DEVELOPMENT AND CALIBRATION OF SAFETY PERFORMANCE FUNCTIONS FOR INTERSECTIONS ON RURAL DIVIDED HIGHWAYS IN ALABAMA

by

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A thesis submitted to the Graduate Faculty of
Auburn University
in partial fulfillment of the
requirements for the Degree of
Master of Science

Auburn, Alabama
August 8, 2020

Keywords: Safety Performance Functions, Crash Modification Factor,
Calibration Factor

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ABSTRACT

Although median separated highways provide apparent benefits over undivided highways, sometimes median openings on rural divided highways (RDHs) provide some of the greatest opportunities for frequent and severe crashes on the highway system. Minor road drivers may fail to select a safe gap when they cross or turn left on to the farside of the intersection. Right-angle crashes are common at a two-way Stop-control intersection (TWSC) and the most problematic of these crashes tend to occur at the farside of the intersection. At-grade intersections with wide medians in rural settings have the potential for severe crashes due to numerous conflict points and high speeds and are therefore worthy of evaluation of the safety performance of these intersections. The locations that are the focus of the study are the unsignalized intersections on rural divided highways with medians wider than 30 feet. Crash prediction models in the Highway Safety Manual (HSM), published by AASHTO in 2010, are statistical tools that can be used to predict the number of crashes and evaluate road safety. This thesis supports the safety analyses by developing a local calibration factor for the HSM-provided safety performance function (SPF) for 3-legged (3ST) and 4-legged (4ST) stop-controlled intersections on rural divided highways in Alabama. This study also calibrated state-specific (SPFs) for unsignalized intersections with wider medians greater than 30 feet on RDHs in Alabama. It also documents the selection of appropriate crash modification factors for a specific countermeasure deployed at a treated location. The calibration factors obtained from the analysis for 3ST and 4ST intersections are 0.61 and 0.57 respectively which implies that the HSM crash prediction methodology over-predicts the crashes at the intersections on RDHs in Alabama. The results of the analysis support the safety analyses needed for the larger research project in planning, design, operations, and maintenance.

ACKNOWLEDGMENTS

I would like to extend my special gratitude to my advisor, Dr. Rod E. Turochy for his mentorship and encouragement throughout my graduate studies at Auburn University. Without his patience and countless hours of long meetings, this thesis would not have been possible. I would also like to thank my committee members Dr. Huaguo Zhou and Dr. Jeffrey LaMondia for serving on my thesis committee as well as helping me expand my horizon of knowledge in transportation engineering.

A special thanks to Dr. Turochy and family for your warm gestures at all times and thank you for always making me feel welcome and at home. You inspire me a lot for your gestures of being humble, kind, and generous. I would say that I am really blessed and grateful that I am one of the students that worked under your guidance.

Lastly, I would like to thank my parents and my brother Srikanth Rayapureddy for always encouraging and supporting me throughout my life. Special gratitude to my brother who is the reason from choosing a career at Auburn university to what I am today.

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LIST OF ABBREVIATIONS

TWSC	Two-way Stop-Control
HSM	Highway Safety Manual
SPF	Safety Performance Function
CMF	Crash Modification Factor
ICWS	Intersection Conflict Warning Systems
IDS	Intersection Decision Support
RCUT	Restricted Crossing U-Turn
ALDOT	Alabama Department of Transportation
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
NCHRP	National Cooperative Highway Research Program
RIRO	Right-in-Right-Out
EB	Empirical Bayes
CARE	Critical Analysis Reporting Environment
GPS	Global Positioning System
TWLTLs	Two-Way Left-Turn Lane
ATD	Alabama Traffic Data
LCF	Local Calibration Factor
AADT	Annual Average Daily Traffic

