AUBURN UNIVERSITY
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Research Report

DEVELOPMENT OF GUIDANCE FOR UNSIGNALIZED INTERSECTIONS ON RURAL MULTILANE DIVIDED HIGHWAYS

Submitted to

The Alabama Department of Transportation

Prepared by

Rod E. Turochy, Ph.D., P.E.

Huaguo Zhou, Ph.D., P.E.

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Highway Research Center
Harbert Engineering Center
Auburn, Alabama 36849

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16. Abstract

This research project examines the safety performance of unsignalized intersections on rural divided highways in Alabama. A summary of the safety problem at these intersections is provided; the concern is the relatively high frequency and severity of crashes at these locations, typically associated with vehicles entering from the minor road and failing to successfully cross or turn left onto the second directional roadway. The project objectives included review of the literature, examination of a small set of such intersections in Alabama with innovative treatments, factors that influence safety performance and approaches to estimating performance, and developing design guidance for these locations. During the course of this study, ALDOT developed an Intersection Control Evaluation (ICE) policy, which to some extent addresses the last objective. This study reviewed the literature, estimated calibration factors for safety performance functions for three-leg and four-leg intersections of this type, reviewed geometric and traffic control features that may improve safety performance, and examined differences in safety performance among several selected intersections in Alabama. A review of the literature and current practice found many treatments with respect to geometrics and traffic control devices that can be applied to the conventional form of this type of intersection with the goal of reducing crash frequency and crash severity. An analysis involving 47 three-leg and 65 four-leg intersections in the state yielded recommend calibration factors for the relevant safety performance functions. Several selected sites with atypical design and traffic control treatments were reviewed. Finally, a traffic conflict study across several intersections with conventional and unconventional treatments was conducted to further identify the types of conflicts that contribute to poor safety performance.

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ABSTRACT

This research project examines the safety performance of unsignalized intersections on rural divided highways in Alabama. A summary of the safety problem at these intersections is provided; the concern is the relatively high frequency and severity of crashes at these locations, typically associated with vehicles entering from the minor road and failing to successfully cross or turn left onto the second directional roadway. The project objectives included review of the literature, examination of a small set of such intersections in Alabama with innovative treatments, factors that influence safety performance and approaches to estimating performance, and developing design guidance for these locations. During the course of this study, ALDOT developed an Intersection Control Evaluation (ICE) policy, which to some extent addresses the last objective. This study reviewed the literature, estimated calibration factors for safety performance functions for three-leg and four-leg intersections of this type, reviewed geometric and traffic control features that may improve safety performance, and examined differences in safety performance among several selected intersections in Alabama. A review of the literature and current practice found many treatments with respect to geometrics and traffic control devices that can be applied to the conventional form of this type of intersection with the goal of reducing crash frequency and crash severity. An analysis involving 47 three-leg and 65 four-leg intersections in the state yielded recommend calibration factors for the relevant safety performance functions. Several selected sites with atypical design and traffic control treatments were reviewed. Finally, a traffic conflict study across several intersections with conventional and unconventional treatments was conducted to further identify the types of conflicts that contribute to poor safety performance.

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INTRODUCTION

1.1 BACKGROUND

Median openings on rural divided highways, sometimes referred to as expressways with partial access control, provide some of the greatest potential for frequent and severe crashes on the highway system. These high-speed facilities afford greater access to adjoining property owners than full-access-controlled freeways but are much less expensive to construct and maintain. However, since these facilities are not designed and operated as freeways, intersections are predominantly at-grade. At-grade intersections on divided highways with wide medians in rural settings have the potential for severe crashes due to the numerous conflict points and high speeds at these locations and are therefore worthy of study to determine treatments that may reduce the frequency and severity of the crashes that occur at these locations.

According to the Federal Highway Administration (FHWA) Publication Highway Statistics 2015, there are 1,247 miles of four-(or more) lane rural divided highways in Alabama that are not freeways (FHWA, 2015). The locations that are the focus of the proposed study are on these highways. These highways tend to have wide medians (>30 ft), which provide the safety benefits of a relatively large degree of separation of opposing direction of traffic. When drivers from side roads cross or turn left onto rural divided highways with full median openings, they tend to complete the maneuver in two stages: first crossing the “near” side roadway, and then pausing or waiting in the median before crossing or turning left onto the “far” side roadway. Drivers have to make multiple judgments pertaining to sight distances, approach speeds of crossing traffic, and available gaps in a high-risk, high-speed setting. As such, many characteristics of the “near” side roadway, “far” side roadway and median opening influence the potential for safe completion of this maneuver. Figure 1 shows an example of two-stage gap acceptance at a divided intersection.

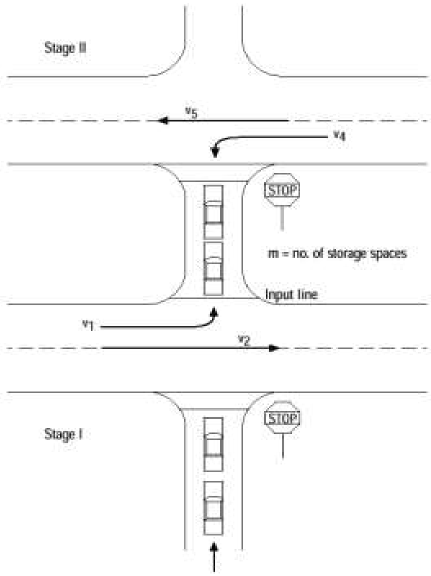


Figure 1. Example of Two-stage Gap Acceptance at a Divided Intersection (TRB 2016)

Further complicating the safe completion of a median crossing is the fact that many of these highways were constructed in multiple time periods with different design standards. In many cases, one of the two directional roadways was constructed in the early to mid-20th century, and more recently (late-20th or early-21st century) a parallel roadway was built to add traffic capacity and improve safety. In these cases, the older of the two directional roadways does not meet sight distance criteria for current practice (and driver expectations); this scenario can lead to sight distances that are less than adequate for the drivers on the side roads attempting to evaluate gaps and make decisions about when to enter or complete the intersection crossing maneuver.

As rural two-lane highways are being expanded to four-lane divided highways, and due to the relatively high crash frequency and severity experienced at these locations, the need for improvements in intersection configuration at these locations has drawn national attention in recent years. For example, in 2010, the National Cooperative Highway Research Program (NCHRP) published *NCHRP Report 650: Median Intersection Design for Rural High-Speed Divided Highways* (Maze et al. 2010). This report focused on documenting guidance for median opening design and traffic control devices (TCDs), reviewing the literature on safety effects of various intersection features, and reporting on case studies of several treatments that had been implemented in recent years. Another substantial effort in this area is FHWA's alternative intersection research program. In recent years, several innovative intersection configurations applicable to roadways with wide medians have been developed and seen varying levels of implementation nationwide. These research efforts provide many resources that can be used to aid in the development of an intersection configuration selection tool for use by ALDOT.

1.2 STUDY OBJECTIVES

With the lack of conclusive design guidance on selection of intersection type/configuration to improve safety at median openings on rural divided highways, the wide variety of design elements and features that exist among them, and the propensity for severe crashes in these scenarios, there is a need for study of these locations in Alabama and development of guidance for roadway designers to apply to relevant projects. Improvements to existing rural divided highways with two or more lanes in each direction as well as projects that convert a two-lane rural highway to a four-lane facility through construction of a parallel directional roadway present typical scenarios in which design guidance could be applied. ALDOT's Traffic and Safety Operations Section has performed some preliminary analyses to identify locations worthy of study due to their roadway geometries and crash histories.

This report aims to address the significance of the safety of unsignalized intersections on multilane rural high-speed highways by developing local calibration factors (LCFs) for the current safety performance functions (SPFs) based on the *Highway Safety Manual* (HSM), and selecting crash modification factors or functions (CMFs/ CMFunctions) to support agency decision making. SPFs are regression equations used in estimating the predicted number of crashes based on traffic volume and roadway features (Kolody et al. 2022). The LCF is used to adjust the predictive models to local conditions (Fletcher et al. 2014).

To attain the research objectives, the main tasks of this research are as follows:

- Develop LCFs for SPFs for 3-leg minor street stop-controlled intersections (3ST) and 4-leg minor street stop-controlled intersections (4ST) on multilane divided highways in HSM based on the calibration procedure outlined in the HSM. These calibration factors modify the predicted average crash frequencies from the default manual predictions to Alabama conditions.
- Apply state-specific calibrated SPFs for unsignalized intersections on rural divided highways in Alabama. The developed Alabama specific calibration factor is then used to calculate the predicted average crash frequencies at a specific intersection.
- Evaluate the performance of the calibrated SPFs when applied to a different set of intersections with similar characteristics as those used in developing the LCFs. Evaluation metrics include the difference between predicted and observed crashes, as well as percent error at each site, and the mean absolute percent error for the entire evaluation set of sites.
- Select appropriate countermeasures and CMFs/CMFunctions for Alabama, and develop guidance for roadway designers to assist in selection of intersection type/geometry on rural divided highway improvement projects.
- Evaluate safety effectiveness of the two types of median opening access control treatments through comparative studies using traffic conflict data (conflict rates and near crash rates), and driver performance features (e.g., whether stopping at the minor road, whether or not stopping at the median opening, and if the driver understands the right of way) collected in the state. The treatments are widely used in Alabama, but there are no CMFs of them.

1.3 REPORT ORGANIZATION

This report consists of six chapters. Chapter 1 includes the research background, objectives, and organization of the report. A comprehensive literature review of developing LCFs, statistical analysis of crash data, safety evaluation of countermeasures at unsignalized intersections, and conflict study at unsignalized intersections is provided in Chapter 2. Chapter 3 discusses the procedures for developing the LCFs for unsignalized intersections on rural multilane divided highways in Alabama. Chapter 4 introduces the selection of appropriate countermeasures and CMFs/ CMFunctions. Chapter 5 presents the safety impacts of two types of median opening access control treatments (stop/ yield control) at unsignalized intersections with wide medians recently installed in Alabama. Chapter 6 provides conclusions and recommendations of this study.

Chapter 2

LITERATURE REVIEW

2.1 INTRODUCTION

The literature review includes studies of the LCFs, studies on statistical analysis of crash data, safety evaluation of different countermeasures at unsignalized intersections (geometric design features, TCDs and other related design manuals), and the conflict studies at the unsignalized intersections.

Based on the previous literature, few studies focusing on creating Alabama localized SPF calibration factors at unsignalized minor-street stop-controlled intersections on rural high-speed divided highways have been identified. Additionally, past work shows that there are some currently applied treatment combinations that have no known CMFs, yet it is necessary to understand the effectiveness of those countermeasures. For example, use of Stop or Yield signs and pavement markings at the median openings of the intersections is a common treatment in Alabama, but the safety effectiveness is unknown. Therefore, researchers performed a conflict study to evaluate the safety effectiveness of the treatment, which is described in Chapter 5 of this report.

2.2 DEVELOPMENT OF LOCAL CALIBRATION FACTORS STUDIES

The HSM, published by the American Association of State Highway and Transportation Officials (AASHTO) in 2010 provides crash prediction models to evaluate roadway safety (Fletcher et al. 2014; Lord et al. 2016). These crash prediction models were developed based on several sites and crash data from several states for varying periods of time (Ogle and Rajabi 2018). As a result, it is recommended practice to calibrate these models for individual jurisdictions or local conditions. Calibration to local conditions accounts for differences in crash reporting thresholds, roadway inventory, weather conditions and traffic counts that vary among states (Aziz and Dissanayake 2017). Therefore, several states have conducted research studies to develop calibration factors that fit local conditions. In this section, case studies of calibration factor development and their findings are provided.

Recently, NCHRP Project 17-68: Intersection Crash Prediction Methods for the Highway Safety Manual developed the new SPFs for many different intersection configurations and traffic control types, including rural and urban all-way stop-controlled intersections, and three-leg intersections where the through movements make turning maneuvers at the intersections (Torbic et al. 2021). However, this work did not include the intersection type in this study, two-way stop-controlled intersections on a rural multilane highway. Zhang et al. (2021) studied the localized SPFs for rural three-leg two-way stop-controlled intersections in Alabama. The study used five-year (2014-2018) crash data and traffic volume information from the Critical Analysis Reporting Environment (CARE) and the Highway Performance Monitoring System (HPMS) and employed a spatial model, Geographically Weighted Negative Binomial Regression (GWNBR), to predict the crash frequency. This study also expanded SPFs with other variables, such as truck percentage, intersection angle and presence of turn lane. However, this study did not include the four-leg two-way stop-controlled intersections and the three-leg one-way stop-controlled intersections on high-speed divided highways.

Studies to calibrate localized SPFs have been performed in many states. A study in Oregon studied calibrated SPFs by applying the HSM procedure to Oregon conditions (Dixon et al. 2013). This study calibrated the SPFs for rural two-lane two-way roads, rural multilane, urban, and suburban arterial roads. Crash data from 2004 to 2006 with various sample sites for different facilities were considered in the study. From the analysis, it was observed that for most of the facility types the calibration factor values are smaller than 1. It was also noticed that the current Oregon crash reporting procedures and thresholds introduce a significant difference in observed crash proportions (much smaller). Another study also developed LCFs for 18 facility types in Maryland (Shin et al. 2014). Comparison of HSM default crash proportions and Maryland-specific data suggested that the SPFs as presented in the HSM overpredict the crashes; it was observed that for all the facility types the calibration factor values are less than 1.

Specifically pertaining to safety on rural two-lane and four-lane divided highways in Alabama evaluated the HSM predictive state-specific statistical models for rural segment facilities (Mehta and Lou 2013). The HSM recommended method and the special case of SPF estimation was used in the analysis. From SPF estimation method based on HSM, it was observed that the calibration factors for rural two-lane two-way rural roads and four-lane divided highways are 1.522 and 1.863 respectively. The study found that the calibration factors for rural two-lane two-way rural roads and four-lane divided highways are 1.392 and 1.103 respectively. This implies that SPFs as presented in the HSM underpredict the mean crash frequencies on these two facility types. Another study performed by Srinivasan et al. (2011) developed calibration factors, segment-and intersection-level SPFs from the HSM for Florida. From the analysis, it was suggested that these calibration factors are to be used with appropriate SPFs for project-level safety analysis in Florida. Another study pertaining to rural road safety developed SPFs for rural road segments and intersections in the state of Michigan (Gates et al. 2018). They have calibrated HSM based SPFs using Michigan specific data, which showed a significant difference in the goodness-of-fit of the HSM models across various site types. Consequently, Michigan specific SPFs were established. The results of their analysis show that three-leg stop-controlled intersections had lower crash occurrence rates than four-leg stop-controlled intersections. There was an increase in the crash occurrence with the increase in the horizontal curvature and skew angle. This suggests that the geometric design of the intersection itself plays a significant role in the crash rate and severity of an intersection and is something that should be taken into account when determining safety countermeasures.

Table 1 shows a summary of the development of state-specific calibration factors by facility type. Studies conducted in Oregon, South Carolina, Kansas, and Maryland had developed calibration factors for rural multilane segments and intersections. Calibration factors for rural two-lane two-way and multilane divided segments have been developed in Alabama.

Table 1. Case Studies of Development of Calibration Factors in Various States

Facility Type	State	Calibration factor
Rural Multilane Divided Segments	Oregon	0.78
Rural Multilane Three-legged Stop-controlled Intersections		0.16
Rural Multilane Four-legged Stop-controlled Intersections		0.40
Rural Multilane Divided segments	Florida	0.67
Rural Four-lane Divided Segments	South Carolina	0.61
Rural Multilane Three-legged Stop-controlled Intersections		0.55
Rural Multilane Four-legged Stop-controlled Intersections		0.26
Rural Four-lane Divided Segments	Kansas	1.436
Rural Multilane Three-legged Stop-controlled Intersections		2.87
Rural Multilane Four-legged Stop-controlled Intersections		0.91
Rural Two-lane Two-way Segments	Alabama	1.522
Four-lane Divided Segments		1.863
Rural Four-lane Divided Segments	Maryland	0.583
Rural Multilane Three-legged Stop-controlled Intersections		0.178
Rural Multilane Four-legged Stop-controlled Intersections		0.366

2.3 STUDIES ON STATISTICAL ANALYSIS OF CRASH DATA

A useful tool in implementing safety measures in unsignalized intersections was studied by Garber and Rivera (2010) who analyzed crashes at Virginia intersections and used the SPF to determine the potential for crash reductions at a specific location. Through this study, the SPFs that were used found annual average daily traffic as the most causal factor developed for the total crashes and those with fatal injuries. The SPFs were developed through a generalized linear model using a negative binomial distribution. What this accomplished was that the SPFs found were able to be utilized to determine the intersections with the highest potential for crash reduction by implementing safety measures. The authors also claimed that this method of using SPFs to identify intersections for improvements is more beneficial than using a crash rate or critical ratio method, potentially allowing for more beneficial and cost-effective safety measures.

Furthering this relation to geometric design as well as other traffic factors, Bauer and Harwood (2000) developed statistical models of the relationship between traffic crashes and highway geometric elements for at-grade intersections. They employed several statistical modeling approaches including lognormal, poisson, and negative binomial regression analyses. It was observed that there had been 16 and 39 percent of the variability in the crash data for the regression models of the relationships between crashes and intersection geometric design, traffic control, and traffic volume variables. It was found that negative binomial distribution models generally fit the crash data at rural 3ST and 4ST, and urban 3ST. Lognormal regression models were found more suitable for modeling crashes at urban, four-leg, stop-controlled and urban, four-leg, signalized intersections.

Bonneson and McCoy (1993) used a generalized linear model to relate crash frequency and unsignalized intersection traffic demands. They accomplished this by using a general linear model with a nonlinear regression procedure, with the best model fit method found to be a plot prediction ratio versus the expected number of crashes. Their findings suggested that, based on generated models, the mean crash frequency increases nonlinearly with increasing major or minor road demand. In their analysis of 125 intersections, they also found that a negative binomial distribution adequately described the distribution of crash frequency, which could be used to identify more hazardous locations within the roadway.

Another study focused on the geometric layout of intersections was performed by Burchett and Maze (2006) who analyzed the effects of different roadway characteristics, in addition to traffic volume, on the safety of at-grade, two-way stop control (TWSC) intersections. They used data from over 600 intersections in Iowa, identified the 100 best and 100 worst performing intersections based on the crash data, and performed a statistical analysis to determine what effect the intersection design and surrounding landscape held. Following this, the 30 intersections with the highest crash severity index rates were more thoroughly analyzed to further prove their findings. Ultimately what they discovered was that intersections on horizontal curves that are non-perpendicular had a much higher rate than on vertical curves or intersections on tangent sections, with judgment of gaps in the far lane being the most problematic for drivers at all intersection types. These tangent segments appear to be the safest geometric layout, experiencing 25% less right-angle crashes than other intersections. Maze et al. (2004) made an attempt to report the TWSC intersection safety strategies and intersection designs of the rural expressways in Iowa. In addition to this, crash characteristics of the TWSC intersections are also analyzed. From their analysis, some of the findings are crash rate, crash severity, and involvement of right-angle crashes increase as the minor roadway volume increases, which are observed as significant findings for systematically identifying intersections to improve or construct a new grade separated facility.

2.4 SAFETY EVALUATION OF COUNTERMEASURES AT UNSIGNALIZED INTERSECTIONS

2.4.1 GEOMETRIC DESIGN FEATURES

Expressway intersections present challenges to minor road drivers attempting to select gaps at unsignalized intersections with median openings. NCHRP Report 500, Volume 5 was developed to address unsignalized intersection collisions (Neuman et al. 2003). This guide mainly emphasizes different strategies like geometric design modifications and TCDs changes to improve safety at unsignalized intersections. Implementation of these strategies was ranked based on timeframe and relative cost. They also proposed a 11-step model process for implementing these programs of strategies for any given emphasis area of the AASHTO strategic highway safety plan. A guide for geometric design modifications at TWSC intersections addressed the safety effects of converting full movement stop-controlled intersections to right-in-right-out (RIRO) operation as measured by the change in crash frequency (Le et al. 2018). The dataset included 138 stop-controlled intersections with a mix of RIRO and full movement operations. A total of 109 with a mix of stop and signal-control are considered in the downstream intersection's dataset. A cross sectional analysis had been used to estimate the effects of turning movement restrictions between the sites with RIRO and full movement. Results of their analysis indicates reduction in crashes for stop-controlled intersections with RIRO compared to full movement. CMFs for total, intersection related, fatal and injury intersection-related crashes were found to be 0.55, 0.32, and 0.20 respectively.

A study pertaining to geometric design modifications considered offset right turn-lane implementation at three TWSC rural expressway intersections and recorded their safety performance using basic before-after crash data analysis (Hochstein et al. 2007). As a part of their research objective, they had conducted case studies with offset right-lane installations found in Iowa and Nebraska. From the results, it was observed that the frequency of near-side right-angle collisions had been decreased at TWSC rural expressway intersections by the provision of offset right-turn lanes. This finding demonstrates a potential safety measure to put into place to reduce the risk of at least certain kinds of crashes in an unsignalized intersection. The authors then assumed that this was due to eliminating a sight-distance obstruction caused by right-turning vehicles, however, this claim was not adequately studied to determine the crash reduction due to this factor. Another study (Zhou et al. 2017) found that the minor-road drivers' views of the through vehicles might be blocked by the vehicles on the right-turn lane of the major road. This sight blockage will lead to potential traffic conflicts and incidents at unsignalized intersections. The addition of an offset right-turn lane can prevent this type of potential traffic conflicts or incidents resulting from blocking the minor-road drivers' views of through vehicles behind right-turn vehicles. The field review of four intersections showed many potential conflicts occurred during the videotaping. Because the right-turn lane is offset, drivers from minor roads will be able to see the through vehicle that they wouldn't be able to see at a conventional right-turn lane intersection. No statistical conclusion can be made on whether the offset right-turn lane at the intersection will significantly reduce the total crash counts based on the historical crash data at the four selected sites. However, drivers' view blocking is a serious problem and needs to be addressed in a proactive manner instead of a reactive manner.

