	25.0
MN4	2015			1	1	1	2	1	3	28,500	1,200	23.8
MN5	2014				1	3	1	3	4	29,000	2,100	13.8
MN5	2015		1	1	3	3	5	3	8	30,500	2,100	14.5
MN6	2013			1	3	3	4	3	7	35,500	1,200	29.6
MN6	2014				1	4	1	4	5	37,000	1,100	33.6
MN6	2015			2	2	6	4	6	10	39,600	1,100	36.0
MN7	2014				2	1	2	1	3	18,000	3,850	4.7
MN7	2015				3	3	3	3	6	18,400	3,850	4.8
MN8	2014				1	6	1	6	7	15,000	3,950	3.8
MN8	2015			1	2	5	3	5	8	15,400	3,850	4.0
MO1	2014			2		5	2	5	7	6,311	1,262.2	5.0
MO1	2015						0	0	0	6,370	1,274	5.0
MO1	2016					1	0	1	1	6,370	1,274	5.0
MO2	2014			2		5	2	5	7	12,425	2,485	5.0
MO2	2015			1		5	1	5	6	13,218	2,643.6	5.0
MO2	2016			1		5	1	5	6	13,218	2,643.6	5.0
MO3	2014		2	6		4	8	4	12	16,025	3,365	4.8
MO3	2015			1		2	1	2	3	16,718	3,100	5.4
MO3	2016			2		5	2	5	7	16,718	3,100	5.4
MO4	2012			2			2	0	2	18,269	3,653.8	5.0
MO4	2013					2	0	2	2	18,434	3,686.8	5.0
MO4	2014						0	0	0	18,434	3,686.8	5.0
MO4	2015						0	0	0	18,434	3,686.8	5.0
MO4	2016			1		1	1	1	2	18,434	3,686.8	5.0
MO6	2012	1	2	4		3	7	3	10	14,522	2,904.4	5.0
MO6	2013			1		4	1	4	5	14,653	2,930.6	5.0
MO6	2014		1	2		1	3	1	4	14,653	2,930.6	5.0
MO6	2015			2		1	2	1	3	15,620	3,124	5.0
MO6	2016		2	1		1	3	1	4	15,620	3,124	5.0
MO7	2012			1		1	1	1	2	14,522	2,904.4	5.0
MO7	2013			1		2	1	2	3	14,653	2,930.6	5.0

MO7	2014		1	1		4	2	4	6	14,653	2,930.6	5.0
MO7	2015			2		6	2	6	8	15,620	3,124	5.0
MO7	2016			3		3	3	3	6	15,620	3,124	5.0
MO9	2015					6	0	6	6	18,354	1,465	12.5
MO9	2016		1	7		5	8	5	13	18,354	1,465	12.5
MO13	2010			1			1	0	1	10,137	2,027.4	5.0
MO13	2011					1	0	1	1	10,137	2,027.4	5.0
MO13	2012						0	0	0	10,137	2,027.4	5.0
MO13	2013					1	0	1	1	10,228	2,045.6	5.0
MO13	2014			1		2	1	2	3	10,228	2,045.6	5.0
MO13	2015			1			1	0	1	9,887	1,977.4	5.0
MO13	2016					1	0	1	1	9,887	1,977.4	5.0
MO14	2014					1	0	1	1	17,110	3,422	5.0
MO14	2015	1		1		1	2	1	3	18,669	3,733.8	5.0
MO14	2016					3	0	3	3	18,669	3,733.8	5.0
WI1	2013					2	0	2	2	6,400	2,300	2.8
WI1	2014					1	0	1	1	6,400	2,300	2.8
WI1	2015					2	0	2	2	6,600	2,300	2.9
WI2	2014					5	0	5	5	19,900	1,800	11.1
WI2	2015			1	1	8	2	8	10	19,900	1,800	11.1
WI2	2016					8	0	8	8	19,900	1,800	11.1
WI3	2014					2	0	2	2	17,600	3,520	5.0
WI3	2015					1	0	1	1	21,700	4,340	5.0
WI3	2016					2	0	2	2	21,700	4,340	5.0
WI5	2015						0	0	0	14,000	400	350.0
WI5	2016						0	0	0	14,000	400	350.0
MS1	2012					2	0	2	2	2,950	3,800	0.8
MS1	2013			1	1	1	2	1	3	2,950	2,400	1.2
MS1	2014				1	1	1	1	2	2,950	2,400	1.2
MS1	2015			1	1	1	2	1	3	2,950	2,400	1.2
MS1	2016				1	6	1	6	7	2,950	2,500	1.2
MS1	2017					4	0	4	4	2,950	2,600	1.1
MS2	2014				1		1	0	1	4,100	1,800	2.3
MS2	2015						0	0	0	4,100	1,800	2.3
MS2	2016						0	0	0	4,100	1,800	2.3
MS3	2014						0	0	0	13,000	2,400	5.4
MS3	2015				1	4	1	4	5	13,000	2,400	5.4
MS3	2016				2	7	2	7	9	13,000	2,400	5.4
MS3	2017				1	3	1	3	4	13,000	2,400	5.4
MS4	2013						0	0	0	5,300	530	10.0
MS4	2014						0	0	0	5,300	530	10.0
MS4	2015						0	0	0	5,300	600	8.8
MS4	2016				1		1	0	1	5,300	610	8.7

MS5	2016				2	3	2	3	5	4,400	1,500	2.9
MS5	2017				0	1	0	1	1	4,400	1,500	2.9
MS6	2015				1		1	0	1	11,000	1,600	6.9
MS6	2016			1		1	1	1	2	11,000	1,600	6.9
MS6	2017						0	0	0	11,000	1,600	6.9
MS7	2017			1		1	1	1	2	14,000	1,550	9.0
SC1	2013					3		3	3	21,200	2,124	10.0
SC1	2014					2		2	2	21,200	2,124	10.0
SC1	2015					1		1	1	21,200	2,124	10.0
SC1	2016						0	0	0	21,200	2,124	10.0
SC2	2014						0	0	0	8,500	1,380	6.2
SC2	2015					1		1	1	8,500	1,380	6.2
SC2	2016						0	0	0	8,500	1,380	6.2
GA2	2016						4	8	12	22,700	2,000	11.4
GA2	2017						5	15	20	24,000	2,000	12.0
GA3	2017						4	15	19	34,800	3,000	11.6
GA5	2017						0	11	11	34,800	5,350	6.5
GA6	2017						1	6	7	12,400	1,530	8.1
GA9	2017						3	2	5	4,490	500	9.0

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