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

A rural divided highway (RDH), also referred to as an expressway, is a high-speed, multilane, divided highway with partial access control. Expressways are typically four-lane divided facilities with two lanes in each direction separated by a wide, depressed, turf median (Maze et al. 2010). Median openings on rural divided highways with partial access control provides some of the greatest potential conflicts for frequent and severe crashes on the highway system (Hu and Donnell 2011). Intersections play an important role in the roadway network as they provide connections to different routes and facilities. They also provide access to adjacent residential, commercial and industrial developments. Although intersections comprise a small portion of total road system mileage, they account for a high percentage of crashes resulting in injuries and fatalities (FDOT 2017). According to the AASHTO Strategic Highway Safety Plan, intersection-related crashes constitute more than 50% of all crashes in urban areas and over 30% in rural areas, and over 30% of crashes at unsignalized intersections result in injury (Neuman et al. 2003). A median width of 12-30 ft. is generally provided which acts as a storage area for left-turning vehicles at intersections. Wider medians may reduce the frequency of cross-median crashes and headlight glare from the vehicles coming from the opposite direction. In the case of rural unsignalized intersections, the frequency of crashes and undesirable driver conditions decrease as the median width increases (Maze et al. 2010) A safety trend review by (Stamatiadis et al. 2009) indicates that median related crashes increases as median width increases with a maximum of about 30 ft and then reduce as the median becomes wider than 30 ft. As this study is mainly focused on the safety of unsignalized intersections with median widths greater than 30 ft, Tables 1-1 and 1-2 shows the effect of median width on crashes. The interim report for NCHRP Project 17-27 developed a set of Crash Modification Factors (CMFs) as shown in Table 1-1 for the effect of median width on crashes for rural multilane roadways (Stamatiadis et al. 2009). (CMF) is a multiplicative factor used to calculate the predicted crash frequency at a site after a countermeasure is applied at a specific site (Gross et al. 2010)

Barrier	Median width (ft)								
	15	20	30	40	50	60	70	80	90
With	1.000	0.997	0.990	0.984	0.977	0.971	0.964	0.958	0.951
Without	1.000	0.994	0.981	0.969	0.957	0.945	0.933	0.922	0.910

Table 1- 1 CMFs for median width in Rural multilane roadways (Stamatiadis et al. 2009)

For every 1-foot increase in median width, there is a 1% reduction in multi-vehicle crashes and the recommended values of CMFs for median widths of divided roadways are shown in Table 1-2 (Stamatiadis et al. 2009). Tables 1-1 and 1-2 also gives some insights about the safety of CMFs of the median width on crashes.

Category	Median width (ft)							
	10	20	30	40	50	60	70	80
Multi-vehicle	1.00	0.91	0.83	0.75	0.68	0.62	0.57	0.51

Table 1- 2: CMFs for median width, divided roadways (Stamatiadis et al. 2009)

According to FHWA Highway Statistics 2017, there are 5,584 miles of other principal arterial rural highways in Alabama (FHWA 2017). The intersections that are the focus of the research involve four-lane divided highways. The intersections on these highways tend to have wider medians which provide the safety benefits of a relatively large degree of separation of opposing direction of traffic.

1.2 PROBLEM STATEMENT

In a rural highway setting with wide medians and two-way stop control (TWSC) on minor road approaches, drivers from the minor road either cross or turn left and complete the maneuver in two stages. First, they cross the near side roadway of the major street and then wait in the median or the storage area before crossing or turning left on to the far side of the roadway. This is called a two-stage gap acceptance (Nabaee 2011). Figure 1-1 shows the two-stage gap acceptance process at divided intersections.