Specifically pertaining to rural road safety, a study analyzed high-speed rural intersections and suggested methods of improvement of safety (Tarko et al. 2012). The objective of the study was to develop a model to estimate how much different factors increase the frequency of crashes. As a part of their study, they had conducted statistical analysis on 553 existing intersections in Indiana and 72 existing intersections in Michigan using crash data between 2004 to 2007. A multivariate ordered probit model identified the factors that decrease or increase the frequency of crashes within the severity level. For the given intersection attributes, the model estimates the probabilities of various crash counts. Dependent variables are the number of crashes at the intersection for each level of severity whereas independent variables are various geometrics, land use, traffic, and other attributes of crashes. Based on their analysis, they have identified several safety factors such as the presence of horizontal curves within the intersection vicinity, traffic volume on the major road, and minor road functional class. Recommendations were made at the existing intersections like median closures, or that a median opening should be restricted to certain maneuvers. Construction of medians wider than 80 ft was suggested at the new intersections.

A study performed by Edara et al. (2013) evaluated the effectiveness of J-turn intersection design in Missouri utilizing field studies, crash analysis, and traffic conflict analysis. The analysis presented the results of performance measures which include operational, safety, and public opinion. They had conducted a crash analysis using empirical Bayes (EB) three-year before-after safety evaluation of five J-turn sites in Missouri. The EB analysis showed that the J-turn design resulted in 34.8% and 53.7% reduction in crash frequency for all crashes, all injury, and fatal crashes. It was also observed that average time to collision was found to be four times higher at the J-turn site compared to the control TWSC site among minor road turning vehicles, indicating greater safety at the J-turn site. The average wait time at the J-turn site was half the wait time at the control site, while the average travel time at the J-turn site was approximately one minute greater than at the TWSC site.

A safety measure that could be implemented is to change the layout of the unsignalized intersection. Hummer and Rao (2017) evaluated restricted crossing U-turn (RCUT) intersections, for the estimation of low-cost safety improvements. As a part of their research, they collected and analyzed crash data to develop a CMF for signalized RCUTs. The purpose of finding a CMF was to determine if an RCUT would be a suitable replacement for a standard intersection, from a safety standpoint. Based on the

results, the odds ratio tests showed that there were high-quality comparison sites available, and regression to the mean was not an issue, which helped to raise the accuracy of the study. Recommended values of CMF were found to be 0.85 for overall crashes and 0.78 for the injury crashes for the conversion of a conventional intersection to an RCUT intersection, suggesting that, in theory, RCUTs would be a safer intersection alternative. Additionally, should an RCUT be implemented, a report by Hummer et al. (2014) provide information and guidance on RCUT intersections. This report provides general information, planning techniques, evaluation procedures for assessing safety and operational performance, design guidelines, and principles to be considered for selecting and designing RCUT intersections. **Error! Reference source not found.**Error! Reference source not found. shows a list of RCUT intersections with CMFs by severity level. All these deployments were implemented in rural expressway or rural multilane settings.

Table 2. List of RCUT Treatments Deployed in Different States

Countermeasure	State	Setting Type	Study Period	Sites	Model	CMF (All)	Fatal	Injury	Author (Year)
RCUT	Maryland	Rural Four-Lane Divided Highways	1998-2003	9 RCUT Intersections	Simple B-A & EB Before-After, B-A Comparisons Adjusted for Annual Crash Rates at Conventional Intersections	Simple B-A: 0.7; B-A Comparisons: 0.72; EB: 0.56			Inman, V.W., & Haas, R. P. (2012)
Unsignalized Superstreets Design	North Carolina	Four-lane Divided Arterials	2004-2009	13 Superstreets	Traffic Flow Adjustment, Comparison-Group, EB Analysis	EB: 0.73	0.5	0.5	Ott, S. E., Haley, R. L. et al. (2012)
J-Turn Intersection	Missouri	Rural Expressway Stop Controlled Intersections	Before-after Period Varied for Different Treatment Sites	5 J-turn Intersections	EB Before-after Safety Evaluation	0.652	0.463	0.463	Edara, P., Sun, C., & Breslow, S. (2013)
Reduced Conflicts Intersections	Minnesota	Rural Expressways	Before Period: 2009-2011; After Period: 2013-2015	8 RCIs	Comparative Site Analysis	0.85	0	0	Leuer, D. & Fleming, P. K. (2017)

2.4.2 TRAFFIC CONTROL DEVICES

Another potentially effective safety measure that might reduce the crash rate and severity of intersections is installing more effective warning signs that will make drivers more aware of any unusual conditions. One such method was presented in a study by Himes et al. (2016) which evaluated a low-cost safety strategy known as intersection conflict warning systems (ICWSs). ICWS's are intended to reduce the frequency of crashes by alerting drivers to conflicting vehicles on adjacent approaches at unsignalized intersections. Some examples of ICWS's are flashing warning signs with messages such as "Traffic approaching when flashing" or "Look for traffic". They conducted an Empirical Bayes before-after analysis with ICWS installations in Minnesota, Missouri, and North Carolina. Each of these states included approximately 30 reference sites for four-leg intersections with four lanes on major roads for the analysis. The results show that there is a significant crash reduction for most crash types for both four-leg two-lane and four lanes on the major route. The ultimate finding from the observations made during this study was that the benefit-cost ratio of implementing ICWS's was 27:1 for all two-lane at two-lane intersections and 10:1 for four-lane at two-lane intersections, heavily implying that the safety benefits accomplished through this method are cost-effective. Studies pertaining to the safety evaluation of multiple strategies at stop-controlled intersections deployed in different states were presented in **Table 3**.

Table 3. Studies on Double Yellow Center Line and Yield Bar Marking Countermeasures

Countermeasure	State	Setting Type	Study Period	Sites	Model	CMF (All)	Fatal	Injury	Author (Year)
Signing, Pavement Markings Include Remark Existing Stop Lines, Crosswalks, Arrows, & Word Messages	South Carolina	Rural Stop-Controlled Intersections	2005-2014	918 Treatment Sites & 3000 Reference Sites	EB observational before-after	0.917	0.899	0.899	Le, T., Gross, F. B., et al. (2017)
Add Centerline & Stop Bar, Replace 24 Inches with 30-Inch Stop Signs	North Carolina	Urban		6	Simple B-A				Polanis, S. F. (2001)

Another method of sign implementation was proposed in a study by Preston et al. (2006) on an Intersection Decision Support (IDS) research project whose main objective is to find the causes of crashes at rural unsignalized intersections and then develop a technology solution to address the cause. A crash analysis in Minnesota was conducted, mainly focusing on the stop intersections in the rural areas. From their analysis, it was observed that strategies like minor street improvements such as Stop Ahead signs, a second Stop sign placed on the left side of the road, overhead red/yellow flashers, Cross Traffic Does Not Stop signs, and streetlights have been very effective at reducing intersection recognition crashes, but unfortunately were ineffective at addressing gap-related crashes. It was also noticed that many of the at-fault drivers are local to the area, living within 30 miles of the crash location. This could suggest that drivers regularly taking the given route might be less attentive towards the installed signage, instead of requiring some other safety measure to be more effective.

A summary of the studies on flashing beacons and stop ahead sign countermeasures deployed in different states was presented in **Table 4**. This Table also includes the number of sites, the statistical model employed, and CMFs developed for total, fatal, injury and angle crashes.

Table 4. Studies on Flashing Beacons and Stop Ahead Signs Countermeasures in Various States

Countermeasure	State	Setting Type	Study Period	Sites	Model	CMF (All)	Fatal	Injury	Author (Year)
Flashing Beacons	North Carolina & South Carolina	Rural Two-Way and Four-Way Stop-Controlled Intersections	2008	64 Sites in NC & 42 Sites in SC	Empirical Bayes B-A	0.95	0.9	0.9	Srinivasan, R., Carter, D., et al. (2008)
Signing & Pavement Markings Enhancements	South Carolina	Urban & Rural	2005-2014	434	Empirical Bayes B-A	0.917	0.899	0.899	Le, T. Q., Gross, F. & Harmon, T. (2017)

Figure 2 shows a series of basic low-cost countermeasures like “double up” or “gateposted” oversize warning signs, stop signs, street name signs, warning arrows at the stem of T-intersections and stop bars at stop-controlled intersections (Le et al. 2018).

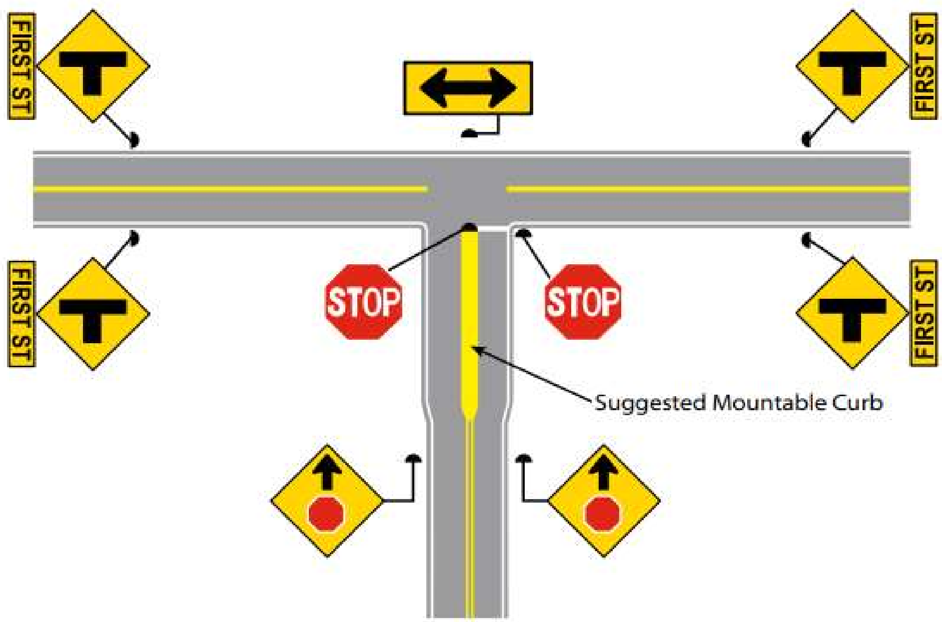


Figure 2. Examples of Low-Cost Countermeasures for Stop-Controlled Intersections in South Carolina (Le et al. 2018)

Rural high-speed at-grade intersections are prone to collisions due to gap acceptance issues. A study performed by Agent (1987) analyzed traffic control, and collisions at rural high-speed intersections in which a sample of 65 rural high-speed at-grade intersections across Kentucky were selected. The main objective of the study was to determine the traffic control measures used at rural high-speed intersections, discover factors that contribute to collisions, and recommend traffic control measures. From their analysis, it was found the type of right-of-way control used at different locations are stop sign, stop sign with beacon and traffic signal. The total number of crashes at different locations are noted based on right-of-way control. Changes in the number of crashes are also noted when right-of-way control has changed. They also analyzed characteristics of crashes at rural high-speed intersections which include various variables like directional analysis, crash severity, light conditions, road surface condition, and contributing factors. Another study associated with safety at side-street stop-controlled intersections developed an intersection safety technologies guidebook which contains several safety strategies to address traffic safety concerns at side-street stop-controlled intersections (Kuehl et al. 2016). Safety improvements range from low-cost sight triangle improvements to high-cost roadway geometric changes. In addition to these traditional methods, the use of Intersection Conflict Warning Systems (ICWS) and flashing LED STOP signs have proven effective in reducing severe crashes.

The literature review on geometric design and TCDs safety evaluations provides insights about the CMFs on crashes after the implementation of a countermeasure at a site. To account for intersection safety, Preston et al. (2008) conducted a safety analysis intersection decision support (IDS) technology at rural intersections. The objective of the study was divided into three parts: 1) identify factors that contribute to collisions at rural stop-controlled intersections; 2) develop a methodology to screen systems of rural intersections and identify candidates for the proactive deployment of low-cost safety strategies; 3) develop a criterion that would allow new technology to evaluate. A predictive methodology and a checklist type of approach are developed with the characteristics of an existing highway system based on the crash analysis.

2.4.3 OTHER RELATED DESIGN MANUALS

The *Manual on Uniform Traffic Control Devices* (MUTCD) contains guidance on treatments for divided highways with medians of 30 ft or greater, as shown in **Figure 3**. The MUTCD suggests treating this kind of median opening as two intersections. It suggests removing the bullet-nose, installing two stop lines at the median opening, and using a double yellow line at the middle to separate the traffic movements from opposite directions. The Stop sign, Yield sign, and One-way sign are also suggested (MUTCD 2019).

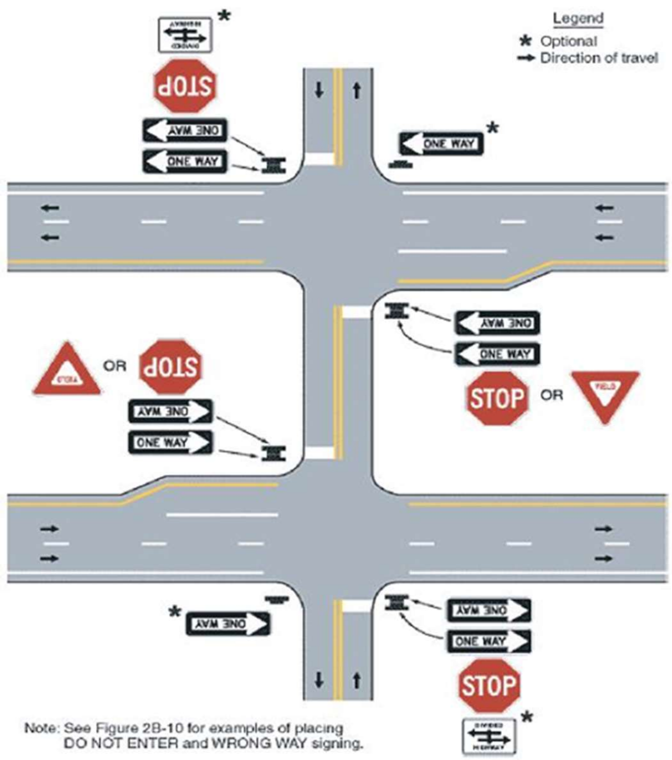


Figure 3. MUTCD Treatments for Divided Highways with Medians of 30 feet or Greater

Recently, the National Committee on Uniform Traffic Control Devices (NCUTCD) suggests divided highway crossings with median widths between 30 ft and 85 ft may function as either one or two intersections depending upon the interaction of the opposing left-turn vehicle paths and the available interior storage in the median for a crossing vehicle, as shown in **Figure 4**. The NCUTCD mentioned that other factors that could determine whether a divided highway crossing is operating as one or two intersections include: the geometric design of the divided highway crossing; the use of positive offset mainline left turn lanes; the length of the median opening (as measured parallel to the centerline of the divided highway); the geometric design of the median noses; other roadway geometric considerations such as a skewed side street approach or a variable median width; intersection sight distance; the physical characteristics of the design vehicle, and the observed prevailing driver behavior with regard to opposing left turn path interaction.

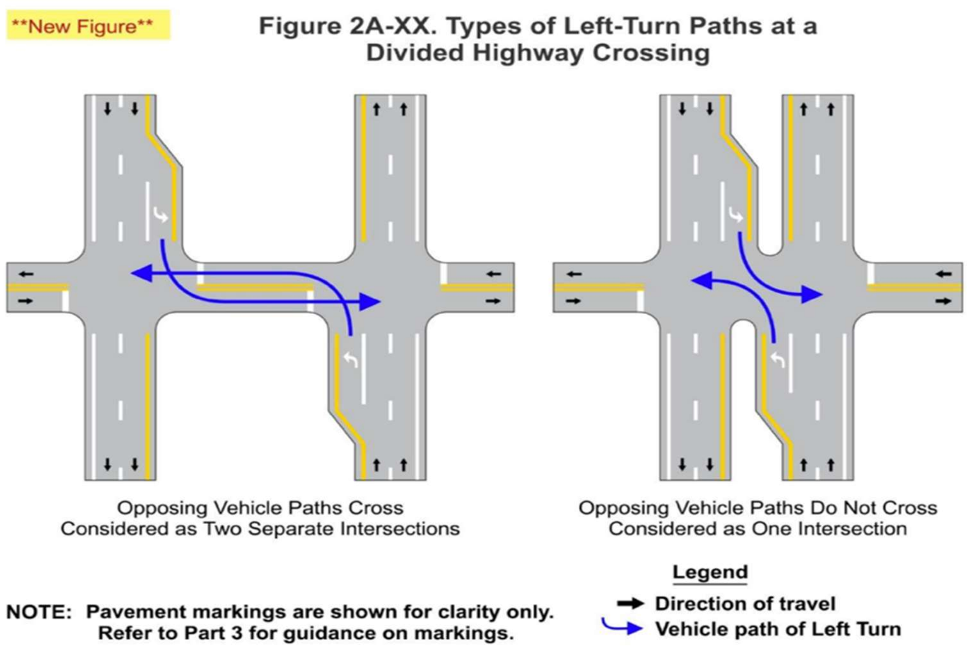


Figure 4. NCUTCD Recommended Treatments for Divided Highways with Wide Medians

NCHRP Report 500 suggested providing a double yellow line in the median opening of a divided highway to avoid the side-by-side queuing and angle stopping within the median area (Neuman et al. 2003). NCHRP Report 650 summarized the current related design guidance and recommended some revision (Maze et al. 2010). It also provided a literature review of the safety treatments at rural expressway intersections. Several case studies on selected rural expressway intersection safety treatments, alternative intersection designs (e.g., J-turn intersection, offset T-intersection, Jughandle intersection) are presented. The static roadside markers, left-turn median acceleration lanes, offset turn lanes, freeway-style advance intersection guide signing, and the dynamic advance intersection warning system are also studied by the researchers. The report gives some suggestions to improve the current design guide. For example, MUTCD does not currently provide adequate guidance for TWSC rural expressway intersections to identify and incorporate any TCDs to assist minor road drivers with their decision-making processes for judging and selecting safe gaps in the expressway traffic stream. The report suggests MUTCD providing some guidance and uniformity for the use of devices as experimental treatments or after they have been sufficiently proven to be effective gap selection aids.

Additionally, field data examined in NCHRP Report 375 suggested that opposing left-turn drivers leaving the expressway tend to turn in front of one another (i.e., simultaneous left-turns) when the median width is 50 feet or less, but tend to turn behind one another (i.e., interlocking left-turns) when the median width is greater than 50 ft, as shown in

Figure 5. The turning behavior of opposing left-turn can also be affected by the median opening length, but NCHRP Report 375 did not discuss it, nor was the turn behavior of opposing minor road left-

turn drivers (Harwood et al. 1995). There is some other literature related to median designs (Qi et al. 2012; Dissanayake et al. 2003; Stamatiadis et al. 2009), but they either did not focus on rural highways or were not related to wide median openings. Therefore, in this study, the researchers evaluated the safety effect of two different experimental access controls at median openings of unsignalized intersection based on a conflict study.

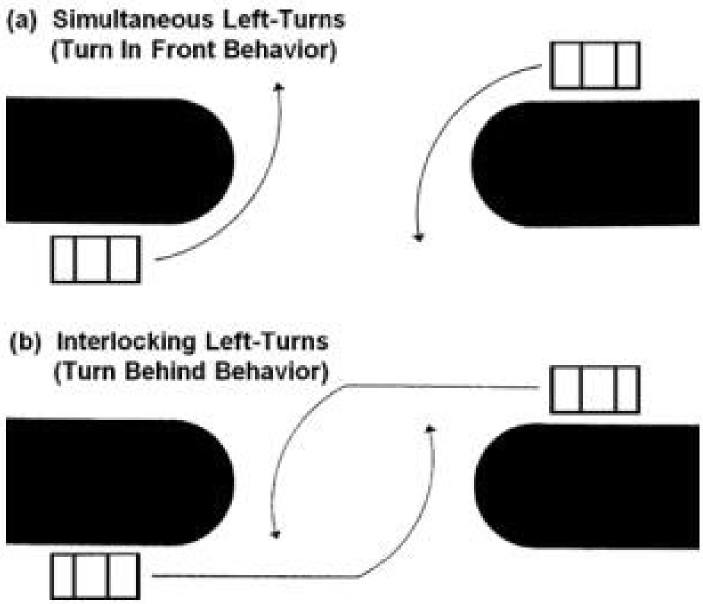


Figure 5. Opposing Left-Turn Leaving Driver Behavior

2.5 CONFLICT STUDY AT UNSIGNALIZED INTERSECTIONS

Crash data is reactive, and safety evaluation takes place after crashes occur, yet conflicts at specific locations are often early warning signs of crashes. Crash data analyses often need more than 5 years to achieve statistical significance, but conflicts occur more frequently and require short periods of observation to capture infrequent events of interest. Using crash surrogate events that properly reflect the data-generating mechanism is critically important (Tarko 2021).

Glauz and Migletz (1980) first proposed the concept of safety-relevant event continuity, as shown in Figure 6. Safety-relevant events including the different level of conflicts and the crash. Figure 7 shows the conceptual safety pyramids built by Hydén in 1987, which shows the relationship between the different level of crash and conflicts (Hydén 1987). Recently, Tarko (2021) summarized the past literature on traffic conflicts and their connection with crashes.

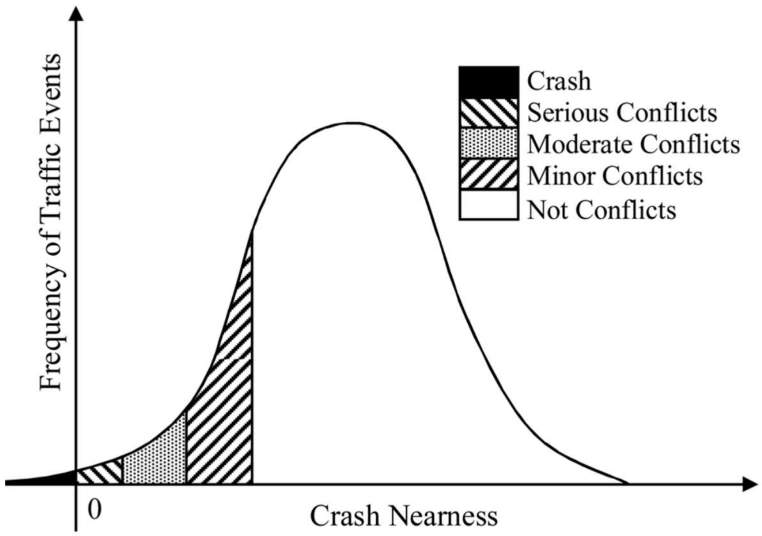


Figure 6. Concept of the Continuous Distribution of Crash Nearness as a Bridge Between Crashes, Near-crashes, and Other Safety-relevant Events (Glauz and Migletz, 1980)

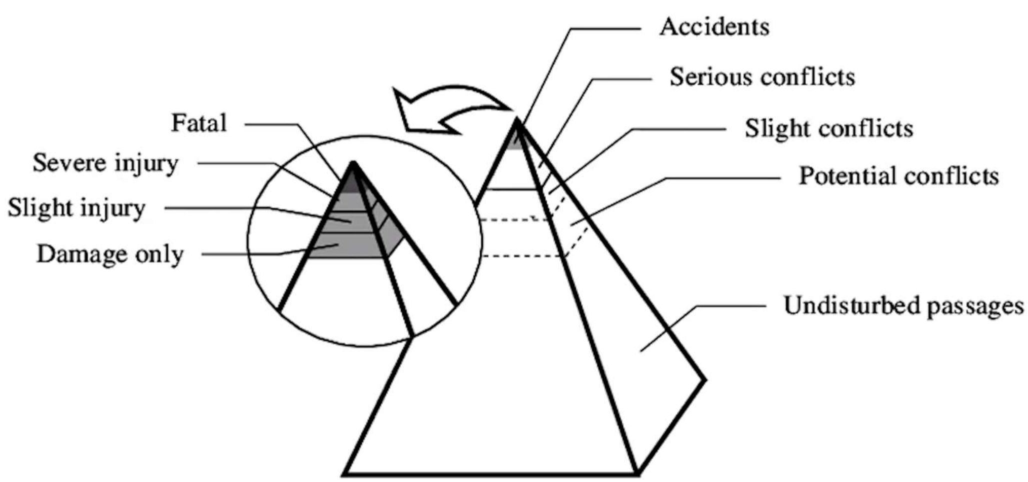


Figure 7. Conceptual Safety Pyramid (Hyden, 1987)

Zheng et al. (2019) suggested that the common conflict indicators at the intersection include: 1) post encroachment time (PET); 2) time to collision (TTC); 3) deceleration to avoid a crash (DRAC). PET is the time difference between the moment an 'offending' vehicle passes out of the area of potential collision. Many studies consider PET smaller than 3 seconds as a conflict, and PET smaller than 2 s as a critical conflict, as shown in Figure 8 below (Zheng et al. 2019; ITS Pactrans 2020). TTC is the time required for two vehicles to collide if they continue at their present speeds and on the same path. Studies usually use the indicator of the risk of collision (ROC): low, moderate, and high, based on the value of TTC, as shown in Table 5. Many studies consider a value for TTC smaller than 1.5 s as a conflict. DRAC is the rate at which a following vehicle must decelerate to avoid the collision with the leading vehicle. Many studies consider vehicle DRAC larger than 11 ft/s^2 as a conflict.

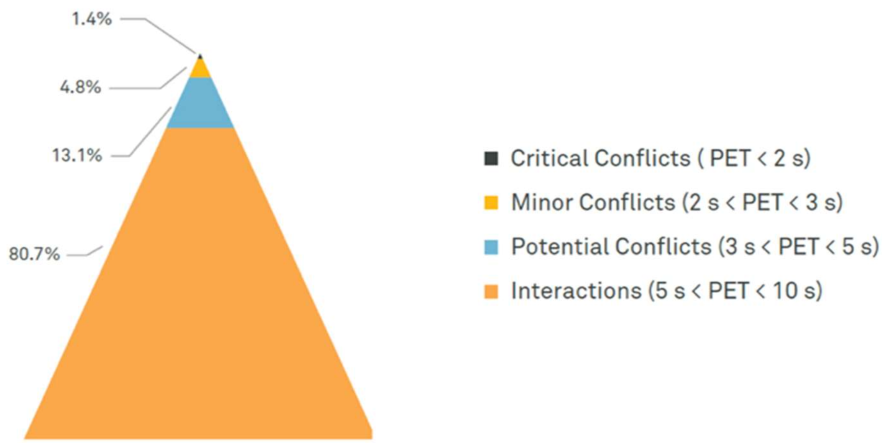


Figure 8. Frequency of Intersections with Different PET Volumes

Table 5. Time to Collision and Risk of Collision Scores

TTC and ROC Scores	**TTC (s)**	**ROC**
1	1.6-2.0	Low risk
2	1.0-1.5	Moderate risk
3	0.0-0.9	High risk

Chapter 3

DEVELOPMENT OF LOCAL CALIBRATION FACTOR FOR UNSIGNALIZED INTERSECTIONS ON RURAL MULTILANE DIVIDED HIGHWAYS

This chapter includes three parts which address the data collection, analysis methods, and results of the LCF development process for unsignalized intersections on rural divided highways. Regarding data collection, the observed crash data collection and the inputs for the HSM crash prediction are presented. In the next section, the methodology for the HSM crash prediction method for rural divided highways, adjustment for predicted crash using CMFs, LCF estimation, and the validation of the calibration factor will be covered. The final section includes the LCF calculation results, and the evaluation of the LCF.

Figure 9 shows a flowchart with a sequence of steps involved in developing the LCFs. In this study, the predictive models (SPFs) for 3-leg and 4-leg unsignalized intersections in HSM on rural multilane divided highways were selected for developing LCFs using the crash data in Alabama. Researchers identified these two types of intersections in Alabama with adequate crash data and traffic volume data (Annual Average Daily Traffic (AADT)) in the study years (2012-2020). After determining the study sites, researchers collected all the input information for the HSM spreadsheet and calculated the total unadjusted predicted crash frequency. The total observed crash frequency was also summarized.

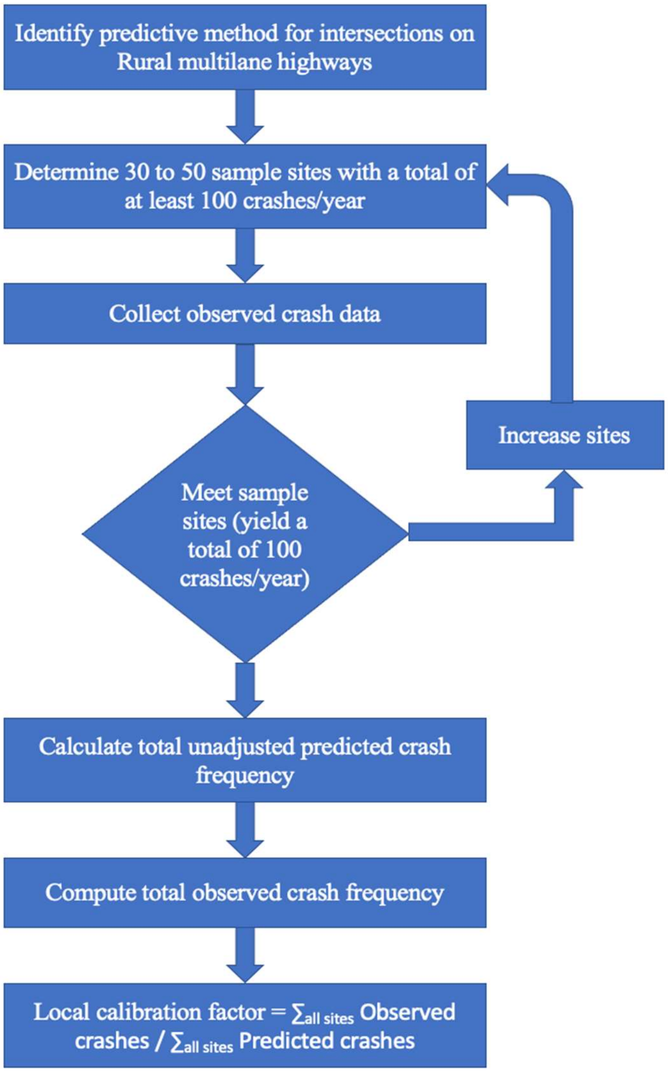


Figure 9. Procedure for Estimating the LCFs

3.1 DATA COLLECTION

3.1.1 OBSERVED CRASH DATA COLLECTION

Crash data from 2012 to 2020 on Alabama rural divided highways were collected from the Critical Analysis Reporting Environment (CARE) software. This research aimed to collect intersection-related crashes that occurred at unsignalized intersections on rural divided highways in Alabama. A logic tree was created in the CARE database as shown in **Figure 10**.

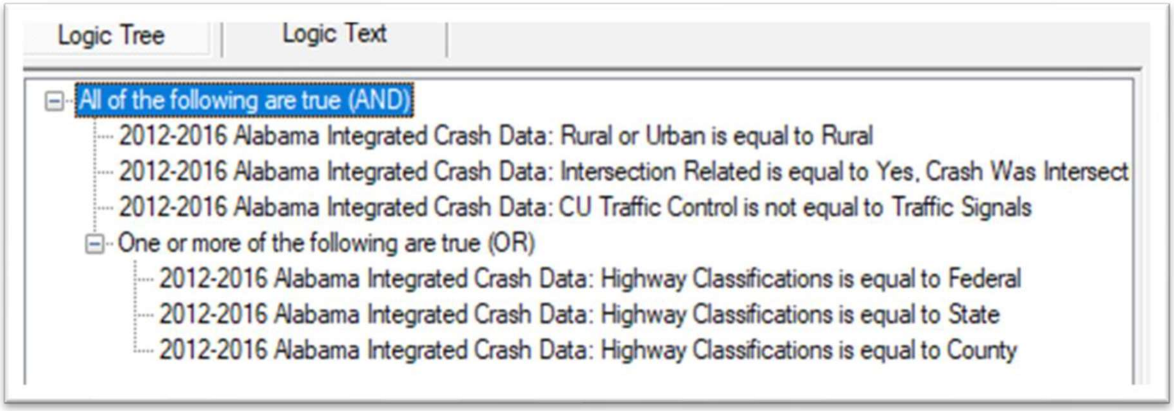


Figure 10. Logic Tree for Crash Records of Specific Interest

Intersections with depressed median widths of 30 ft or wider are the specific area of interest; therefore, data is further screened to meet this criterion. Crashes on facilities with two-way left-turn lane (TWLTLs) medians which were encountered during the screening process were also removed. Each of these crash records includes a unique crash identity number, crash severity, crash type, driver related factors, and environmental factors. This information was critical to obtain descriptive statistics. **Table 6** shows the intersection median width distribution based on intersection types.

Table 6. Intersection Median Width Distribution based on Intersection Type

Intersection Type	Geometric Characteristics	Frequency	Percentage
3ST (47)	30-50	20	44 %
	51-70	21	44 %
	71-130	6	13 %
4ST (65)	30-50	17	26 %
	51-70	42	65 %
	71-130	6	9 %

Locations whose configurations remained the same over the study period were initially identified. The HSM calibration procedure recommends 30 to 50 sample sites with a total of at least 100 crashes per year. A list of intersections that had not been treated with safety countermeasures was selected from routes including US-82, US-80, US-11, US-43, US-72, US-431, SR-157, SR-69, and SR-24 as a representative statewide sample of rural multilane divided highways. Most of these routes have four-lane divided highways with wider medians greater than 30 ft, which were the focus of this study. The research team used these intersections as potential reference sites. **Figure 11** shows the locations of the reference sites/intersections as a representative statewide sample considered in this study. The information for all the study intersections can be found in **Appendix A**.

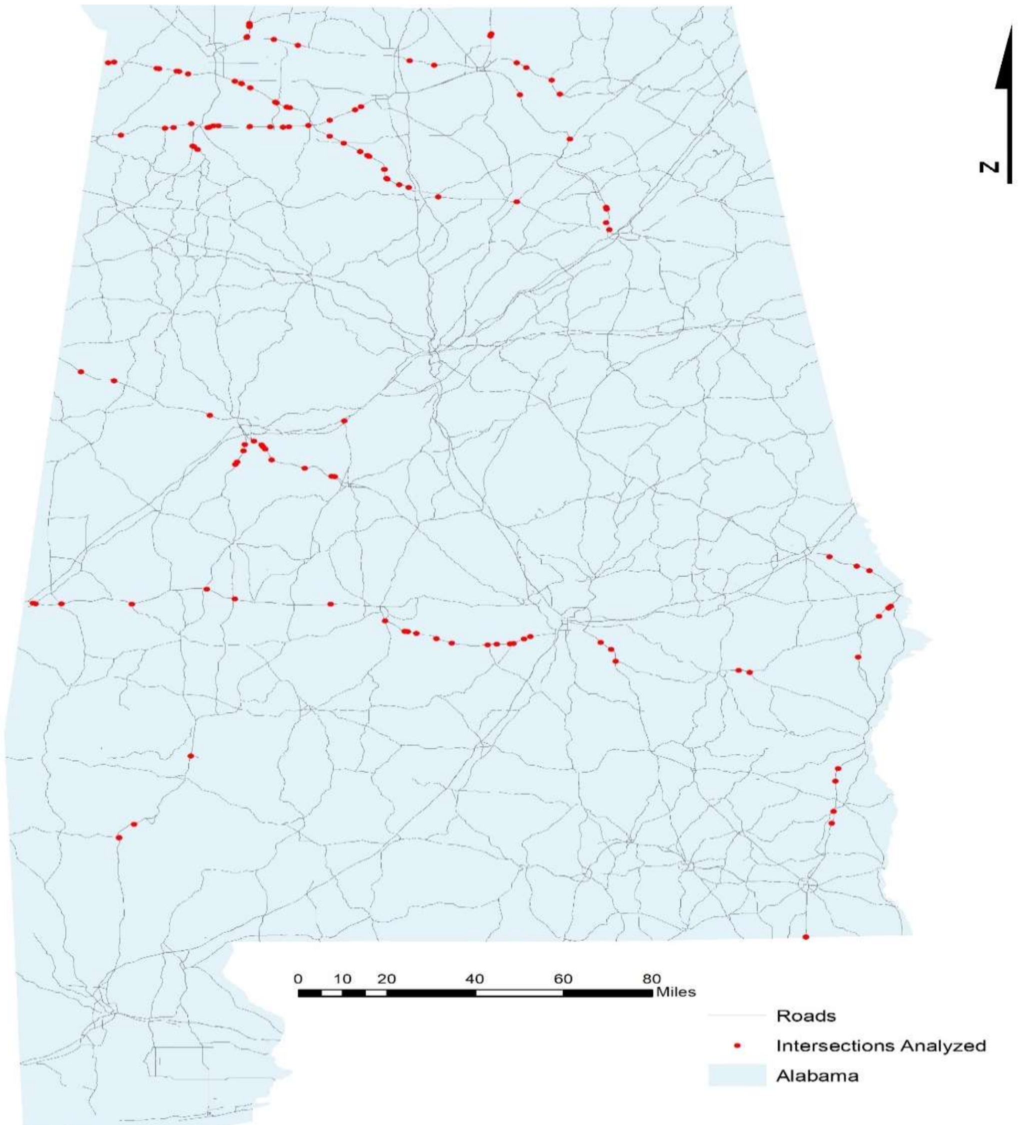


Figure 11. A Map Showing Potential Reference Sites Considered in this Study

The final study locations include all the available intersections with complete AADT data in the state. There is a total of 47 three-leg (3ST) and 65 four-leg (4ST) stop-controlled intersections. In total, 296 crashes occurred at the 3ST during the nine-year study period, and 496 at the 4ST. The number of sample sites meets the requirement by HSM method, however, crash number did not yield a total of at least 100 crashes per year.

3.1.2 INPUTS FOR THE HSM CRASH PREDICTION

Required inputs together with data collection approaches for the crash prediction by HSM method are shown in **Table 7**. Most of the roadway geometry data were collected from Google Maps. Variables like the presence of median, median width, speed limits of major and minor road, the number of lanes on major and minor road, and facility type were collected.

Table 7. Input Data for the HSM Crash Prediction

Intersections	Units/Description	Source
Intersection Type	Unsignalized 3ST and Unsignalized 4ST	Google Maps
Traffic flow major road	$AADT_{major}$	ALDOT AADT Map
Traffic flow minor road	$AADT_{minor}$	MicroStation
Intersection skew angle	Degrees	Google Maps
Number of uncontrolled approaches with a left-turn lane	0 to 4	Google Maps
Number of uncontrolled approaches with a right-turn lane	0 to 4	Google Maps
Intersection lighting	Present or not present	Google Maps Street View

Major and minor road traffic volumes were collected from the Alabama Traffic Data website maintained by ALDOT. Data from 2012 to 2020 were collected for both major and minor roads. Most of the traffic data for the major road were readily available. Some of the minor roads are county roads for which the traffic volume was not available. So, these sites without minor road AADTs were excluded from the study sample. This data screening included a total of 126 intersections meet the requirements of the HSM calibration procedure. Traffic volume data screening revealed that at 14 sites, the traffic volume percentage change from one year to next year was greater than 20%, and therefore these 14 intersections were suspected to be erroneous. This quality control of data yielded a total of 112 intersections with 47 3ST and 65 4ST with a total of 792 crashes in nine years.

Figure 12. Example of Major and Minor Road AADT from Alabama Traffic Data

There are many intersections in the sample sites that have a skewed configuration. The skewness of the intersection was measured by taking screen captures of the intersection in Google Maps and placing those in MicroStation v8i, and then using the “Measure angle” tool (Figure 13).

Figure 13. Example of Intersection Skew Angle Estimation (Google Earth)

Table 8 shows the distribution of skew angle of the intersections. Skew angles greater than 15 degrees were observed in 38% and 40% of the three-legged and four-legged stop-controlled intersections respectively.

Table 8. Frequency of Skew Angle of the Intersections

Intersection Type	Skew Angle	Frequency	Percentage
3ST (47)	0-15	29	62 %
	16-31	10	21 %
	32-47	6	13 %
	48-63	2	4 %
4ST (65)	0-15	39	60 %
	16-31	15	23 %
	32-47	11	17 %

Base conditions for the SPFs assume turn lanes do not exist at these intersections; adjustments must be made for the presence of turn lanes. Therefore, the number of left-turn and right-turn lanes present on the uncontrolled major-road approaches were identified manually using Google Maps Street View (Figure 14).

Figure 14. Example of Intersection with Left-Turn and Right-Turn Lanes (Google Earth)

Intersection lighting is another variable defined in the SPF base condition. Hence, the lighting condition was checked at each of study sites through Google Street View (Figure 15).

Figure 15. Intersection Lighting Present at US-231 at Trotman Road (Google Maps Street View)

3.2 METHODOLOGY

3.2.1 HSM CRASH PREDICTIVE METHOD FOR RURAL DIVIDED HIGHWAYS

Various types of statistical models like generalized linear and negative binomial models were generally used for the development of SPFs (Gates et al. 2018). The HSM is one such effective resource that provides statistical tools that can be implemented in various phases of transportation systems like planning, design, construction, operations, and maintenance.

Part C of the HSM provides a detailed description of the applicability of the predictive method to different facility types (Kolody et al. 2022). As the current study is specific to unsignalized intersections on rural divided highways, the predictive method for rural multilane highways was applied. This methodology is applicable to all rural multilane highways with partial access control and outside urban areas with a population of less than 5,000 persons.

In general, the HSM predictive method involves three components: identification of the base SPF, application of relevant CMFs to adjust for conditions that deviate from the base assumptions, and development of a local calibration factor. The predicted average crash frequency at an intersection is determined by equation (1) below (Sun et al. 2018).

$$N_{\text{Predicted intersection}} = N_{\text{spf intersection x}} * C * (CMF_1 * CMF_2 * \ldots\ldots\ldots * CMF_n) \quad (1)$$

Where,

$N_{Predicted\ intersection}$: total predicted crash frequency for an individual intersection for a selected year

$N_{spf\ intersection}$: safety performance functions developed for stop-controlled intersections

C: Calibration Factor for intersections of a specific type

$CMF_1 * CMF_2 * \ldots\ldots * CMF_n$: Crash modification factors for intersections

The HSM SPFs for base conditions for rural multilane unsignalized intersections is given by equation (2) (Kolody et al. 2022). a, b, c are the regression coefficients for a specific facility type and can be obtained from Table 11-7 of the HSM (2010), summarized in **Table 9** below.

$$N_{spf\ intersection} = \exp\left[a + b \times \ln(AADT_{major}) + c \times \ln(AADT_{min})\right] \qquad (2)$$

Where,

$N_{spf\ intersection}$: Predicted crash frequency at an intersection for base conditions

$AADT_{major}$: Major-road traffic volume for the specified period

$AADT_{minor}$: Minor-road traffic volume for the specified period

Table 9. SPF Coefficients for 3ST and 4ST Intersections with Minor-Road Stop-Controlled for Total Crashes

Intersection Type/Severity Level	**a**	**b**	**c**
Four-leg Intersection (4ST) Total	-10.008	0.848	0.448
Three-leg Intersection (3ST) Total	-12.526	1.204	0.236

The development of the LCF ideally involves predicting the crash frequencies of 30 to 50 sample sites or more. NCHRP-sponsored research studies have developed a number of spreadsheet tools which assist with the implementation of HSM Part C predictive methods. Primarily, there are spreadsheets for the rural roadways and urban arterial segments and intersections and for freeway segments and interchange elements; the relevant HSM crash prediction spreadsheet tools were used to calculate the predicted crash frequency at each intersection.