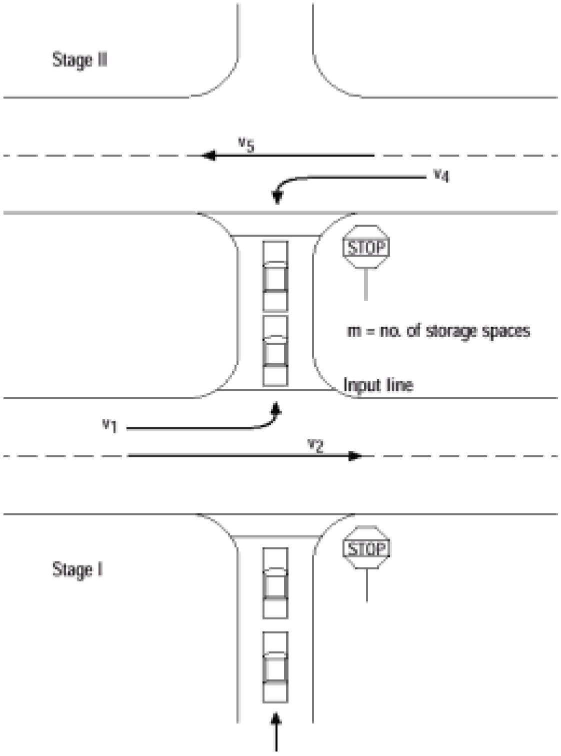

Figure 1- 1: Example of a Two-stage gap acceptance at a divided intersection (Highway Capacity Manual 2000)

During the process of two-stage gap acceptance, minor road drivers may fail to select a safe gap in the mainline intersection when they enter from the stop-control condition. This is because, drivers have to make multiple judgments pertaining to sight distances, approach speeds of crossing traffic, and available gaps in these high-speed rural settings. As such, many characteristics of the near side roadway, far side roadway and median opening influence the potential for safe completion of this maneuver. (Maze et al. 2010). At TWSC expressway intersections, right-angle crashes are common and the most problematic of these crashes tend to occur at the far-side of the intersection. It was also known that many highways were constructed in multiple time periods with different design standards as such two-lane roads were constructed in the early to mid-20th century (FHWA n.d.). Increased traffic volumes created the necessity to construct parallel roadways more recently to more modern design criteria, as such rural two-lane highways were converted to four-lane highways. The older of the twodirectional roadways often does not meet sight distance criteria for present driver expectations. These scenarios 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 (Maze et al. 2010) (Council and Stewart 1999). Apart from the safety benefits associated with converting two-lane highways to four-lane divided highways, other factors like high crash frequency and severity experienced at these locations, the need for improvements in intersection configuration at these locations has drawn national attention in the recent years. According to the FHWA office of highway policy information’s annual highway statistics reports, rural expressway mileage in the united states increased nationally by 2400 miles from 1995 to 2005 (Maze et al. 2010). One such effort in this area is FHWA’s alternative intersection research program. This report provides alternative intersection design features, their operational and safety issues, access management costs, etc. to a conventional intersection design (FHWA 2009). Another substantial effort in this area is a data-driven, performance based framework that aims to provide a geometric and control solution for a conventional intersection (FHWA, n.d.). This thesis aims to address the significance of the safety of unsignalized intersections on multilane rural high-speed highways by developing a local calibration factor (CF) for the current safety performance functions SPFs in the Highway safety manual (HSM) and selecting crash modification factors (CMFs) 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. 2014). The CF is used to adjust the predictive models to local conditions (Fletcher et al. 2014).

1.3 RESEARCH OBJECTIVES

This thesis is intended to support ongoing research related to a project entitled “Development of Guidance for Unsignalized Type Intersection Configuration on Rural Divided Highways”, funded by the Alabama Department of Transportation (ALDOT). With the lack of conclusive design guidance on the selection of intersection type to improve safety at wider medians on rural divided highways, there is a need to study these locations in Alabama and develop guidance for roadway engineers to apply to relevant projects. ALDOT’s Office Of Safety Operations had conducted some preliminary analysis to identify locations that are worthy of study based on crash histories and roadway geometries. This thesis supports the safety analysis needed for the larger research project. The objectives of this thesis are:

1. Develop a local CF for SPF for 3-legged and 4-legged stop-controlled intersections on multilane divided highways in HSM based on the calibration procedure outlined in Appendix A of part C of the HSM. This calibration factor modifies the predicted average crash frequencies from the default manual predictions to Alabama conditions.
2. Calibrate state-specific SPF’s for unsignalized intersections on rural divided highways in Alabama. The developed Alabama specific calibration factor is used to calculate the predicted average crash frequencies at a specific intersection. This calibration factor can be applied to any unsignalized intersections with medians greater than 30 ft on rural divided highways in AL.
3. Select appropriate CMFs for specific countermeasures that had been deployed at the treatment locations. These CMFs provide an estimate of the safety performance of the deployed countermeasure.