Figure 16 shows a representative example of the project information and CMFs that had been entered in the HSM spreadsheet to calculate the predicted crash frequency for a single year at one intersection. The crash prediction spreadsheet used here is the third version of the rural multilane highways spreadsheet, updated in July 2019.

Worksheet 2A – General Information and Input Data for Rural Multilane Highway Intersections

General Information		Location Information	
Analyst	(enter name)	Roadway	AL 157
Agency or Company	Auburn University	Intersection	AL 157 at AL 101
Date Performed	(enter date)	Jurisdiction	(enter jurisdiction)
		Analysis Year	2020

Input Data		Base Conditions	Site Conditions
Intersection type (3ST, 4ST, 4SG)		--	4ST
$AADT_{major}$ (veh/day)	$AADT_{MAX}$ = 78,300 (veh/day)	--	8,177
$AADT_{minor}$ (veh/day)	$AADT_{MAX}$ = 7,400 (veh/day)	--	2,368
Intersection skew angle (degrees)		0	15
Number of non-STOP-controlled approaches with left-turn lanes (0, 1, 2)		0	2
Number of non-STOP-controlled approaches with right-turn lanes (0, 1, 2, 3, or 4)		0	2
Intersection lighting (present/not present)		Not Present	Not Present
Calibration Factor, C_i		1.00	1.00

Worksheet 2B – Crash Modification Factors for Rural Multilane Highway Intersections

(1) Crash Severity Level	(2) CMF for Intersection Skew Angle (CMF_{1i}) from Equations 11-18 or 11-20 and 11-19 or 11-21	(3) CMF for Left-Turn Lanes (CMF_{2i}) from Table 11-22	(4) CMF for Right-Turn Lanes (CMF_{3i}) from Table 11-23	(5) CMF for Lighting (CMF_{4i}) from Equation 11-22	(6) Combined CMF (CMF_{COMB}) (2)*(3)*(4)*(5)
Total	1.36	0.52	0.74	1.00	0.52
Fatal and Injury (FI)	1.50	0.42	0.59	1.00	0.37

Note: The 4-leg Signalized Intersection (4SG) models do not have base conditions and so can only be used for estimation purposes. As a result, there are not CMFs provided for the 4SG condition.

Worksheet 2C – Intersection Crashes for Rural Multilane Highway Intersections

(1)	(2)			(3)	(4)	(5)	(6)	(7)
Crash Severity Level	SPF Coefficients from Table 11-7 or 11-8			$N_{spf\ int}$	Overdispersion Parameter, k	Combined CMFs	Calibration Factor, C_i	Predicted average crash frequency, $N_{predicted\ int}$
	a	b	c or d (4SG)	from Equation 11-11 or 11-12	from Table 11-7 or 11-8	from (6) of Worksheet 2B		(3)*(5)*(6)
Total	-10.008	0.848	0.448	3.042	0.494	0.52	1.00	1.589
Fatal and Injury (FI)	-11.554	0.888	0.525	1.691	0.742	0.37	1.00	0.628
Fatal and Injury[a] (FI^a)	-10.734	0.828	0.412	0.929	0.655	0.37	1.00	0.345
Property Damage Only (PDO)	--	--	--	--	--	--	--	$(7)_{TOTAL} - (7)_{FI}$ 0.960

Figure 16. Example of HSM Spreadsheet

Table 10 and

Table 11 show the predicted average crash frequency of a 4ST reference site by crash severity level and by collision type using the intersection of AL-157 at AL-101 in Lawrence County as an example.

Table 10. Predicted average crash frequency by crash severity level at AL-157 and AL-101

Crash Severity Level	$N_{spf\ int}$	Predicted Average Crash Frequency ($N_{predicted\ int}$)
Total	3.042	1.589
Fatal and Injury (FI)	1.691	0.628
Fatal and Injury[a] (FI^a)	0.929	0.345
Property Damage Only (PDO)	--	0.960

NOTE: Using the KABCO scale, these include only KAB crashes. Crashes with severity level C (possible injury) are not included.

Where,

$N_{spf\ int}$ = Predicted average crash frequency under base conditions for the 4ST intersection AL-157 at AL-101 in Lawrence County. This was obtained by replacing AADTs for major and minor roads in SPFs with site-specific values.

$N_{predicted\ int}$ = Predicted average crash frequency under site conditions. This was obtained by multiplying the CMFs for geometric design and traffic control features with $N_{spf\ int}$ for the intersection AL-157 at AL-101.

Table 11. Predicted average crash frequency by collision type at AL-157 at AL-101

Collision Type	$N_{predicted}$ (Total) Crashes/year	$N_{predicted}$ (FI) Crashes/year	$N_{predicted}$ (FI[a]) Crashes/year	$N_{predicted}$ (PDO) Crashes/year
Head-on collision	0.025	0.011	0.008	0.014
Sideswipe collision	0.17	0.026	0.014	0.150
Rear-end collision	0.362	0.134	0.037	0.231
Angle collision	0.628	0.336	0.197	0.280
Single-vehicle collision	0.321	0.093	0.069	0.233
Other collision	0.083	0.028	0.020	0.052

3.2.2 ADJUSTMENT FOR PREDICTED CRASH USING CMFS

When applying the HSM predictive method to real-world conditions, more CMFs, such as those that adjust for specific traffic control devices (TCDs), need to be considered to improve the crash number prediction accuracy since the spreadsheets only considered limited CMFs, like number of lanes, skew angle and number of turn lanes.

TCDs and other geometric features of each intersection were identified using Google Maps Street View. Some treatments, such as flashing beacons, channelization islands, and rumble strips were found installed at certain intersections during the study period. Relevant CMFs were selected from the CMF Clearinghouse, and only the high-quality CMFs (more than or equal to three stars) were applied. Below list the selected CMFs for the countermeasures applied in some study locations. The selected CMF values are for all types of crashes.

- Flashing beacons (0.83)

- Transverse rumble strips (0.71)
- Major-road painted left turn channelization island (0.67)
- Major-road physical left turn channelization island (0.87)

3.2.3 LOCAL CALIBRATION FACTOR ESTIMATION

A nominal calibration factor of 1 was taken to calculate the unadjusted predicted crash frequency at an intersection by using equation (1). In the estimation of the LCF for an intersection, the sum of total unadjusted predicted crash frequencies ($\Sigma_{\text{all sites}}$ unadjusted predicted crashes) and the sum of the total observed crash frequencies ($\Sigma_{\text{all sites}}$ observed crashes) were used. The estimation of the LCF for an intersection can be obtained by equation (3) (Shin et al. 2014).

$$\text{Local Calibration Factor} = \frac{\Sigma_{all\ sites}\ Observed\ crashes}{\Sigma_{all\ sites}\ unadjusted\ Predicted\ crashes} \qquad (3)$$

3.2.4 VALIDATION OF THE CALIBRATION FACTOR

To evaluate the accuracy of the developed LCF, researchers randomly selected 70% of the study intersections to calculate the LCFs and used the other 30% of the study intersections to validate the accuracy of the developed LCFs by calculating the mean absolute percentage error (MAPE). The MAPE measures the accuracy as a percentage and can be calculated as the average absolute percent error for each time period, as shown in equation (4).

$$\text{MAPE} = \frac{1}{n}\sum_{t=1}^{n}\left|\frac{A_t - F_t}{A_t}\right| \qquad (4)$$

Where:

n: the number of validation intersections

A_t: the observed crash number of each location

F_t: the adjusted predicted crash number of each location

= unadjusted predicted crash frequency * LCF

In addition to evaluating model performance, the final objective of the research, as stated previously, was to determine the impact of how the dataset of study sites was divided into the model development group (70% of the sites) and evaluation group. The function “RANDARRAY” in Microsoft Excel was used to randomly generate a sequence of random numbers for selecting the intersections. To reduce the possible impacts of the random selection bias, researchers repeated the random selection process 10 times and developed LCFs for each case. The corresponding MAPEs were also calculated for each case.

3.3 ANALYSIS RESULTS

3.3.1 LOCAL CALIBRATION FACTOR CALCULATION RESULTS

The number of predicted crashes for all 47 3ST intersections was 489 during the nine-year period, but the total number of actual observed crashes was only 279. The LCF of 0.571 was obtained as follows:

3 ST LCF = $\Sigma_{\text{all sites}}$ Observed crashes / $\Sigma_{\text{all sites}}$ Predicted crashes

= 279/489 = 0.571

The number of predicted crashes for all 65 4ST intersections was 908 during the nine-year period, but the total number of actual observed crashes was 482. The LCF of 0.53 was obtained as follows:

4 ST LCF = $\Sigma_{\text{all sites}}$ Observed crashes / $\Sigma_{\text{all sites}}$ Predicted crashes

= 482/908 = 0.531

The calculated values of the LCF shows that the HSM prediction method overestimated the unsignalized intersection in Alabama rural multilane highways.

3.3.2 EVALUATION OF THE LOCAL CALIBRATION FACTORS

To evaluate the predictive performance of LCFs of the HSM prediction method, for both types of intersections, 70% of the study intersections were randomly selected to calculate the LCFs, with the remaining 30% of the study intersections used to validate the accuracy of the developed LCFs by calculating the MAPE.

Table 12 shows one example of calculating and evaluating the LCFs for 3ST intersections. In this example, the LCF was found to be 0.56 based on the randomly selected intersections. The adjusted predicted crash frequency was calculated based on the LCFs. The last column shows the average percentage error (APE) for each intersection, and the MAPE, representing predictive performance across all sites, is 0.72.

To address the final objective, the impact of how the entire dataset is subdivided into model development and model evaluation groupings on LCF calculations and predictive performance was determined. Ten groups of randomly selected intersections (70% of the study sites) were obtained to develop the CFs. Finally, 10 LCFs and the corresponding MAPE for each grouping were determined for both 3ST and 4ST.

Table 13 shows the results of different groupings for the dataset split between model development and evaluation.

The average LCF for 3ST is 0.598, and for 4ST is 0.537. Among the 10 iterations, the LCF values are very close for each type of the intersections. The average MAPE for 3ST is 0.722, but for 4ST is higher (1.128). For 3ST, among the 10 iterations, most of the MAPEs are smaller than 1. Results show that the lowest MAPE for 3ST is 0.454 when the LCF is 0.62, and the lowest MAPE for 4ST is 0.644 when the LCF is 0.53. Since LCFs of 0.62 for 3-leg intersections under minor street stop control and 0.53 for 4-leg intersections under stop control resulted in the lowest MAPE values, these are recommended for use in Alabama when applying the SPFs as presented in the HSM.

Table 12. An Example of Calculating and Evaluating the LCF of 3ST

Test (70%)				Evaluation (30%)				
Intersection No.	Predicted crash frequency	Observed crash frequency		Intersection No.	Predicted crash frequency	Adjusted predicted crash frequency	Observed crash frequency	APE
2	8.314	2		1	6.646	3.691	1	0.729
3	9.081	2		6	4.217	2.342	1	0.573
4	4.776	1		14	11.345	6.301	16	1.539
5	4.018	1		15	12.817	7.118	4	0.438
7	2.477	2		46	26.728	14.844	5	0.663
8	2.36	6		18	15.488	8.602	25	1.906
9	3.29	2		19	6.791	3.771	1	0.735
10	0.88	8		27	15.157	8.418	9	0.069
11	8.094	1		29	9.788	5.436	5	0.08
12	16.301	8		32	2.949	1.638	5	2.053
13	19.282	18		38	5.327	2.958	2	0.324
16	5.958	7		39	6.287	3.492	2	0.427
17	26.093	3		45	17.919	9.952	11	0.105
20	18.016	2		47	3.088	1.715	1	0.417
21	23.337	1					**MAPE**	**0.719**
22	10.638	4						
23	17.79	5						
24	25.382	10						
25	6.337	18						
26	10.715	3						
28	17.555	20						
30	8.319	1						
31	19.655	5						
33	4.828	4						
34	15.343	6						
35	7.356	8						
36	4.155	1						
37	10.508	25						
40	7.473	6						
41	3.098	2						
42	6.824	3						
43	11.996	4						
44	3.659	2						
Total	**343.908**	**191**						
LCF		**0.555**						

Table 13. Results of Iterations of Model Development and Evaluation Results

	3-Leg		4-Leg	
Iteration No.	LCF Developed by 70% Intersections	MAPE of 30% Evaluation Intersections	LCF Developed by 70% Intersections	MAPE of 30% Evaluation Intersections
1	0.557	0.606	0.490	1.207
2	0.555	0.719	0.569	1.026
3	0.617	0.454	0.549	1.311
4	0.611	0.563	0.542	1.177
5	0.631	0.525	0.494	1.421
6	0.631	1.583	0.494	1.140
7	0.549	0.882	0.504	1.140
8	0.638	0.655	0.611	1.162
9	0.619	0.513	0.532	0.644
10	0.573	0.720	0.583	1.054
Average	0.598	0.722	0.537	1.128

Chapter 4

SELECTED CMFS FOR ENGINEERING TREATMENTS AT UNSIGNALIZED INTERSECTIONS

This chapter summarizes a list of treatments that are recommended for improving traffic safety at unsignalized intersections on rural high-speed divided highways with wide medians. The treatments include several TCDs (such as signs, pavement markings, delineators) and geometric design improvements. Listed below are the three guidelines used to select the countermeasures.

- *Safety Countermeasures at Unsignalized Intersections – A Toolbox Approach* (Li et al. 2020). National Surface Transportation Safety Center for Excellence (NSTSCE), VTTI.
- *Unsignalized Intersection Improvement Guide* (McGee et al. 2015). FHWA.
- *Innovative Operational Safety Improvements at Unsignalized Intersections* (Freeman et al. 2008). FDOT.

Below is a list of the related countermeasures by different categories. The treatments with asterisks are recommended by the research team for application with local calibrated SPFs in Alabama. **Appendix C** contains detailed guidance on each of the recommended treatments. For treatments like: Install a Left-Turn Lane on the Major Road and Install Intersection Lighting, since these commonly used treatments already been considered in base function of the HSM crash prediction method, they will not be included in the detailed guidance. The guidance includes the information of: 1) definition of treatment; 2) target crash types or problems addressed; 3) selected CMF values and standard errors; 4) examples in either Alabama (if not available, then from other states); and 5) other related design resources.

Traffic Control Devices - Signs

- Duplicate Stop Sign
- Oversized Stop Sign (R1-1)
- LED-Enhanced Stop Sign
- Retroreflective Panels on Sign Posts
- Signs with Red or Orange Flags
- Warning Signs with Perimeter Retroreflective Sheeting

Traffic Control Devices - Pavement Markings and Delineators

- Center Line Pavement Markings in a Median Crossing*
- Center Line Pavement Markings on the Minor Road Approach
- Dotted Line Pavement Markings
- Dotted Lines Through Full Median Openings
- Dotted Turn Path Markings
- Raised Pavement Markers at Intersection Approach
- Speed Reduction Pavement Markings (Peripheral Transverse Pavement Markings)
- Transverse Rumble Strips on Stop Control Approaches*
- Wider Longitudinal Pavement Markings
- Post-Mounted Reflective Delineators at Intersection
- Install High-Friction Surface Treatment on Intersection Approaches

Traffic Control Devices - Traffic Signals

- Intersection Control Beacon
- Stop Beacon
- Advance Stop Beacon*

Geometric Improvements - Channelizing Islands and Devices

- Channelization to Limit Turning Movements*
- Install Splitter Island on Minor Road Approaches
- Offset Left-Turn Lanes on Major Approaches*
- Offset Right-Turn Lane on Major Approaches*

Geometric Improvements-Intersection Realignment

- Convert to RCUT Intersection*
- Convert Between a Four-Legged Intersection and Two T-Intersections
- Install a Roundabout*
- Modify Skewed Intersections
- Modify Horizontal/Vertical Alignment of Intersection Approach
- Modified T-Intersection

Geometric Improvements-Intersection Reconfiguration

- Close Median Opening
- Extend Left-Turn Lane
- Extend Right-Turn Lane
- Increase Intersection Curb Radius
- Install Left-Turn Lane on the Major Road
- Install Right-Turn Lane along the Major Road
- Install Left-Turn Acceleration Lane
- Install Right-Turn Acceleration Lane
- Lane Narrowing with Median Rumble Strips
- Reduce Width of Travel Lanes on Major Road Approaches (reduce speed)
- Restrict Driveway Access, Install Right-In-Right-Out (RIRO) Operations

Others

- Improve Intersection Sight Triangles Distance
- Eliminate Parking at or Near Intersection
- Install Intersection Lighting

Table 14 summarizes the features of widely used countermeasures by different categories, including TCDs, geometric design, and some other treatments, the features of these treatments were described previously.

Table 14. Summary of the Selected Countermeasures by Categories

			Available CMFs	Target Crash Types or Problems Addressed						Relative Cost
				Angle	Rear-end	Left-turn	Head-on	Speed-relate	Visibility	
Traffic Control Devices	Signs	Duplicate Stop Sign								Low
		Oversized Stop Sign (R1-1)								
		LED-Enhanced Stop Sign								
		Retroreflective Panels on Sign Posts								
		Signs with Red or Orange Flags								
		Warning Signs with Perimeter Retroreflective Sheeting								
	Pavement Markings and Delineators	Double-Yellow Centerline Within Median Opening								
		Center Line Pavement Markings on the Minor Road								
		Dotted Line Pavement Markings								
		Dotted Lines Through Full Median Openings								
		Dotted Turn Path Markings								
		Raised Pavement Markers at Intersection Approach								
		Speed Reduction Pavement Markings (Peripheral Transverse Pavement Markings)								

		Transverse Rumble Strips on Intersection Approach								Low to Medium
		Wider Longitudinal Pavement Markings								Low
		Post-Mounted Reflective Delineators at Intersection								
		High-Friction Surface Treatment on Intersection Approaches								Medium to High
	Traffic Signals	Intersection Control Beacon								Medium
		Stop Beacon								
		Advance Stop Beacon								

			Available CMFs	**Target Crash Types or Problems Addressed**						**Relative Cost**
				Angle	**Rear-end**	**Left-turn**	**Head-on**	**Speed-relate**	**Visibility**	
Geometric Design Treatments	**Channelizing Islands and Devices**	Channelization to Limit Turning Movements								Medium to High
		Splitter Island on Minor Road Approaches								low
		Offset Left-Turn Lanes								Medium to High

		Offset Right-Turn Lane on Major Approaches								Medium to High
		Restrict Driveway Access (Right-in Right-Out Channelization)	☑							Medium
	Intersection Realignment	Convert to RCUT intersection								High
		Convert Between a Four-Legged Intersection and Two T-Intersections								High
		Install a Roundabout								High
		Modify Skewed Intersections								High
		Modified T-Intersection								High
	Intersection Reconfiguration	Close Median Opening								Medium to High
		Extend Left-Turn Lane								Low to High
		Extend Right-Turn Lane								High

		Increase Intersection Curb Radius									High
		Install a Left-Turn Lane on the Major Road									High
		Install a Right-Turn Lane along the Major Road									Medium to High
		Install Left-Turn Acceleration Lane									High
		Install Right-Turn Acceleration Lane									High
		Lane Narrowing with Median Rumble Strips									Low
		Reduce Width of Travel Lanes on Major Road Approaches									Medium to High
Others		Improve Intersection Sight Triangles Distance									Low to High
		Eliminate Parking at or Near Intersection									Low to Medium
		Install Intersection Lighting									Low to Medium

Most of the selected countermeasures have CMFs or CMFunctions with acceptable ratings. Some countermeasures, such as Center Line Pavement Markings in a Median Crossing and Median Acceleration Lane, have no CMFs provided in the CMF Clearinghouse although past studies showed they are effective in improving intersection safety. The rest of the chapter will give a brief introduction of CMFs/CMFunctions, methods used for selecting CMFs, examples for applying these CMFs, and some treatment sites in Alabama.

4.1 INTRODUCTION OF CMFS / CMFUNCTIONS

As defined by the HSM, “A CMF is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site”. A CMF can be used to identify the most cost-effective countermeasures when considering various countermeasures and to implement the calibrated SPFs for Alabama, it is crucial to have a list of recommended CMFs for evaluating various countermeasures at unsignalized intersections in Alabama.

4.2 SELECTION OF APPROPRIATE CMFS / CMFUNCTIONS

4.2.1 NEW CMF EVALUATION STANDARD

The CMF Clearinghouse transitioned to the new rating system on February 15, 2021, based on the findings of NCHRP Project 17-72. This rating system is much more rigorous and provides scores for more factors. The previous standard only considers five properties (study design, sample size, standard error, potential bias and data source) for developing the CMF. **Table 15** shows the updated CMF star rating standard. **Table 16** lists the various factors (there are multiple levels within factors and points for each level) used for evaluating the three study types for developing CMFs.