1.4 ORGANIZATION OF THIS THESIS

This thesis is organized into five chapters. Chapter 1: Introduction, introduces and explains the concept of a rural expressway and effect of median width on these expressways. It also explains statistics of crashes involved at intersections on these highways. It further explains the concept of two-stage gap acceptance and a need for the development of guidance at the unsignalized intersection type configurations. Chapter 2: Literature review, reports past research and findings of rural divided highway intersection safety treatments. As the development of the local calibration factor is one of the objectives of this thesis, case studies and literature review of various state-specific calibration factors was documented. Chapter 3: Methodology, describes in detail the statistical models and any tools or software used for the development of calibration factor and calibration of intersection specific safety performance functions (SPFs). Chapter 4: Data, describes the data source, method of data collection, and data cleaning. It also provides the summary statistics of the final dataset and mentions the caveats, if there are any. Chapter 5: Results, reports the final local calibration factor value, reviewed crash modification factors, and predicted crash frequencies at the intersections. Chapter 6: Conclusions, summarizes the need for this research, data used, methods adopted, and significant results found. It discusses the need for future research and make recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

This chapter synthesizes relevant literature pertinent to the (RDH) intersection safety treatments and case studies of the development of local calibration factor. The first section describes various RDH intersection treatments divided into subsections and categorized based on geometric design and Traffic control devices (TCDs). The second section documents the case studies of various states that had been involved in the development of local CFs.

2.1.1 GEOMETRIC DESIGN SAFETY EVALUATIONS

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 Two-way stop-controlled (TWSC) intersections (Le et al. 2018) 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. 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 naive 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.

Specifically pertaining to rural road safety, a study (Tarko and Leckrone 2010) analyzed high-speed rural intersections and suggested methods of improvement of safety. 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 like the presence of horizontal curves within the intersection vicinity, traffic volume on the major road, minor road functional class, etc. Recommendations were made at the existing intersections like median closures or a median opening should be restricted to certain maneuvers. Construction of medians wider than 80 ft was suggested at 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) 3year 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. (J. E. Hummer and Rao 2017) evaluated Restricted crossing U-turn (RCUT) intersections, a variety of unsignalized intersection, for the estimation of low-cost safety improvements. As a part of their research, they collected and analyzed crash data to develop a crash modification factor (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. From the results it was found, 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 (J.

Hummer et al. 2014) provide information and guidance on RCUT intersections. In this report, they had documented 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. Table 2-1 shows a list of RCUT intersections with CMFs by severity level. All these deployments were implemented in rural expressway or rural multilane settings.

S.NO	Countermeasure	Title	Author	State	Setting Type	Year	Study period	Sites included	Model	CMF (All)	fatal	Injury	PDO	Angle
1	R-cut	Field Evaluation of a Restricted Crossing U-Turn Intersection	Inman, V.W., Haas	Maryland	Rural fourlane divided Highways	2012	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				
2	unsignalized Superstreets design	Safety effects of unsignalized superstreets in North Carolina	Ott, Sarah E., et al.	North Carolina	Four-lane divided Arterials	2011	2004-2009	13 superstreets	Traffic flow adjustment, comparison-Group, EB analysis	EB:0.73	0.5	0.5		0.14 for angle and right turn crashes and 0.24 for left turn crashes
3	J-Turn Intersection	Evaluation of J-Turn Intersection Design Performance in Missouri	Edara, P., Sun, C., Breslow, S.	Missouri	Rural expressway stop controlled intersections	2013	Before-After period varied for different treatment sites	5 J-turn sites	EB Before_After safety evaluation	0.652	0.463	0.463		
4	Reduced conflicts intersections	A study of the traffic safety at reduced conflict intersections in Minnesota	Leuer, Derek and Fleming, Katie	Minnesota	Rural expressways	2017	Before period: 2009-2011, After period:2013-2015	8 RCIs	Comparative site analysis	0.85	0	0		Right angle-0.23

Table 2- 1: List of RCUT treatments deployed in different states

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 some of the key findings of the research tells that right-angle crashes are overrepresented at rural stop-controlled intersections.