Table 15. Updated CMFs Rating Standard (Source: CMF Clearinghouse)

Score	Star Rating
135-150	5 Star
110-134	4 Star
75-109	3 Star
35-74	2 Star
0-34	1 Star

Table 16. Factors Used for Evaluating the Three Study Types for Developing CMFs (Source: CMF Clearinghouse)

Before/After and Cross-Sectional Studies	Meta-Analysis Studies	Meta-Regression Studies
Sample size	Methodology and data	Methodology and data
Study design and statistical methodology	Individual CMF quality	Individual CMF quality
Statistical significance	Appropriateness of combining	Appropriateness of developing a CMF
-	Statistical significance	Appropriateness of statistical analysis

4.2.2 METHOD FOR SELECTING APPROPRIATE CMFS

To select appropriate CMFs for different countermeasures at unsignalized intersections for Alabama, researchers first collected all the available CMFs for unsignalized intersections from the CMF clearinghouse website, and then reviewed all the factors associated with each CMF. After excluding the CMFs developed only for urban areas, researchers selected the "high quality" CMFs. Below are the defined criteria for selecting CMFs:

1) Exclude the CMFs developed only for urban areas
2) Select CMFs with Star Quality Rating: ≥ 3 stars and unadjusted Standard Error: ≤ 0.1
3) Crash Data Obtained States: Select southern or eastern states

High-quality CMFs were defined as those having a rating of three stars or higher, and the unadjusted standard error less than or equal to 0.1. If countermeasures have both 4 stars and 3 stars CMFs, the 4 stars CMFs will be selected. The CMFs developed based on crash data from southern or eastern states were preferred over those developed by the crash data from other regions.

All the selected CMFs are highlighted in green in Appendix B for each countermeasure. The CMF ID, star rating, standard error, crash severity, crash type, traffic volumes, intersection geometry, crash data obtained states, publication year, and the area information are included in the table in **Appendix B**. CMF ID can be used to find the original study report that developed the CMF from the CMF clearinghouse website. The low-quality CMFs (with one or two stars) are also listed in Appendix B.

4.3 EXAMPLES OF APPLYING CMFS AND LOCAL CALIBRATED SPFS

When applying these CMFs, analysts should be careful to apply the CMF only to the designated crash types, crash severities, and intersection geometry. Below is an example.

A 3-leg stop-controlled intersection is located on a rural four-lane roadway in Alabama. Determine the predicted average crash frequency of the stop-controlled for a particular year.

Road Features: 3 legs; minor-road stop control; no right turn lanes on major road; 1 left-turn lane on major road; 30-degree skew angle; AADT of major road = 8,000 veh/day; AADT of minor road = 1,000 veh/day; intersection lighting present.

Step 1 – Identify data needs for the facility

Existing Intersection:

- 3 legs
- minor-road stop control
- no right turn lanes on major road
- 1 left-turn lane on major road 30-degree skew angle
- AADT of major road = 8,000 veh/day
- AADT of minor road = 1,000 veh/day
- intersection lighting present
- flashing beacon
- painted intersection left turn

Step 2 – Divide locations into homogeneous intersections

For this case example, the study location is a single intersection.

Step 3 – Apply the appropriate SPF

$N_{Predicted\ intersection}$ = $N_{spf\ intersection\ x}$ * $(CMF_1 * CMF_2 * \ldots\ldots * CMF_n)$ * C

Based on **Table 9** (SPF coefficients for 3ST and 4ST),

$N_{spf\ intersection}$ = exp [a + b * ln ($AADT_{maj}$) + c * ln ($AADT_{min}$)]

= exp [-12.526 + 1.204 * ln (8,000)] + 0.236 * ln (1,000)]

= 0.928 crashes / year

Step 4 – Apply CMFs as needed

Condition 1: Intersection of Base Conditions:

Skew angle 0 degrees; No intersection left turn lanes, 0 except on stop-controlled approaches.

No intersection right turns lanes, 0 except on stop-controlled approach.

Lighting – none

Condition 2: Intersection of Combined CMF:

All the CMFs are assumed to be independent of each other. CMF values are selected from the CMF Clearinghouse.

Flashing Beacon with CMF = 0.83

Painted Intersection Left Turn with CMF = 0.67

$CMF_{combined}$ = 0.83 * 0.67 = 0.5561

Step 5 – Apply Local Calibration Factor

$N_{Predicted\ intersection}$ = $N_{spf\ intersection\ x}$ * $(CMF_1 \ * \ CMF_2 \ * \ \ldots\ldots \ * \ CMF_n)$ * LCF

= 0.928 * 0.5561 * 0.571

= 0.295 crashes / year

4.4 TREATMENT SITES

Information on four intersections that were modified physically, geometrically, or with changes to signs/markings to restrict certain movements or provide guidance regarding the right-of-way assignment was obtained from ALDOT. **Table 17** lists the information of intersections with modifications.

Table 17. List of Modified Intersections Obtained from ALDOT

Recently Modified Intersections	County	Route	Before Modification	After Modification	Date Modified	Median width (ft)
US 82 at AL 219/ Birmingham Road	Bibb	AL0006	Standard Crossover	RCUT	2017	46
US 82 at County Road 140	Tuscaloosa	AL0006	Standard Crossover	Directional left in	2018	70
US 11 at US 80	Sumter	AL0008	Four-Way stop Control	Flashing Beacons and Stop ahead signs	2015	55
US 431 at AL 169	Russell	AL0001	Standard Crossover	Installation of Double yellow and yield bar markings	2010	55

US 82 at AL 219/Birmingham Road:

The intersection of US 82 at AL 219/Birmingham Road was modified from a typical crossover into an RCUT intersection. The RCUT design prohibits the left-turn and crossing maneuvers from the minor-road onto the major-road. These movements are accommodated by forcing the minor road drivers to take a right-turn on the major road and then make a U-turn maneuver at a median opening, typically 400 to 1,000 ft after the intersection (Hughes and Jagannathan 2009).

This project started in late 2016 and ended in early 2017. A total of 9 crashes were observed from 2012 to 2016. After modification, 4 crashes were recorded from 2018 to 2020. Aerial photographs of before and after conditions are shown in **Figure 17** and **Figure 18**. At this intersection, US 82 is a four-lane divided highway with two lanes in each direction, a posted speed limit of 65 mph, and a depressed median of width 46 ft. AL 219 is a two-lane undivided highway with a posted speed limit of 45 mph. Before the construction of the RCUT, intersection lighting was present at both the minor road approaches along with overhead flashing beacons and yield signs at the median. In the after condition, the RCUT design replaced a typical crossover.

Figure 17. US 82 at AL 219/Birmingham Road Before Condition (Google Earth)

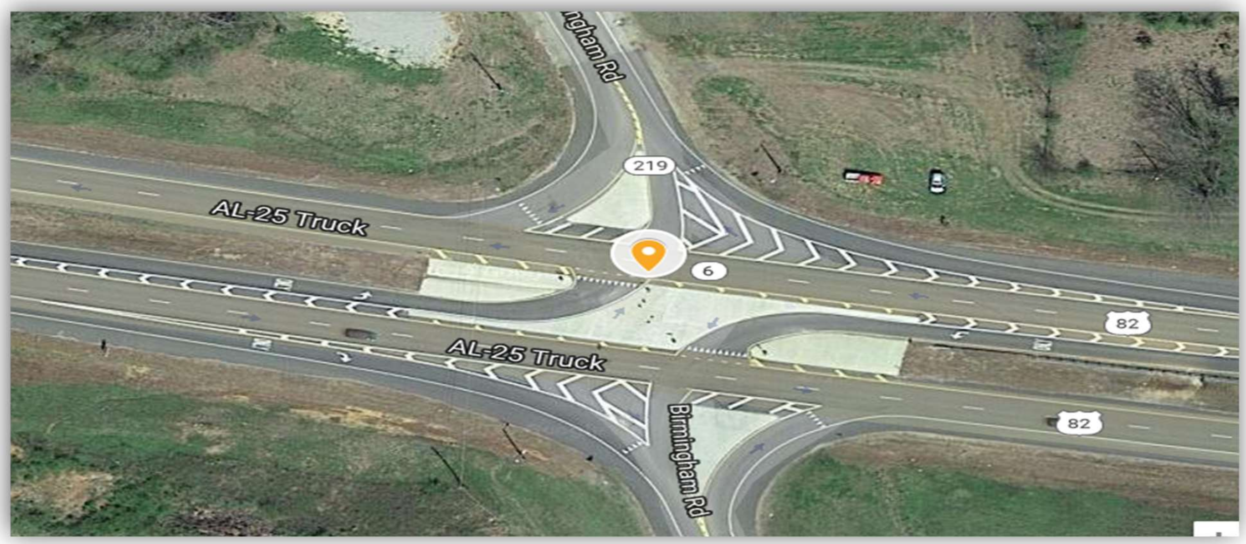


Figure 18. US 82 at AL 219/Birmingham Road After Condition (Google Earth)

US 82 at County Road 140:

The intersection of US 82 at County Road 140 located in Tuscaloosa County was a standard crossover. At this intersection, US 82 is a four-lane divided highway with two lanes in each direction, separated by a depressed median of width 70 ft, and a posted speed limit of 65 mph. CR 140 is a two-lane undivided highway with a posted speed limit of 45 mph. This intersection has a three-legged approach and was modified during a permit project. This crossover is actually the one just west of CR 140 but has been used as a route to get to and from US 82 to CR 140. This crossover was changed from a standard crossover into a directional left-in as left turns from the entrance are prohibited. A right-turn lane into the gas station for US 82 eastbound was also added. These changes were made around May 2018. A total of 3 crashes were recorded from 2012 to 2019. Aerial photographs of Before and After modifications were shown in **Figure 19** and **Figure 20** respectively.

Figure 19. US 82 at County Road 140 Before Condition (Google Earth)

Figure 20. US 82 at County Road 140 After Condition (Google Earth)

US 11 at US 80:

The intersection of US 11 at US 80 was a standard crossover with four-way stop-control located in Sumter County. At this intersection, US 80 is a four-lane divided highway with two lanes in each direction, separated by a depressed median of width 55 ft and a posted speed limit of 65 mph. US 11 is a two-lane undivided highway with a posted speed limit of 45 mph. This intersection has a four-legged approach and was modified approximately seven years ago. Around 2015 flashing beacons were added to the advanced warning stop ahead signs. In addition to this overhead flashers were also added at this intersection. A total of 2 crashes was observed from 2012 to 2014. Google Earth aerial photographs of before and after modifications were shown in **Figure 21** and **Figure 22** respectively.

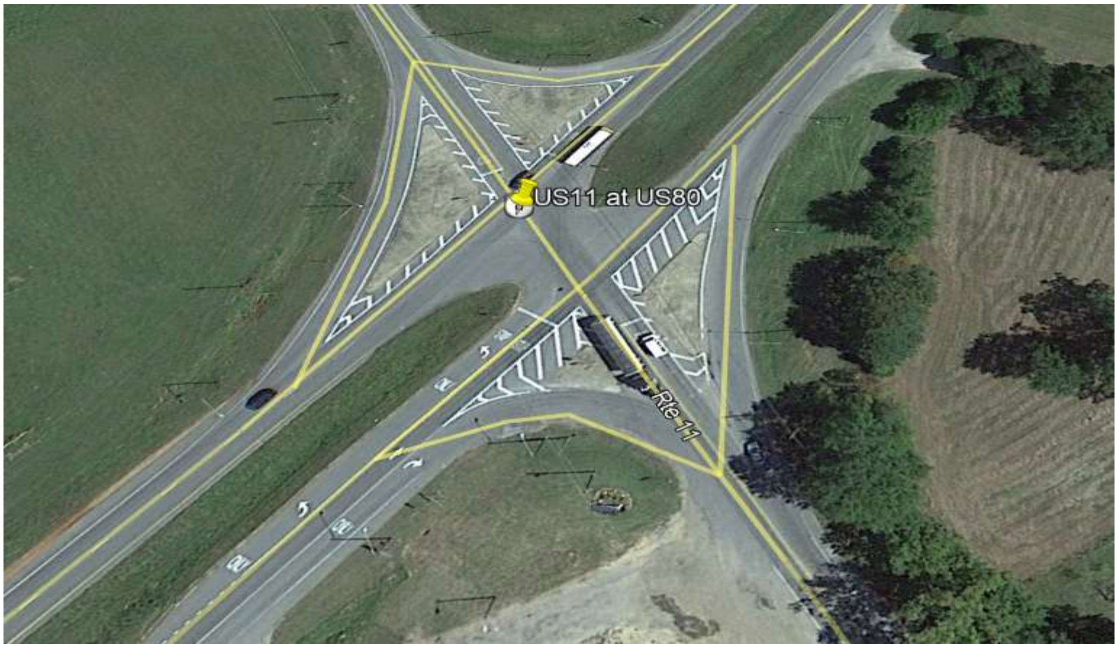


Figure 21. US 11 at US 80 Before Condition (Google Earth)

Figure 22. US 11 at US 80 After Condition (Google Earth)

US 431 at SR 169:

The intersection of US 431 at SR 169 was a two-way stop-controlled intersection located in Russell County in Alabama. At this intersection, US 431 is a four-lane divided highway with two lanes in each direction and separated by a depressed median of width 55ft and a posted speed limit of 65 mph. SR 169 is a two-lane undivided highway with a posted speed limit of 55 mph. This intersection has a 4-legged approach and was modified around 2010. This intersection also recorded 2 crashes from 2008 to 2012. In the before condition, the original crossover had no stripe or markings. In the after condition, modifications include installation of double yellow and yield bar markings. Google Earth aerial photographs of before and after modifications were shown in **Figure 23** and **Figure 24** respectively.

Figure 23. US 431 at SR 169 Before Condition (Google Earth)

Figure 24. US 431 at SR 169 After Condition (Google Earth)

Chapter 5

SAFETY IMPACT OF TWO TYPES OF MEDIAN ACCESS CONTROL TREATMENT AT UNSIGNALIZED INTERSECTIONS WITH WIDE MEDIANS

5.1 INTRODUCTION

Conventional unsignalized intersection on a four-lane divided highway with wide median has 42 conflict points when considered at a lane-specific level (see **Figure 25**), resulting in large amounts of interactive information and complex decision-making for drivers when crossing the wide median intersections (Maze et al. 2002). To improve the safety of the wide median unsignalized intersection in suburban and rural areas, ALDOT implemented two types of low cost median opening treatments: (1) stop line, stop sign, and double yellow line (see **Figure 26);** (2) yield lines and yield signs, and double yellow line (see **Figure 27)** to provide additional access control at the median openings. These treatments have been applied at multiple locations in Alabama. However, no CMFs have been developed because of the limited number of sites. A conflict study was conducted for this project to better understand the safety benefits of the treatments.

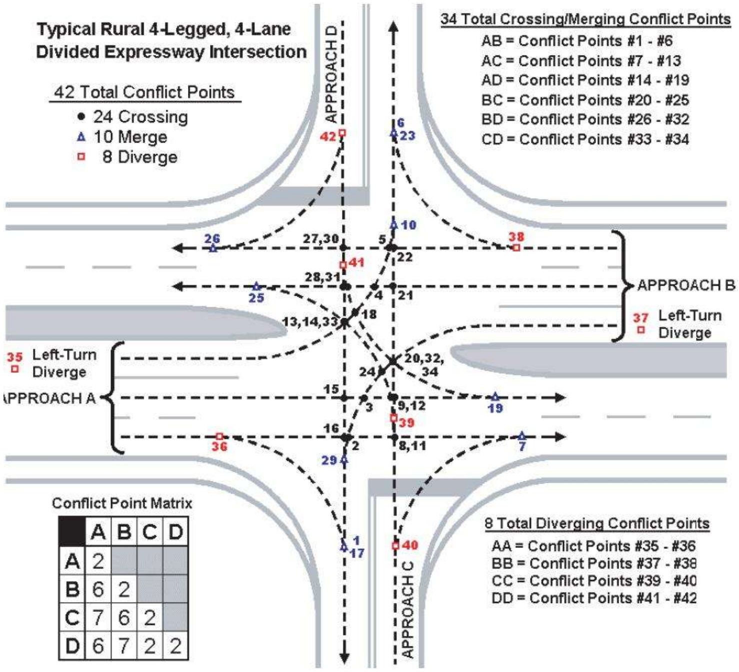


Figure 25. Conflict Points of the Divided Highway Unsignalized Intersections

To evaluate the safety benefits of these two median opening treatments, six pairs of locations (twelve locations) were selected for field data collection, including six locations with treatments and six similar locations with no treatments. The traffic conflicts (conflict rates) and driver performance (understanding right-of-way, whether or not stopping at the median opening, and using two-stage left-turn movements) were used to quantify the safety effects of the median opening treatments.

Figure 26. Stop Lines, Stop Signs and Double Yellow Lines

Figure 27. Yield Lines, Yield Signs and Double Yellow Line

The remainder of Chapter 5 is structured as: the data collection of the 6 pairs of the study intersections; then a description of the methodology employed, including the intersection conflict study and the other driver behaviors for safety evaluations. The results are then described, followed by conclusions and discussion.

5.2 DATA COLLECTION

5.2.1 STUDY INTERSECTION SELECTION

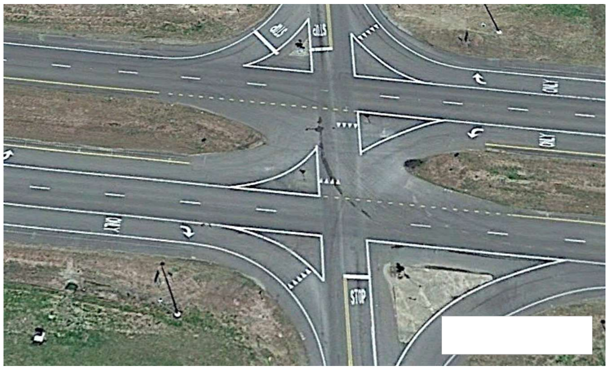
For the conflict data collection, six pairs (6 with treatments intersections vs. 6 without treatment intersections) of study locations (in total 12 locations) were selected for a comparative analysis. Each study location should meet the following criteria: unsignalized intersection on multilane divided highways, wide median (> 30 ft), major road with high speed limit (> 45 mph). Most of these types of intersections are currently treated as one intersection. ALDOT recently implemented two types of access control treatments at some locations. Three of the treated intersections had the stop lines/signs control and the other three had just yield lines/sign control. An additional six locations with no traffic control devices in the median openings were selected as comparison locations. The paired treated and untreated locations are located close to each other on the same major road. Cameras were installed on the roadside at the study locations, and 48-hour videos during a weekday of each location was collected for each location.

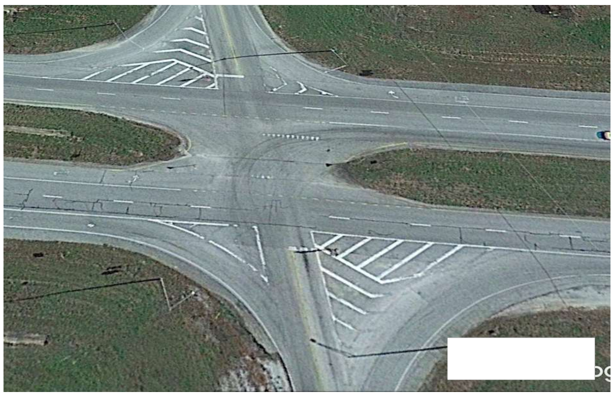
5.2.2 STUDY INTERSECTION DETAILED INFORMATION

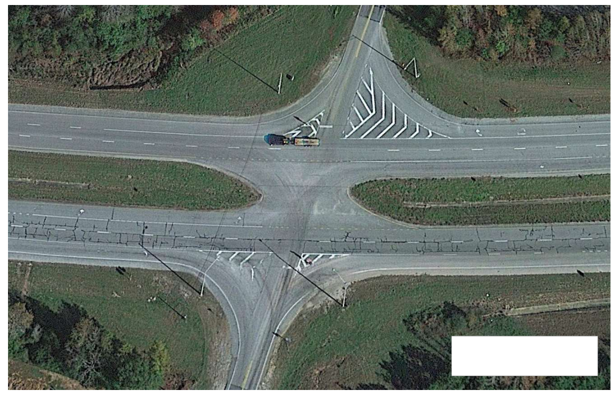
Table 18 lists the detailed geometric design features and median treatments at the six pairs of study locations. **Figure 28** shows the Google Maps Street View of the six pairs of the study locations. On the left side of the figure are all the six treated intersections, and on the right side are the untreated intersections for comparisons. All the study locations are on rural four-lane divided highways with left-turn bays on the major roads. There are no sight distance issues at any of these 12 locations. Geometric design features, major road traffic volumes and speeds are very similar within each pair of the study location. The study aims to see if this treatment is effective in reducing the traffic conflict rates and guiding the crossing drivers follow the right of way at the median openings.

Table 18. Detailed Information of the Six Pairs of Study Locations

Pair #	Location #	Route	Median Width (ft)	Median Opening Width (ft)	Major Road Speed Limit (mph)	Median Treatments
Pair #1	1.0	U.S. 80 & AL 25	42	72	65	Yield lines and yield signs; double yellow line; painted triangle islands.
	1.1	U.S. 80 & AL 97	43	62	65	-
Pair #2	2.0	U.S. 431 & AL 169	60	90	65	Yield lines and yield signs; double yellow line (faded)
	2.1	U.S. 431 & Cutrin Dr	55	90	65	-
Pair #3	3.0	U.S. 280 & County Road 21	45	85	65	Yield lines and yield signs; double yellow line
	3.1	U.S. 280 & County Road 87	55	90	65	-
Pair #4	4.0	U.S. 280 & County Road 40	70	50	65	Stop lines and stop signs; double yellow line
	4.1	U.S. 280 & County Road 87	55	70	65	-
Pair #5	5.0	U.S. 84 & AL 51	70	40	65	Stop lines and stop signs; tapered on median opening two sides; double yellow line.
	5.1	U.S. 84 & County Road 533	50	80	65	-
Pair #6	6.0	Atlanta Hwy & Somerset Dr	70	40	55	Stop lines and stop signs; double yellow line
	6.1	Atlanta Hwy & New Haven Blvd	40	60	55	-


STOP





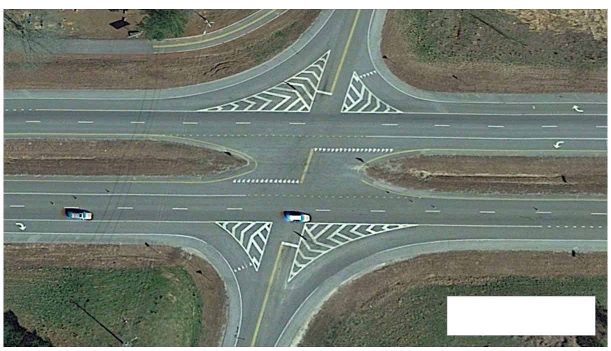


Figure 28. Images of the Six Pairs of Study Locations (Google Maps)

Figure 29 shows an example of the screenshot of the video recording of one study intersection. The time and date of the recording shows on the right bottom side of the figure based on the time on the videos. The time on the recording was used for obtaining the post-encroachment time (PET).