2.1.2 TRAFFIC CONTROL DEVICES SAFETY EVALUATIONS

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-legged 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-legged 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 effective.

Studies pertaining to the safety evaluation of multiple strategies at stop-controlled intersections deployed in different states were presented in Table 2-2.

S.NO	Countermeasure	Title	Author	State	Setting Type	Study period	Sites included	Model	CMF (All)	fatal	Injury	PDO	Angle
1	Signing, pavement markings include remark existing stop lines, crosswalks, arrows and word messages	Safety Evaluation of Multiple Strategies at Stop-Controlled Intersections	Le, Gross, Persaud, Eccles, and Soika	SC	Rural stop-controlled intersections	2005-2014	918 teatment sites and 3000 reference sites	EB observational before-After	0.917	0.899	0.899		0.941
2	Add centerline & stop bar, Replace 24 inch with 30-inch stop signs	Low-Cost Safety Improvements Chapter 27, The Traffic Safety Toolbox: a primer on traffic safety	Polanis, S. F.	NC	urban		6 sites	simple B-A					0.33

Table 2- 2: Studies on double yellow center line and yield bar marking countermeasures deployed in various states

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Another method of sign implementation was proposed in a study by (Preston et al. 2006) initiated 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. They have conducted a crash analysis in Minnesota state mainly focusing the thru-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 street lights 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 studies on flashing beacons and stop ahead sign countermeasures deployed in different states was presented in Table 2-3. This Table also included the number of sites, the statistical model employed, and CMFs developed for total, fatal, injury and angle crashes

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S.NO	Countermeasure	Title	Author	State	Setting Type	Study period	Sites included	Model	CMF (All)	fatal	Injury	PDO	Angle
1	Flashing Beacons	Safety evaluation of flashing beacons at stop controlled intersections	Srinivasan et al.	NC and SC	Rural two-way and four-way stop-controlled intersections		64 sites in NC and 42 sites in SC	Emperical Bayes B-A	0.95	0.9	0.9		0.87
2	Signing and pavement markings enhancements	Safety Effects of Low-Cost Systemic Safety Improvements at Signalized and Stop-Controlled Intersections	Le et al	SC	urban & rural	2005 to 2014	434	Emperical Bayes B-A	0.917	0.899	0.899		0.941 and 0.853-nighttime

Table 2- 3: Studies on Flashing beacons and stop ahead signs countermeasures in various states

Figure 2-1 shows the some of the basic low-cost countermeasures like double up oversize warning signs, double stop signs, street name signs, double up warning arrows at the stem of T-intersections and stop bars at stop-controlled intersections (Le et. al 2009)

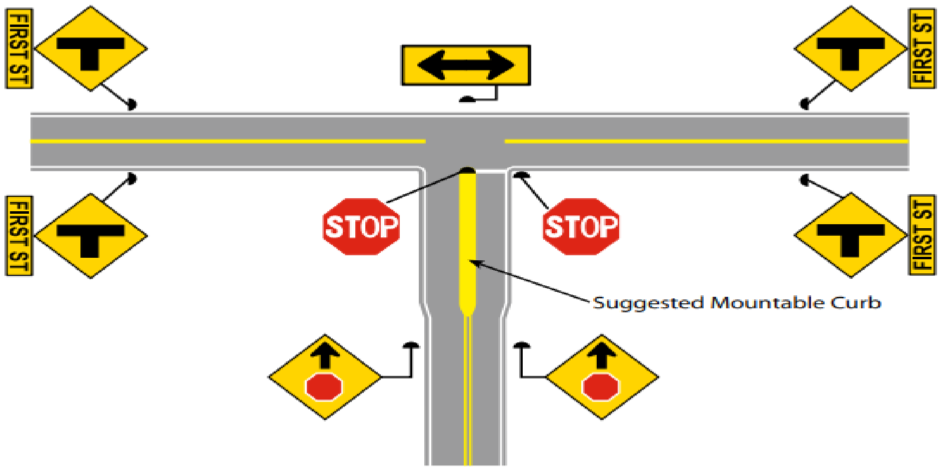

Figure 2- 1: Examples of low-cost countermeasures for stop-controlled intersections in South Carolina (Le et. al 2009)