Figure 29. Screenshot of the Recording of One Study Intersection

5.3 METHODOLOGY

5.3.1 INTERSECTION CONFLICT STUDY

In this study, a comparative analysis was conducted to understand the safety issues of a median opening designed as a single intersection compared to that designed as two separate intersections. In doing so, a conflict study was conducted by watching videos of traffic movement for 8-hours of two weekdays for each location. The 16-hour video for conflict observation consisted of 3-hours morning (AM) peak, 2-hours mid-day, and 3-hours afternoon (PM) peak to capture all possible heavy traffic conditions throughout the two weekdays.

The study mainly focused on observing conflicts with the following movement: left-turning movements from minor road approaches. Consequently, the conflict study consisted of observing conflicts and other safety performance measures for the above-mentioned movements. To evaluate the safety issues at median opening designed as a single intersection compared to that designed as two separate intersections, this study used the following performance measure:

Traffic Conflicts - defined as an observable situation in which two or more road users approach each other in time and space to such an extent that there is risk of collision if their movements remain unchanged (Amundsen and Hyden 1977). The total observed traffic conflicts are converted into the following two performance measures:

$$Conflict\ rate\ (per\ left-turn\ vehicle) = \frac{\#\ of\ conflicts}{Total\ left{-}turn\ volume} * 100\% \qquad (5)$$

Figure 30 below shows the six defined study conflict paths with directions, including (1) the minor road left turn interacting with major road left side through movement (MALT); (2) the minor road left turn interacting with major road right side through movement (MART); (3) the minor road left turn interacting with major road right side left turn movement (MALL); (4) the minor road left turn interacting with major road left side left turn movement (MARL); (5) the minor road left turn interacting with the opposite direction minor road through movement (MIT); and (6) the minor road left turn interacting with the opposite direction minor road left movement (MIL).

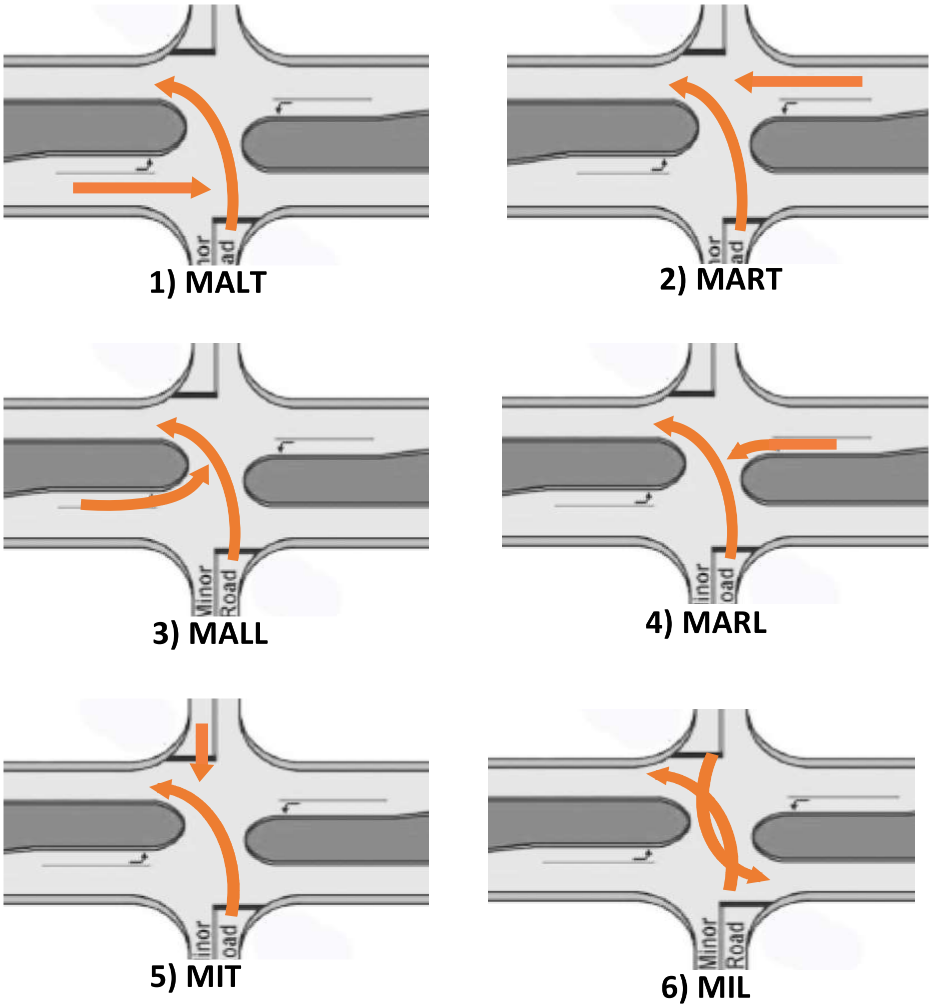


Figure 30. Six Defined Study Conflict Path with Directions

PET - The time difference between the moment an 'offending' vehicle passes out of the area of potential collision. PETs are sometimes used to measure the nearness of crash when two paths cross each other. In this study, a PET value smaller than 3 seconds was considered a conflict, and a PET smaller than 1.5s was a critical conflict (near crash). The timeline on the video screen was used to estimate the PET time.

Near Crash - An event is classified as a near-crash if an imminent crash is avoided due to a rapid evasive maneuver by the subject vehicle or any other vehicle that was required to avoid a crash. The total observed near-crash are converted into the following two performance measures:

$$Near\ crash\ rate\ (per\ left-turn\ vehicle) = \frac{\#\ of\ conflicts}{Total\ left\text{-}turn\ volume} * 100\% \qquad (6)$$

5.3.2 OTHER DRIVER BEHAVIORS FOR SAFETY EVALUATIONS

Stopped/Slow down Behavior - This performance measure indicates if a vehicle stops, slow down or not stop at the median while at the minor road stop sign, and while crossing the median opening. As indicated earlier, stopping at the median is associated with less safety risk as the driver is more cautious and a better sight distance to the conflicting traffic is available to them.

Understanding of the Right-of-Way - This performance measure indicates if a vehicle used their correct right-of-way while crossing the median opening. Left turn trajectory types are categorized into three types, Type 1, Type 2, Type 3. They are defined in the figure below (**Figure 31**) from left to right. The mainly difference part is the trajectory at the median openings. For Type 1, vehicles keep on the right side of the median opening to make the left turn; for Type 2, vehicles stayed in the middle of the median openings to make the left turn; for Type 3, vehicles driving toward the right side of the median openings to make the left turn. Among the six pairs of the study locations, since the median opening width are wide enough to store two vehicles side by side, the Type 1 trajectory was considered as the conditions under which drivers "Understanding the Right of Way."

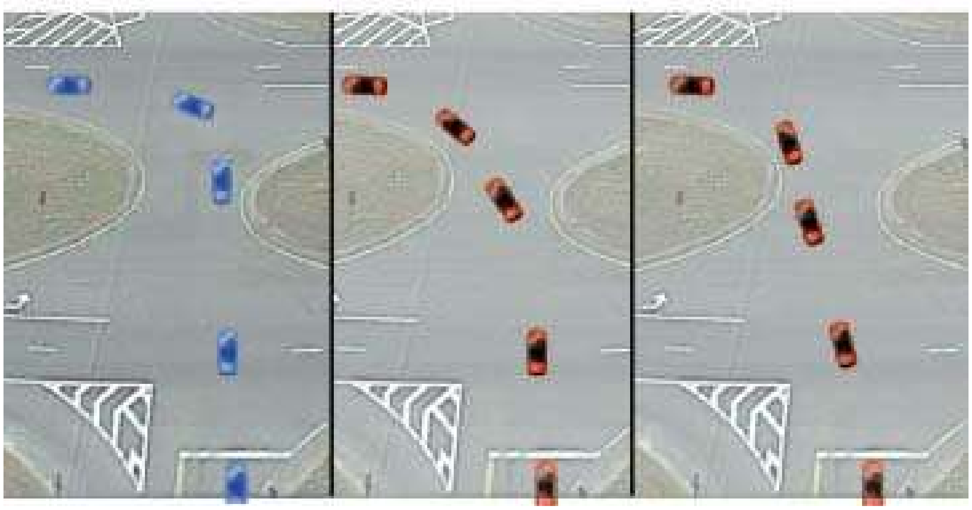


Figure 31. Three Types of Trajectories of Left Turn Vehicles

5.4 TRAFFIC CONFLICT STUDY RESULTS

Intersection safety treatments including yield sign and yield line, and the stop sign and lines at the median opening were evaluated. The first three pairs of the study locations were used to evaluate the safety effectiveness of yield sign and yield line, and the last three pairs were analyzed for evaluating the effectiveness of stop sign and stop line.

5.4.1 SUMMARY OF THE SAFETY EVALUATIONS OF THE SIX PAIRS OF THE STUDY LOCATIONS

Figure 32 shows the conflict rates between treated and untreated locations among the six pairs of the study locations. The conflict here includes all types of left turn trajectory paths. The results suggested that the treated locations have lower conflict rates than the untreated locations. Stop control reduced more conflict than the yield control. The conflict rates were reduced by 10% to 40% with stop sign and stop line.

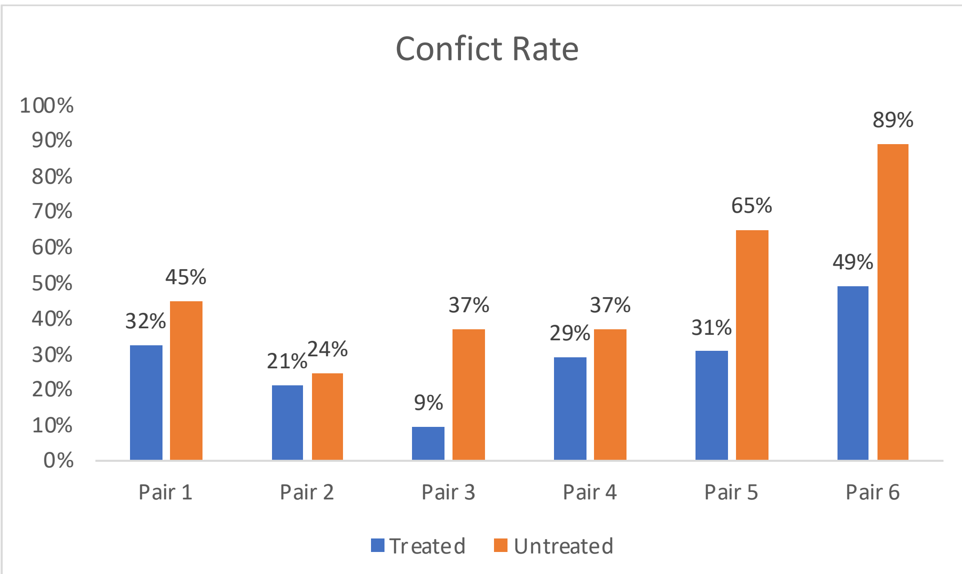


Figure 32. Conflict Rate Among the Six Pairs of the Study Locations

Figure 33 shows the near crash rates among the six pairs of the study locations. The near crash here includes all types of left turn trajectory paths. The results suggested that most of the treated locations have lower near crash rates than the untreated locations.

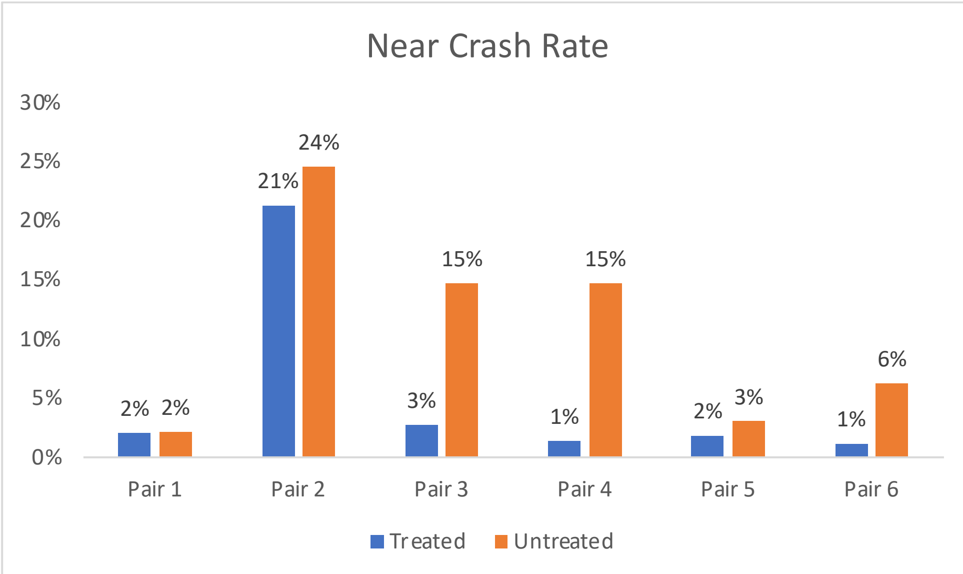


Figure 33. Near Crash Rate Among the Six Pairs of the Study Locations

Figure 34 shows the percentage of driver stopped at the minor road among the six pairs of the study locations. Most of the treated locations have higher stopping rates than the untreated locations.

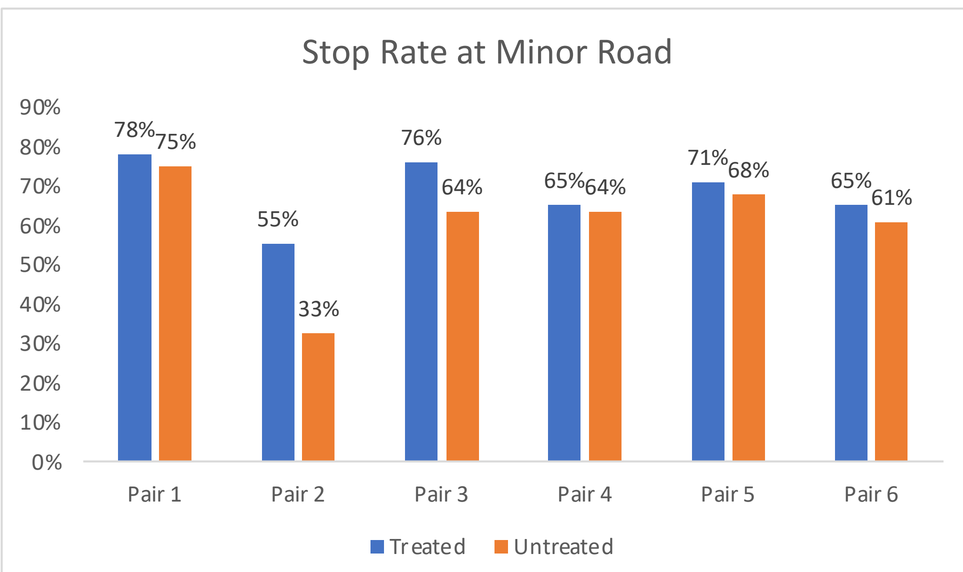


Figure 34. Stop Rate at Minor Road Among the Six Pairs of the Study Locations

Figure 35 shows the percentage of driver stopped at the median openings among the six pairs of the study locations. Most of the treated locations have much higher stopping rates than the untreated locations, especially for Locations 3.0, 4.0, and 6.0.

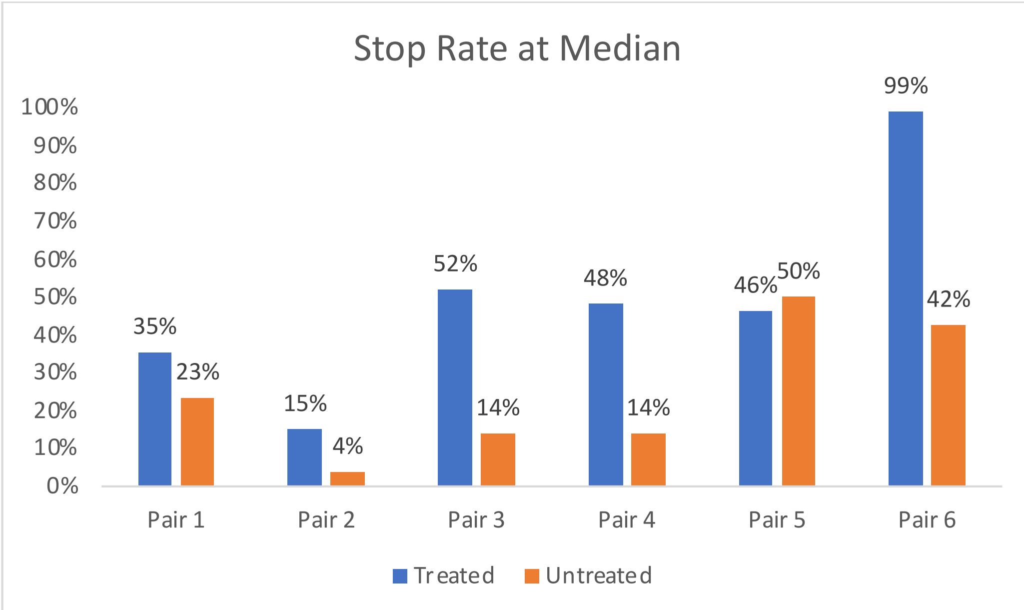


Figure 35. Stop Rate at Median Among the Six Pairs of the Study Locations

Figure 36 shows the percentage of left turn drivers following the right of way among the six pairs of the study locations. The results indicated that most of the treated locations had more drivers following the right of the way. For the stop treatment intersections, the percentage of vehicles following the right of way can be up to 99% and all three locations experienced a rate higher than 50%.

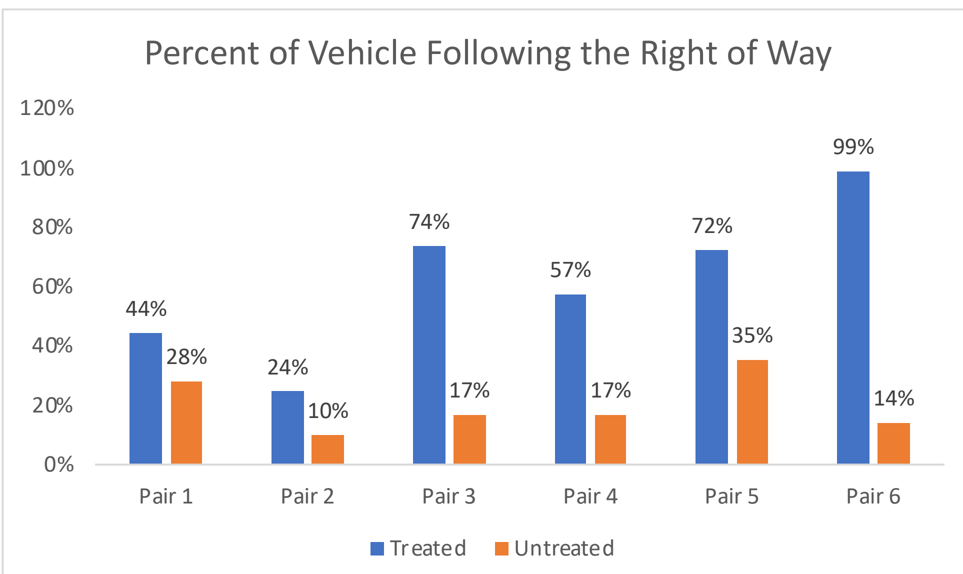


Figure 36. Percent of Vehicle Following the Right of Way Among the Six Pairs of the Study Locations

5.4.2 DETAILS OF THE SAFETY EVALUATIONS

This part will discuss the details of the safety evaluations of the pair 1 and pair 4. The detailed analysis results of the other pairs can be found in **Appendix D**.

Table 19 shows the detailed conflict study results of Locations 1.0 and 1.1, including the information of the percentage of the conflict paths by direction, and the average PET of each direction. It shows that around 50% of the conflicts are between minor road left turn and the major road through movement vehicles for both treated and untreated sites. The average PET was also calculated for different types of the conflicts. The results indicated that the treated locations had larger average PET than the untreated locations.

Table 19. Detailed Conflict Study Results of Locations 1.0 and 1.1

Conflict Path with Directions	Percent of Conflicts		Ave. PET (s)	
	Treated	Untreated	Treated	Untreated
MALT	33.33%	20.73%	3.00	2.00
MART	31.25%	24.88%	3.00	2.00
MALL	10.42%	23.41%	2.60	2.45
MARL	25.00%	27.07%	2.55	3.00
MIT	0.00%	2.44%	-	2.30
MIL	0.00%	1.46%	-	3.00

Table 20 shows the detailed driver behavior study results of the Location 1.0 and Location1.1. The table includes the left turn traffic volumes in 16 hours, the number of potential conflict by the left turn in 16 hours, the number of near crash, the vehicle stopping condition (stop, slow down and not stop) at both minor road and the median opening, and the vehicle left turn trajectories.

A simple descriptive analysis in Table 20 found that (1) 12% reduction in the conflict rates at the treated sites (2) no significant reduction in the near crash rate; (3) 12% more drivers stopped at the median openings with the treatments; and (4) 16% more vehicles followed the right of way. The Pearson Chi-square test results indicated that only the left turn trajectory between the treated and untreated experienced statistically significant differences at 95% confidence level.

Table 20. Detailed Driver Behavior Study Results of Locations 1.0 and 1.1

		Treated (Loc 1.0)		Untreated (Loc 1.1)					
		Number	%	Number	%	Difference After Treatments (%)	Chi-Square Test		
Left Turn Traffic Volumes		296		916			χ^2	df	p-value
Potential Conflict		96	32.43%	410	44.76%	-12.33%	0.34	1	0.56
Near Crash		6	2.03%	20	2.18%	-0.16%	0.09	1	0.764
Stop Condition at Minor Road	Stop	231	78.04%	687	75.00%	3.04%	2.78	2	0.249
	Slow down	46	15.38%	119	12.99%	2.39%			
	None	19	6.42%	110	12.01%	-5.59%			
Stop Condition at Median	Stop	104	35.14%	211	23.03%	12.10%	4.56	2	0.102
	Slow down	27	9.12%	46	11.22%	-2.10%			
	None	165	55.74%	824	89.96%	-34.21%			
Left Turn Trajectory Type	1	131	44.26%	256	27.95%	16.31%	6.54	2	<0.05
	2	62	20.95%	348	37.99%	-17.05%			
	3	103	34.80%	312	34.06%	0.74%			

Table 21 shows the detailed conflict study results of Locations 4.0 and 4.1, including the information of the percentage of the conflict paths with directions, and the average PET of each direction. The results found that around 60% of the conflicts are between minor road left turn and the major road through movement vehicles.

The average PET was also calculated for different types of the conflicts. It shows that the treated locations normally have longer PET than the untreated locations. The PET for treated location are normally around 3s, and the PETs for the untreated locations are 2.5s.

Table 21. Detailed Conflict Study Results of Locations 4.0 and 4.1

Conflict Path with Direction	Percent of Conflicts		Ave. PET (s)	
	Treated	Untreated	Treated	Untreated
MALT	34.62%	32.88%	3.00	2.50
MART	31.54%	30.14%	3.00	2.00
MALL	19.23%	19.18%	2.60	2.50
MARL	14.62%	16.44%	3.00	2.50
MIT	0.00%	1.37%	-	2.50
MIL	0.00%	0.00%	-	-

Table 22 shows the detailed driver behavior study results of the Locations 4.0 and 4.1. The simple descriptive analysis indicated that the treated sites had (1) 8% reduction in the conflict rates; (2) 13% reduction in the near crash rates; (3) 34% more drivers stopped at the minor road; (4) 40% more drivers stopped at the median openings; and (5) 40% more vehicles followed the right of way when making the left turns.

The Pearson Chi-square tests show that all the test results are significant at the 95% confidence interval. It implies that the stop sign and stop line installed at the median openings can significantly reduce the conflicts and change the driver behaviors.

Table 22. Detailed Driver Behavior Study Results of Locations 4.0 and 4.1

		Treated (Loc 4.0)		Untreated (Loc 4.1)					
		Number	%	Number	%	Diff. After Treatments (%)	Chi-Square Test		
Traffic Volume		446		198			χ2	df	p-value
Potential Conflict		130	29.15%	73	36.87%	-7.72%	99.30	1	< 0.001
Near Crash		6	1.35%	29	14.65%	-13.30%	20.10	1	< 0.001
Stop Condition at Minor Road	Stop	291	65.12%	126	63.64%	1.48%	11.34	2	0.003
	Slow down	112	25.12%	47	23.74%	1.38%			
	None	43	9.64%	25	12.63%	-2.99%			
Stop Condition at Median	Stop	214	47.98%	27	13.64%	34.35%	74.25	2	0.004
	Slow down	27	6.05%	34	17.17%	-11.12%			
	None	205	45.96%	137	69.19%	-23.23%			
Left Turn Trajectory Type	1	254	57.00%	33	16.67%	40.33%	81.14	2	<0.001
	2	49	10.99%	134	67.68%	-56.69%			
	3	143	32.01%	31	15.66%	16.36%			

The detailed analysis results of all the other pairs of study locations can be found in **Appendix D**. The conflict study results of all the locations can be summarized as:

1) The stop control at the median openings was more effective in reducing conflict and changing driver behaviors (stop behaviors at median and the left turn trajectories) than the yield control.

2) Median openings treated as two intersections with signs and marking can reduce approximately 10% to 40% of conflict rates.

3) More drivers (50%) stopped to make two-stage left turns at median opening treated with stop lines/ signs control than yield lines/yield signs (40%).

4) For median openings with no access control, approximately 30% of the minor road vehicles stopped at the median opening to make a two-stage left-turn.

Chapter 6

CONCLUSIONS AND SUGGESTIONS

First, this study developed LCFs in Alabama for 3-leg and 4-leg TWSC intersections on rural multilane highways. These calibration factors were then used in conjunction with the relevant SPFs from the HSM to assess the predictive performance of those models. Finally, the entire set of study sites is divided into a smaller dataset for use in calculating the calibration factor (model development). In general, across the 10 groupings of data into the model development and evaluation sets, the average LCF was found to be 0.598 for 3ST intersections and 0.537 for 4ST intersections. The derived LCF values range from 0.549 to 0.632 for 3ST intersections, and from 0.494 to 0.611 for 4ST intersections.

The study found that the SPFs for unsignalized intersections on rural highways in the HSM would overpredict the number of crashes in both the 3ST and 4ST cases. This is consistent with what past studies have shown in several other states.

The predictive performance of the calibrated models varies widely among sites. For example, for the 3ST intersections, an average MAPE among the 10 groupings was about 72%. The variability among sites is evident in Table 1, where for that particular iteration, among the 14 locations used in the model evaluation group, the percent error at each of those 14 sites ranged from 6.9% to 205%. This is consistent with the random nature of crashes and provides a limitation on the use of these models, and SPFs in general, for specific sites.

Regarding recommendations, the calibration factors developed herein are recommended for use in Alabama and are preferred to using uncalibrated SPFs. These local calibration factor values are 0.62 and 0.53 for 3-leg and 4-leg minor street stop control intersections, respectively. Recommended future work would include increasing the sample size of sites when available and considering other approaches, such as the use of machine learning tools, to subdivide the dataset in the model development and evaluation groups. In addition to developing LCF, the study selected appropriate CMFs/ Functions for some countermeasures implemented in Alabama. The guidance for the countermeasures can be found in **Appendix C**.

The researchers also studied the safety effects of two types of median opening treatments based on a study of traffic conflict and driver behavior. The results suggested that stop/yield control treatment at the median opening could improve driver behaviors and reduce the traffic conflicts.

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Appendix A

STUDY SITE INFORMATION

Table A.1. Study Site Details for 3-leg Intersections

S.NO	Route	Intersecting street	County	Observed crash frequency from CARE (2012-2019)	CMF Predicted avg crash frequency (2012-2019)
1	AL 157	County Road 1114	Cullman	1.00	6.65
2	AL 157	County Road 1188	Cullman	2.00	8.31
3	AL 157	County Road 55	Morgan	2.00	9.08
4	AL 157	County Road 63	Colbert	1.00	4.78
5	AL 157	J Mcgee Road	Colbert	1.00	4.02
6	AL 24	County Road 120	Lawrence	1.00	4.22
7	AL 24	County Road 44	Franklin	2.00	2.48
8	AL 24	Old AL 24	Franklin	6.00	2.36
9	AL 24	W Lawrence St	Franklin	2.00	3.29
10	US 82	AL 51	Bullock	8.00	0.88
11	US 231	County Road 203	Houston	1.00	8.09
12	US 231	Meriwether Road	Montgomery	8.00	16.30
13	US 231	Steeger (Steger) Road	Madison	18.00	19.28
14	US 231	Trotman Road	Montgomery	16.00	11.35
15	US 43	County Road 17	Franklin	7.00	5.96
16	US 431	AL 74	Etowah	3.00	26.09
17	US 431	AL 79	Marshall	25.00	15.49
18	US 431	County Road 79	Barbour	1.00	6.79
19	US 431	Lee Road 391	Lee	2.00	18.02
20	US 431	Lee Road 430	Lee	1.00	23.34
21	US 431	Old Hwy 431	Madison	4.00	10.64
22	US 431	Sand Valley Road	Etowah	5.00	17.79
23	US 431	South Seale Road	Russell	10.00	25.38
24	US 72	AL 247	Colbert	18.00	6.34
25	US 72	AL 35	Jackson	3.00	10.71

26	US 72	AL 65	Jackson	9.00	15.16
27	US 72	Brock Road	Madison	20.00	17.55
28	US 72	County Road 51	Lauderdale	5.00	9.79
29	US 72	Mulberry Lane	Colbert	1.00	8.32
30	US 72	Wall Road	Madison	5.00	19.66
31	US 80	AL 17	Sumter	5.00	2.95
32	US 80	AL 69	Hale	4.00	4.83
33	US 80	County Road 17	Lowndes	6.00	15.34
34	US 80	County Road 37	Lowndes	8.00	7.36
35	US 80	County Road 43	Dallas	1.00	4.15
36	US 80	Mitchell Young Rd	Montgomery	25.00	10.51
37	US 80	Steel Haven Road	Lowndes	2.00	5.33
38	US 80	Benton Road	Lowndes	2.00	6.29
39	US 80	Cantelou Road	Montgomery	6.00	7.47
40	US 82	County Road 58	Bibb	2.00	3.10
41	US 82	Curry Road	Tuscaloosa	3.00	6.82
42	US 82	Daffron Road	Tuscaloosa	4.00	12.00
43	US 82	Loop Road	Pickens	2.00	3.66
44	US 82	Monticello Dr	Tuscaloosa	11.00	17.92
45	US 82	Old Carterhill Road	Montgomery	5.00	26.73
46	US 82	Pleasant Hill Church Road	Bibb	1.00	3.09
47	US 82	Westwood School Road	Tuscaloosa	4.00	12.82
			Σall	279.00	488.45

Table A.2. Study Site Details for 4-leg Intersections

S.NO	Route	Intersecting street	County	Observed crash frequency from CARE (2012-2019)	CMF Predicted avg crash frequency (2012-2019)
1	AL 13	County Road 20	Franklin	2.00	12.61
2	AL 157	AL 101	Lawrence	24.00	11.15
3	AL 157	AL 36	Lawrence	38.00	10.05
4	AL 157	Campground Road	Morgan	1.00	12.01
5	AL 157	County Line Road	Colbert	21.00	8.84
6	AL 157	County Road 108	Lawrence	1.00	7.93
7	AL 157	County Road 1101	Cullman	6.00	21.51
8	AL 157	County Road 1212	Cullman	2.00	18.93
9	AL 157	County Road 1218	Cullman	1.00	17.00
10	AL 157	County Road 1246	Cullman	5.00	9.84
11	AL 157	County Road 136	Lawrence	4.00	7.79
12	AL 157	County Road 150	Lawrence	6.00	6.52
13	AL 157	County Road 184	Lawrence	5.00	5.01
14	AL 157	Danville Road	Morgan	10.00	17.66
15	AL 157	Ricks Lane	Colbert	12.00	9.97
16	AL 157	US 278	Cullman	1.00	17.14
17	AL 24	AL 187	Franklin	12.00	12.42
18	AL 24	County Road 108	Lawrence	3.00	5.05
19	AL 24	County Road 217	Lawrence	31.00	21.55
20	AL 24	County Road 23	Franklin	8.00	4.58
21	AL 24	County Road 358	Lawrence	3.00	20.04
22	AL 24	County Road 36	Franklin	2.00	2.64
23	AL 24	County Road 50	Lawrence	6.00	7.46
24	AL 24	County Road 75	Franklin	2.00	8.16
25	AL 24	County Road 77	Franklin	28.00	5.23
26	AL 24	County Road 99	Franklin	2.00	3.80
27	AL 24	Hudson Road	Morgan	7.00	25.31
28	AL 69	Lower Hull Road	Tuscaloosa	5.00	13.42
29	AL 69	Upper Hull Road	Tuscaloosa	8.00	13.40
30	AL 69 S	Old Greensboro Road	Tuscaloosa	2.00	56.79
31	US 11	Giles Road	Tuscaloosa	14.00	20.83

32	US 280	County Road 179	Lee	2.00	26.93
33	US 43	AL 178	Clarke	7.00	10.11
34	US 43	AL 64	Lauderdale	20.00	6.32
35	US 43	County Road 22	Franklin	10.00	27.93
36	US 43	County Road 65	Lauderdale	7.00	24.05
37	US 43	County Road 73	Lauderdale	19.00	8.74
38	US 43	Lannes W Dr	Lauderdale	5.00	17.14
39	US 43	Lauderdale County 394	Lauderdale	1.00	13.45
40	US 431	Balenger (Ballenger) Ln	Etowah	2.00	41.50
41	US 431	Clark Road	Russell	5.00	13.23
42	US 431	County Road 41	Henry	4.00	6.53
43	US 431	County Road 45	Henry	4.00	10.27
44	US 431	County Road 54	Henry	2.00	4.21
45	US 431	Freeman Road	Russell	11.00	15.03
46	US 431	Lawson Gap Road	Etowah	8.00	32.21
47	US 431	Prudence Road	Russell	1.00	5.80
48	US 72	Allsboro Road	Colbert	2.00	10.58
49	US 72	Asphalt Rock Road	Colbert	2.00	7.77
50	US 72	Cambridge Ln	Limestone	9.00	28.59
51	US 72	County Road 33	Colbert	3.00	10.43
52	US 72	County Road 53	Colbert	2.00	10.91
53	US 72	Hawk Pride Mountain Road	Colbert	9.00	15.99
54	US 72	Houstontown Road	Lauderdale	3.00	11.03
55	US 80	AL 25	Marengo	29.00	6.31
56	US 80	AL 28	Sumter	7.00	8.46
57	US 80	County Road 45	Dallas	5.00	6.77
58	US 80	County Road 69	Dallas	1.00	11.04
59	US 80	County Road 7	Dallas	1.00	9.09
60	US 80	Sheep Skin Road	Sumter	2.00	8.11
61	US 82	Bearmont Road	Tuscaloosa	10.00	24.95
62	US 82	County Road 1	Tuscaloosa	2.00	12.18
63	US 82	County Road 30	Bullock	2.00	6.44
64	US 82	Jug Factory Road	Tuscaloosa	6.00	35.98
65	US 82	Pickens County Road 75	Pickens	7.00	4.97
			Σall	331.00	701.32

Appendix B

SELECTION OF APPROPRIATE CMFS FOR DIFFERENT COUNTERMEASURES

Table B.1. Transverse Rumble Strips on Intersection Approach

Specific Treatment	CMF				Crash Severity	Crash Type	Intersection Geometry	State	Year Published
	ID	Value	Star Rating	Unadjusted Standard Error					
Install transverse rumble strips on stop controlled approaches in rural areas	2698	1.223	4	0.142	All	All	Not specified	IA,MN	2010
	2699	1.284	3	0.185	PDO	All	3-leg	IA,MN	2010
	2700	1.192	3	0.207	KABCO	All	3-leg	IA,MN	2010
	2701	0.903	3	0.211	KAB	All	3-leg	IA,MN	2010
	2702	1.066	4	0.104	All	All	4-leg	IA,MN	2010
	2703	1.138	3	0.121	PDO	All	4-leg	IA,MN	2010
	2704	0.913	3	0.124	KABCO	All	4-leg	IA,MN	2010
	2705	0.745	4	0.121	KAB	All	4-leg	IA,MN	2010
	2706	1.118	4	0.086	All	All	3-leg,4-leg	IA,MN	2010
	2707	1.191	4	0.102	PDO	All	3-leg,4-leg	IA,MN	2010
	2708	0.987	3	0.109	KABCO	All	3-leg,4-leg	IA,MN	2010
	2709	0.785	4	0.107	KAB	All	3-leg,4-leg	IA,MN	2010
	2710	0.798	3	0.32	All	All	3-leg	IA	2010
	2711	0.819	3	0.232	All	All	4-leg	IA	2010
	2712	0.818	3	0.191	All	All	3-leg,4-leg	IA	2010
	2713	0.671	3	0.278	All	All	3-leg	MN	2010
	2714	1.357	3	0.447	All	All	4-leg	MN	2010
	2715	1.182	3	0.316	All	All	3-leg,4-leg	MN	2010
	9032	0.82	3	0.16	All	All	3-leg	MO,ND,OR	2015
	9033	0.63	3	0.2	KABCO	All	3-leg	MO,ND,OR	2015
	9034	0.87	3	0.21	PDO	All	3-leg	MO,ND,OR	2015
	9035	0.57	3	0.26	All	Angle	3-leg	MO,ND,OR	2015
	9036	0.56	3	0.33	KABCO	Angle	3-leg	MO,ND,OR	2015
	9038	0.84	3	0.29	All	Rear end	3-leg	MO,ND,OR	2015
	9039	0.4	3	0.29	KABCO	Rear end	3-leg	MO,ND,OR	2015
	9040	0.94	3	0.37	PDO	Rear end	3-leg	MO,ND,OR	2015
	9045	0.87	3	0.07	All	All	4-leg	AR,KS,MO,ND,OR	2015
	9046	0.71	4	0.08	KABCO	All	4-leg	AR,KS,MO,ND,OR	2015
	9047	0.86	3	0.09	PDO	All	4-leg	AR,KS,MO,ND,OR	2015
	9048	0.87	3	0.08	All	Angle	4-leg	AR,KS,MO,ND,OR	2015
	9049	0.75	4	0.1	KABCO	Angle	4-leg	AR,KS,MO,ND,OR	2015
	9050	0.87	3	0.12	PDO	Angle	4-leg	AR,KS,MO,ND,OR	2015
	9051	0.44	3	0.08	All	Rear end	4-leg	AR,KS,MO,ND,OR	2015
	9052	0.22	3	0.08	KABCO	Rear end	4-leg	AR,KS,MO,ND,OR	2015
	9053	0.46	3	0.1	PDO	Rear end	4-leg	AR,KS,MO,ND,OR	2015

Table B.2. Advanced Stop Beacon

Specific Treatment	CMF				Crash Severity	Crash Type	Intersection Geometry	State	Year Published
	ID	Value	Star Rating	Unadjusted Standard Error					
Flashing beacons at All way stop controlled intersections	446	0.95	4	0.04	All	All	4-leg		2008
Flashing beacons at All way stop controlled intersections	447	0.9	4	0.05	ABC	All	4-leg		2008
Flashing beacons at All way stop controlled intersections	448	0.92	4	0.09	All	Rear end	4-leg		2008
Flashing beacons at All way stop controlled intersections	449	0.87	4	0.05	All	Angle	4-leg		2009
Flashing beacons at Rural All way stop controlled intersections	450	0.84	4	0.05	All	Angle	4-leg		2009
Flashing beacons at All way stop controlled intersections	451	0.88	3	0.1	All	Angle	4-leg		2008
Flashing beacons at 2-way stop controlled intersections	453	0.87	4	0.05	All	Angle	4-leg		2008
Flashing beacons at All way stop controlled intersections	454	0.72	3	0.21	All	Angle	4-leg		2008
Flashing beacons at All way stop controlled intersections	456	0.42	4	0.16	All	Angle	4-leg		2008
Actuated beacons	458	0.86	3	0.1	All	Angle	4-leg		2008

Table B.3. Channelization to Limit Turning Movements

Specific Treatment	CMF				Crash Severity	Crash Type	Intersection Geometry	State	Year Published
	ID	Value	Star Rating	Unadjusted Standard Error					
Painted channelization of left-turn lane on major road	251	0.78	3	0.14	ABC	All	3-leg		2004
Painted channelization of left-turn lane on major road	252	0.8	3	0.19	PDO	All	3-leg		2004
Painted channelization of left-turn lane on major road	258	1.28	3	0.27	ABC	All	4-leg		2004
Painted channelization of left-turn lane on major road	259	0.74	3	0.12	PDO	All	4-leg		2004
Introduce raised/curb left-turn channelization	278	0.75	3	0.14	All	Rear end, sideswipe	4-leg		2007
Introduce raised/curb left-turn channelization	279	0.87	3	0.14	All	All	4-leg		2007
Introduce painted left-turn channelization	280	0.61	4	0.09	All	Rear end, sideswipe	4-leg		2007
Introduce painted left-turn channelization	281	0.67	4	0.09	All	All	4-leg		2007
Physical channelization of right-turn lane on major road	282	0.98	3	0.35	ABC	All	3-leg		2004
Physical channelization of right-turn lane on major road	283	0.87	3	1.08	ABC	All	4-leg		2004
Physical channelization of right-turn	284	0.81	3	0.47	PDO	All	4-leg		2004

lane on major road									
Physical channelization of both major and minor roads	**291**	**1.16**	**3**	**0.09**	**KABCO**	**All**	**3-leg**		**2004**
Physical channelization of both major and minor roads	**292**	**0.73**	**3**	**0.06**	**KABCO**	**All**	**4-leg**		**2004**
Physical channelization of both major and minor roads	**293**	**0.87**	**3**	**0.22**	**PDO**	**All**	**4-leg**		**2004**
Painted channelization of both major and minor roads	**294**	**0.43**	**3**	**0.07**	**ABC**	**All**	**4-leg**	**MO**	**2004**