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 (Kuehl et al. 2016) developed an intersection safety technologies guide book which contains several safety strategies to address traffic safety concerns at side-street stop-controlled intersections. 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 traffic control devices safety evaluations provides insights about the crash modification factors on crashes after the implementation of a countermeasure at a site. Tables 2-1, 2-2 and 2-3 will be used as a reference to compare and apply the most appropriate CMFs to the treated sites in section 5.5

2.1.3 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 a (SPF) to determine the potential for crash reductions at a specific location. An SPF is a mathematical model that relates the frequency of crashes by severity and the most significant causal factors. Through this study, the SPFs that were found used annual average daily traffic as the most causal factor developed for the total crashes and those with fatal injuries. Additionally, they 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 claim 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. This report is a supplement to the work published in FHWA-RD-99-094, 2000, which consists of models for both multiple-vehicle and single-vehicle crash collision types. They employed several statistical modeling approaches like lognormal, Poisson, and negative binomial regression analyses. From the results, it was observed 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 is also noticed that negative binomial distribution models generally fit the crash data at rural three and four-leg STOP-controlled intersections, and urban three-leg STOP-controlled intersections. Besides lognormal regression models were found more suitable for modeling crashes at urban, four-leg, STOP-controlled and urban, four-leg, signalized intersections.

Another model used by (Bonneson and McCoy 1993) that shows promise in the crash analysis was 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 vs 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 that focused on the geometric layout of intersections was performed by (Burchett and Maze 2006) which analyzed the effects of different roadway characteristics, in addition to traffic volume, on the safety of at-grade, (TWSC). They accomplished this by using data from over 600 intersections in Iowa, identifying the 100 best and 100 worst performing intersections based on crash data, and performing 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 judging gaps in the far lane being the most problematic for drivers at all intersection types. These tangential routes appear to be the safest geometric layout, experiencing 25% less right-angle crashes than other intersections. Also, when looking at the surrounding land of the intersection, they found that the fatality rate at intersections next to residential areas was 25% greater than those in agricultural areas and 50% greater than at commercial land. In a previous study (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 is observed as a significant finding for systematically identifying intersections to improve or construct a new grade separated facility.

2.2 CALIBRATION STUDIES

The Highway safety manual (HSM) published by the American Association of State Highway and Transportation Officials (AASHTO) in 2010 provides crash prediction models to evaluate roadway safety (Lord et al. 2016)(Kolody et al. 2014). These crash prediction models were developed based on the historic site and crash data from selected states for givens periods of time (Ogle et al. 2018). As a result, it is necessary 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 (Dissanayake 2017). Therefore, several states had 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.

Calibration factor development study from Oregon state (Dixon et al. 2013) calibrated safety performance functions(SPFs) by applying the (HSM) procedure to Oregon conditions. 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. The calibration procedure outlined in the HSM part C Appendix A was used to develop the Oregon calibration values. From the analysis, it was observed that for most of the facility types the calibration factor values are smaller than 1. It was also observed that the calibration factors for total crashes in Oregon had a significant difference in observed crash frequencies. Another study also developed a local calibration factor for 18 facility types in Maryland (Shin et al. 2014). Comparison of HSM default crash proportions and Maryland specific data suggested that the HSM method over predicts the crashes. It was also observed that for all the facility types the calibration factor values are less than 1 which implies that Maryland had fewer crashes than the predicted crashes estimated by the HSM predictive methods.

Specifically pertaining to safety in rural two-lane and four-lane divided highways in Alabama (Mehta and Lou 2013) evaluated the HSM predictive state-specific statistical models for rural segment facilities. HSM recommended method and the special case of SPF estimation was used in the analysis. From the SPF estimation method, 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. From the HSM recommended method, it was observed 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 HSM base SPFs underpredicts the mean crash frequencies on these two facilities. For the development of state-specific SPFs for Alabama, four different models from the literature were reviewed. Out of them four different models were investigated that could fit well with Alabama data. For two-lane two-way rural roads, model-3 fits the data better and concluded as the best model among others. In case of four-lane divided highways, model-3 outperforms all other models Goodness-of-fit measures like Log-likelihood (LL) and Akaike information criterion were used to evaluate the suitability of models. Three additional parameters like Mean absolute deviation (MAD), mean square prediction error (MSPE) and mean prediction bias (MPB) were used for the model validation. Another study performed by(Srinivasan et al. 2011) developed calibration factors, segment-and intersection-level SPFs from the HSM for Florida conditions. 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, (Gates et al. 2018) developed SPF's for rural road segments and intersections in the state of Michigan. They have calibrated (HSM) base 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 a three-leg stop-controlled intersection 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 measures.