Table B.4. Install Left-Turn (median) Acceleration Lane

Specific Treatment	CMF				Crash Severity	Crash Type	Intersection Geometry	State	Year Published
	ID	Value	Star Rating	Unadjusted Standard Error					
Install median acceleration lane	2742	1.13	1	0.33	All	All	4-leg	MO	2010
	2743	0.88	1	0.4	ABC	All	4-leg	MO	2010
	2744	1.25	1	0.5	PDO	All	4-leg	MO	2010
	2745	0.9	1	0.36	All	Angle	4-leg	MO	2010
	2746	0.61	1	0.35	All	Angle	4-leg	MO	2010
	2747	1.43	1	0.84	All	Angle	4-leg	MO	2010
	2748	0.4	1	0.44	All	Left turn	4-leg	MO	2010
	2749	0.5	1	0.56	All	Left turn	4-leg	MO	2010
	2750	0.44	1	0.35	All	Rear end	4-leg	MO	2010
	2751	1	1		All	Sideswipe	4-leg	MO	2010
	2752	4.67	1	3.22	All	Not specified	4-leg	MO	2010
	2753	0.77	1	0.19	All	All	4-leg	MO	2010
	2754	1.56	1	1.42	Fatal	All	4-leg	MO	2010
	2755	0.55	1	0.22	ABC	All	4-leg	MO	2010
	2756	0.95	1	0.34	PDO	All	4-leg	MO	2010
	2757	0.75	1	0.22	All	Angle	4-leg	MO	2010
	2758	0.52	1	0.41	All	Angle	4-leg	MO	2010
	2759	0.8	1	0.25	All	Angle	4-leg	MO	2010
	2760	1.17	1	0.83	All	Left turn	4-leg	MO	2010
	2761	0.21	1	0.22	All	Rear end	4-leg	MO	2010
	2762	7	1	8.08	All	Sideswipe	4-leg	MO	2010
	2763	1.17	1	1.43	All	Not specified	4-leg	MO	2010

Table B.5. Install a Left-Turn Lane on the Major Road

Specific Treatment	CMF ID	CMF Value	CMF Star Rating	CMF Unadjusted Standard Error	Crash Severity	Crash Type	Intersection Geometry	State	Year Publish
Provide a left-turn lane on one major-road approach	260	0.72	3	0.13	All	All	4-leg		2004
Provide a left-turn lane on one major-road approach	264	0.65	3	0.23	KABCO	All	4-leg		2004
Provide a left-turn lane on both major-road approaches	268	0.52	3	0.14	All	All	4-leg		2004
Provide a left-turn lane on both major-road approaches	272	0.42	3	0.19	KABCO	All	4-leg		2004
Provide a left-turn lane on one major-road approach	2968	0.61	4	0.06	All	All	3-leg		2002
Installation of left-turn lanes on both major road approaches	2969	0.98	4	0.08	All	All	3-leg		2002
Install one left-turn lane on both major road directions	3008	1.36	3	0.12	All	All	3-leg		2004
Installation of left-turn lanes on both major road approaches	3018	0.73	3	0.22	All	All	4-leg	IA	2004

Table B.6. Offset Right turn Lane on the Major Road

Specific Treatment	CMF				Crash Severity	Crash Type	Intersection Geometry	State	Year Publish
	ID	Value	Star Rating	Unadjusted Standard Error					
Install offset right turn lane	2764	1.02	1	0.42	All	All	4-leg	IA	2010
	2765	2.78	1	3.48	Fatal	All	4-leg	IA	2010
	2766	0.7	1	0.4	ABC	All	4-leg	IA	2010
	2767	1.39	1	1.01	PDO	All	4-leg	IA	2010
	2768	0.96	1	0.43	All	Angle	4-leg	IA	2010
	2769	1.39	1	0.83	All	Angle	4-leg	IA	2010
	2770	1.41	1	0.91	All	Angle	4-leg	IA	2010
	2771	1.37	1	2	All	Angle	4-leg	IA	2010
	2772	0.6	1	0.43	All	Angle	4-leg	IA	2010
	2773	0	1	0	All	Left turn	4-leg	IA	2010
	2774	0.94	1	0.48	All	All	4-leg	IA	2010
	2775	1.41	1	0.92	ABC	All	4-leg	IA	2010
	2776	0.47	1	0.42	PDO	All	4-leg	IA	2010
	2777	0.31	1	0.26	All	Angle	4-leg	IA	2010
	2778	0.47	1	0.42	All	Angle	4-leg	IA	2010
	2779	0.47	1	0.42	All	Angle	4-leg	IA	2010
	2780	0	1	0	All	Angle	4-leg	IA	2010
	2781	0	1	0	All	Left turn	4-leg	IA	2010
	2782	0	1	0	All	Rear end	4-leg	NE	2010
	2783	3.67	1	2.68	All	All	4-leg	NE	2010
	2784	1	1		ABC	All	4-leg	NE	2010
	2785	2.93	1	2.24	PDO	All	4-leg	NE	2010
	2786	1.1	1	1.35	All	Angle	4-leg	NE	2010
	2787	0	1	0	All	Angle	4-leg	NE	2010
	2788	2.2	1	3.11	All	Angle	4-leg	NE	2010
	2789	6.6	1	7.62	All	Rear end	4-leg	NC	2010

Table B.7. Offset Left turn lane on the Major Road

Specific Treatment	CMF				Crash Severity	Crash Type	Intersection Geometry	State	Year Publish
	ID	Value	Star Rating	Unadjusted Standard Error					
Install positive offset left turn lanes	2790	0.5	1	0.19	All	All	4-leg	NC	2010
Install positive offset left turn lanes	2791	0.16	1	0.11	ABC	All	4-leg	NC	2010
Install positive offset left turn lanes	2792	1.57	1	0.9	PDO	All	4-leg	NC	2010
Positive left-turn lane offset (left turn crashes)	2793	0.15	1	0.12	All	Left turn	4-leg	NC	2010
Install positive offset left turn lanes	2794	0.22	1	0.15	All	Left turn,Rear end	4-leg	NC	2010
Install positive offset left turn lanes	2795	0.37	1	0.27	All	Angle	4-leg	NC	2010
Install positive offset left turn lanes	2796	2.62	1	2.18	All	Not specified	4-leg	NC	2010
Install positive offset left turn lanes	2797	0.67	1	0.2	All	All	4-leg	NC	2010
Install positive offset left turn lanes	2798	0	1	0	Fatal	All	4-leg	NC	2010
Install positive offset left turn lanes	2799	0.35	1	0.16	ABC	All	4-leg	NC	2010
Install positive offset left turn lanes	2800	1.65	1	0.85	PDO	All	4-leg	NC	2010
Positive left-turn lane offset (left turn crashes)	2801	0	1	0	All	Left turn	4-leg	NC	2010
Install positive offset left turn lanes	2802	0.24	1	0.15	All	Left turn,Rear end	4-leg	NC	2010
Install positive offset left turn lanes	2803	1.24	1	0.59	All	Angle	4-leg	NC	2010
Install positive offset left turn lanes	2804	0.83	1	0.62	All	Not specified	4-leg	WI	2010

Improve left-turn lane offset to create positive offset	**6095**	**0.662**	**3**	**0.06**	**All**	**All**	**4-leg**	**WI**	**2009**
Improve left-turn lane offset to create positive offset	**6096**	**0.644**	**3**	**0.09**	**KABCO**	**All**	**4-leg**	**WI**	**2009**
Improve left-turn lane offset to create positive offset	**6097**	**0.62**	**3**	**0.089**	**All**	**Left turn**	**4-leg**	**WI**	**2009**
Improve left-turn lane offset to create positive offset	**6098**	**0.683**	**3**	**0.109**	**All**	**Rear end**	**4-leg**	**MD**	**2009**

Table B.8 Convert intersection to RCUT

Specific Treatment	CMF				Crash Severity	Crash Type	Intersection Geometry	State	Year Publish
	ID	Value	Star Rating	Unadjusted Standard Error					
Convert intersection to RCUT	10056	0.714			All	All	4-leg	LA	2019
	10057	0			K	All	4-leg	LA	2019
	10058	0.585			ABC	All	4-leg	LA	2019
	10059	0.777			PDO	All	4-leg	LA	2019
	10377	0.86	2	0.04	All	All		LA	2020
	10378	0.69	2	0.05	All	All		LA	2020
	10379	0.87	2	0.054	All	All		LA	2020
	10380	1.06	2	0.135	All	All		LA	2020
	10381	0.77	2	0.081	All	All		LA	2020
	10382	0.8	4	0.068	All	All		LA	2020
	10383	0.8	4	0.073	All	All		LA	2020
	10384	0.42	4	0.163	All	All		LA	2020
	10385	1.07	3	0.339	All	All		LA	2020

Appendix C

UNSIGNALIZED INTERSECTION TREATMENTS DESIGN GUIDANCE

Table C.1 Transverse Rumble Strips on Stop-Controlled Approaches

Transverse Rumble Strips on Stop Control Approaches

To alert approaching drivers of the upcoming intersection. Can be particularly beneficial at intersections where users do not expect Stop signs, or roads with high-speed limit.

Target Crash Type	**Rear-end crash**		**Target Problem**	**Speeding** **Low Stop sign compliance**
Selected CMFs	**ID**	**9046**	**9049**	
	CMF	**0.71**	**0.75**	
	Severity	**KABCO**	**KABCO**	
	Quality	**4 Star**	**4 Star**	
	Unadjusted SE	**0.08**	**0.1**	
	Crash Type	**All**	**Angle**	
	Intersection Geometry	**4-leg**		
Example	**US 431 @ AL 169, AL**			

Minor road speed limit: 55 mph; Grade change between minor road and the intersection. The start point of the rumble strip is 900ft away from the intersection.

Other Resources

- **NCHRP Report 613: Guidelines for Selection of Speed Reduction Treatments at High-Speed Intersections**
- **Safety Evaluation of Transverse Rumble Strips on Approaches to Stop-Controlled Intersections in Rural Areas**

Table C.2 Advance Stop Beacon

Advance Stop Beacon					
The beacon indications supplement STOP (R1-1) signs and face the minor road. It can be used to increase the conspicuity of the Stop sign; used at locations or conditions where users do not expect Stop signs, such as poor nighttime visibility.					
Target Crash Type	**Right-angle**		**Target Problem**	**Inadequate visibility of the intersection**	
	Rear-end crash				
	Opposing left turn			**Low Stop sign compliance**	
Selected CMFs	**ID**	**446**	**447**	**448**	**449**
	CMF	**0.95**	**0.9**	**0.92**	**0.87**
	Severity	**All**	**ABC**	**All**	**All**
	Quality	**4 Star**	**4 Star**	**4 Star**	**4 Star**
	Unadjusted SE	**0.04**	**0.05**	**0.09**	**0.05**
	Crash Type	**All**	**All**	**Rear end**	**Angle**
	Intersection Geometry	**4-leg**			
Example	**AL 25 @ U.S. 80, AL**				
				**An isolated intersection in rural area, with poor nighttime visibility. Minor road speed limit: 40mph.**	
Other Resources	**• MUTCD Section 4L.02: Flashing Beacons**				
	• Safety Evaluation of Flashing Beacons at STOP-Controlled Intersections, FHWA				

Table C.3 Left turn (Median) Acceleration Lane

<table>
<tr><td colspan="4">Left turn (Median) Acceleration Lane</td></tr>
<tr><td colspan="4">An auxiliary lane that allows left-turning vehicles from the minor road to accelerate along the major road before merging into the through lane.</td></tr>
<tr><td rowspan="3">Target Crash Type</td><td>Right-angle</td><td rowspan="3">Target Problem</td><td>High left-turn volume onto high-speed or high-volume major road</td></tr>
<tr><td>Rear-end (major road)</td><td>High volume of trucks or RV turn left</td></tr>
<tr><td>Sideswipe, same direction</td><td>Misjudgment of gaps</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">No Recommended CMFs.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Example</td><td colspan="3">St. & Tom Mann Rd., Newport, NC</td></tr>
<tr><td colspan="3">

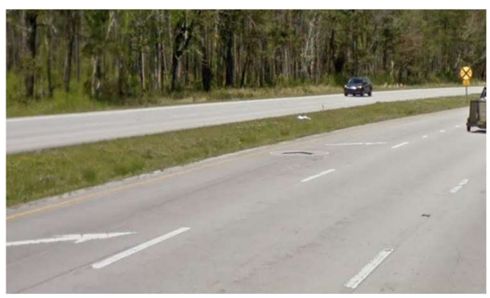</td><td>It's a T-intersection with a physical channelization. Picture shows the major road left-turn acceleration lane with the pavement arrow.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Other Resources</td><td colspan="3">• AASHTO Green Book Section 9.7: Auxiliary Lanes</td></tr>
</table>

Table C.4 Center Line Pavement Markings in a Median Crossing

<table>
<tr><td colspan="4">Center Line Pavement Markings in a Median Crossing</td></tr>
<tr><td colspan="4">Application of double yellow line to delineate the center of a median crossing can be used to serve vehicles in both directions, and to promotes two-stage crossing.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td rowspan="4">Target Crash Type</td><td>Right-angle</td><td rowspan="4">Target Problem</td><td>Interlocking left turns on the major road</td></tr>
<tr><td>Opposing left turn</td><td>Side-by-side left-turn queuing in median</td></tr>
<tr><td>Sideswipe, same direction</td><td rowspan="2">Observed conflicts in median</td></tr>
<tr><td>Head-on</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td colspan="4">No Recommended CMFs</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Example</td><td colspan="3">Co Rd 21 & U.S. 280, AL</td></tr>
<tr><td colspan="3">
</td><td>The median opening is wide (85ft). The double yellow line helps to separate the crossing vehicles queueing in median.</td></tr>
<tr><td colspan="4"></td></tr>
<tr><td>Other Resources</td><td colspan="3">• MUTCD, Installation of Pavement Markings</td></tr>
</table>

Table C.5 Convert to RCUT

Convert to RCUT				
Conversion of minor road left turns and through movements to right turns and U-turns, usually on divided highways with wide median and multiple lanes in each direction.				
Target Crash Type	Right-angle		**Target Problem**	Insufficient gaps for minor road crossing vehicles
	Opposing left turn			
	Rear-end (major road)			
	Pedestrian			
Selected CMFs	ID	10382	10383	-
	CMF	0.8	0.8	
	Severity	All	All	
	Quality	4 Star	4 Star	
	Unadjusted SE	0.0683	0.073	
	Crash Type	All	All	
Example	AL219 & US82, Centreville, AL			
				Unsignalized RCUT intersections are installed with flashing beacons to reduce the minor road left turn crashes
Other Resources	●Restricted Crossing U-Turn Intersections, FHWA			
	● MUTCD, Section 2B.18: Movement Prohibition Signs			
	● GDOT, RCUT			

Appendix D

CONFLICT AND DRIVER BEHAVIOR STUDY RESULTS

Table D.1 Detailed Conflict Study Results of Location 2.0 and Location 2.1

Conflict Path with Directions	Percent of Conflits		Ave. PET (s)	
	Treated	Untreated	Treated	Untreated
MALT	33.90%	46.97%	2.83	2.92
MART	44.07%	43.94%	2.54	3.00
MALL	1.69%	3.03%	2.00	1.00
MARL	8.47%	6.06%	1.20	1.00
MIT	11.86%	0.00%	1.30	-
MIL	0.00%	0.00%	-	-

Table D.2 Detailed Driver Behavior Study Results of Location 2.0 and Location 2.1

		Treated (Loc 2.0) Number	%	Untreated (Loc 2.1) Number	%	Difference after Treatments (%)	Chi-Square Test		
Traffic Volume (16hrs)		278		270			χ^2	df	p-value
Potential Conflict (16hrs)		59	21.22%	66	24.44%	-3.22%	1.21	1	0.271
Near Crash		4	1.44%	11	4.07%	-2.64%	0.28	1	0.597
Stop Condition at Minor Road	Stop	154	55.40%	88	32.59%	22.80%	6.91	2	0.052
	Slow down	106	38.13%	144	53.33%	-15.20%			
	None	18	6.47%	38	14.07%	-7.60%			
Stop Condition at Median	Stop	42	15.11%	10	3.70%	11.40%	3.89	2	0.143
	Slow down	41	14.75%	14	5.19%	9.56%			
	None	195	70.14%	246	91.11%	-20.97%			
Left Turn Trajectory Type	1	68	24.46%	26	9.63%	14.83%	5.42	2	0.067
	2	146	52.52%	160	59.26%	-6.74%			
	3	64	23.02%	84	31.11%	-8.09%			

Table D.3 Detailed Conflict Study Results of Location 3.0 and Location 3.1

Conflict Path with Directions	Percent of Conflicts		Ave. PET (s)	
	Treated	Untreated	Treated	Untreated
MALT	32.11%	43.12%	3.00	2.00
MART	41.12%	40.02%	2.50	2.00
MALL	2.12%	4.21%	2.60	2.45
MARL	12.41%	6.06%	3.00	3.00
MIT	10.12%	3.12%	-2.50	2.30
MIL	2.12%	3.47%	3.00	3.00

Table D.4 Detailed Driver Behavior Study Results of Location 3.0 and Location 3.1

		Treated (Loc 3.0) Number	%	Untreated (Loc 3.1) Number	%	Difference After Treatments (%)	Chi-Square Test		
Traffic Volume (16hrs)		938		198			χ2	df	p-value
Potential Conflict (16hrs)		88	9.38%	73	36.87%	-27.49%	60.12	1	< 0.01
Near Crash		25	2.67%	29	14.65%	-11.98%	18.01	1	< 0.01
Stop Condition at Minor Road	Stop	713	76.01%	126	63.64%	12.38%	3.90	2	0.142
	Slow down	163	17.38%	47	23.74%	-6.36%			
	None	61	6.50%	25	12.63%	-6.12%			
Stop Condition at Median	Stop	485	51.71%	27	13.64%	38.07%	7.54	2	<0.01
	Slow down	211	22.49%	34	17.17%	5.32%			
	None	242	25.80%	137	69.19%	-43.39%			
Left Turn Trajectory Type	1	690	73.56%	33	16.67%	56.89%	81.14	2	<0.01
	2	225	23.99%	134	67.68%	-43.69%			
	3	23	2.45%	31	15.66%	-13.20%			

Table D.5 Detailed Conflict Study Results of Location 5.0 and Location 5.1

Conflict Path with Direction	Percent of Conflicts		Ave. PET (s)	
	Treated	Untreated	Treated	Untreated
MALT	46.67%	41.84%	2.50	2.50
MART	42.86%	43.95%	2.50	2.00
MALL	10.48%	9.21%	3.00	3.00
MARL	0.00%	3.68%	0.00	2.60
MIT	0.00%	0.79%	-	2.50
MIL	0.00%	0.53%	-	3.00

Table D.6 Detailed Driver Behavior Study Results of Location 5.0 and Location 5.1

		Treated (Loc 5.0) Number	%	Untreated (Loc 5.1) Number	%	Diff. After Treatments (%)	Chi-Square Test		
Traffic Volume (16hrs)		684		588			χ2	df	p-value
Potential Conflict (16hrs)		210	30.70%	380	64.63%	-33.92%	70.23	1	< 0.05
Near Crash		12	1.75%	18	3.06%	-1.31%	0.12	1	0.72
Stop Condition at Minor Road	Stop	486	71.05%	399	67.86%	3.20%	3.12	2	0.077
	Slow down	179	26.17%	167	28.40%	-2.23%			
	None	19	2.78%	22	3.74%	-0.96%			
Stop Condition at Median	Stop	3566	52.05%	150	21.93%	30.12%	71.30	2	< 0.01
	Slow down	253	36.99%	237	34.65%	2.34%			
	None	75	10.96%	201	29.39%	-18.42%			
Left Turn Trajectory Type	1	492	72.00%	206	35.00%	37.00%	69.08	2	<0.01
	2	82	12.00%	241	40.99%	-28.99%			
	3	109	16.00%	141	24.01%	-8.01%			

Table D.7 Detailed Conflict Study Results of Location 6.0 and Location 6.1

Conflict Path with Direction	Percent of Conflicts		Ave. PET (s)	
	Treated	Untreated	Treated	Untreated
MALT	45.69%	36.91%	2.50	2.00
MART	47.37%	43.38%	3.00	2.00
MALL	4.07%	8.68%	3.00	2.50
MARL	2.87%	9.62%	3.00	2.50
MIT	0.00%	0.47%	-	2.50
MIL	0.00%	0.95%	-	2.50

Table D.8 Detailed Driver Behavior Study Results of Location 6.0 and Location 6.1

		Treated (Loc 6.0)		Untreated (Loc 6.1)					
		Number	%	Number	%	Diff. After Treatments (%)	Chi-Square Test		
Traffic Volume (16hrs)		856		714			χ2	df	p-value
Potential Conflict (16hrs)		418	48.83%	634	88.80%	-39.96%	100.12	1	< 0.01
Near Crash		10	1.17%	44	6.16%	-4.99%	1.22	1	0.203
Stop Condition at Minor Road	Stop	558	65.19%	435	60.92%	4.26%	3.52	2	0.172
	Slow down	215	25.12%	193	27.00%	-1.88%			
	None	83	9.70%	86	12.04%	-2.35%			
Stop Condition at Median	Stop	847	98.95%	303	42.44%	56.51%	80.43	2	< 0.01
	Slow down	2	0.23%	200	28.01%	-27.78%			
	None	7	0.82%	211	29.55%	-28.73%			
Left Turn Trajectory Type	1	847	98.95%	100	14.01%	84.94%	90.22	2	<0.01
	2	5	0.58%	89	12.46%	-11.88%			
	3	4	0.47%	525	73.53%	-73.06%			