S.NO	Facility Type	State	Calibration factor
1	Rural Multilane Divided segments	Oregon	0.78
	Rural Multilane 3-legged Stop-control intersections		0.16
	Rural Multilane 4-legged Stop-control intersections		0.40
2	Rural Multilane Divided segments	Florida	0.67
3	Rural 4-lane divided segments	South Carolina	0.61
	Rural Multilane 3-legged Stop-control intersections		0.55
	Rural Multilane 4-legged Stop-control intersections		0.26
4	Rural 4-lane divided segments	Kansas	1.436
	Rural Multilane 4-legged Stop-control intersections		0.91
	Rural Multilane 3-legged Stop-control intersections		2.87
5	Rural two-lane two-way segments	Alabama	1.522
	Four-lane divided segments		1.863
6	Rural 4-lane divided segments	Maryland	0.583
	Rural Multilane 3-legged Stop-control intersections		0.178
	Rural Multilane 4-legged Stop-control intersections		0.366

Table 2- 4: Case studies of development of calibration factor in various states.

Table 2-4 shows a summary of the development of state-specific calibration factor by facility type. States like Oregon, South Carolina, Kansas, and Maryland had developed calibration factors for rural multilane segments and intersections. Alabama had developed calibration factor for rural two-lane two-way and multilane divided segments.

CHAPTER 3: METHODOLOGY

3.1 INTRODUCTION

This chapter is intended to describe the statistical models or tools that lead to results, conclusions, and recommendations. This chapter describes the statistical method used to predict crashes on rural divided highways, development of calibration factor, calibration of intersection specific safety performance functions (SPFs), and selection of appropriate crash modification factors for the deployed countermeasures.

3.2 HSM 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 safety performance functions (SPFs) (Gates et al. 2018). The Highway Safety Manual (HSM) is one such effective resource that provides statistical tools that can be implemented in various forms of systems like planning, design, construction, operations, and maintenance. It is developed by the American Association of State and Highway Transportation Officials (AASHTO) in 2010 (Kolody et al. 2014). This manual bridges the gap between traffic safety researchers and safety improvement applications in highways (Park 2015). A user-friendly document called HSM user-guide helps safety analysts as a reference document. This user guide provides an outline of the application of HSM and also provides insights to practitioners (Kolody et al. 2014)

The crash frequency at an individual facility or an intersection can be predicted using the predictive method outlined in Part C of HSM. SPFs are regression models that follow a negative binomial structure. Negative binomial regression is an extension of the Poisson regression model and accounts for the overdispersion of data. Overdispersion of crash frequency data occurs when the variance exceeds the mean. Over-dispersed data can result in biased parameter estimates which could affect the crash frequency (Lord and Mannering 2010). HSM Part C provides a detailed description of the applicability of the predictive method to different facility types (Kolody et al. 2014) Table 3-1 specifies the predictive method for segments and intersections.

HSM Chapter	Undivided Roadway Segments	Divided Roadway Segments	Intersections			
			Stop Control on Minor Leg(s)		Signalized	
			Three-Leg	Four-Leg	Three-Leg	Four-Leg
10 – Predictive Method for Rural, Two-Lane, Two-Way Roads	✓		✓	✓		✓
11 – Predictive Method for Rural Multilane Highways	✓	✓	✓	✓		✓
12 – Predictive Method for Urban and Suburban Arterials	✓	✓	✓	✓	✓	✓

Table 3- 1: Applicability of predictive method for different facility types (Kolody et al. 2014)

As this research is specific to unsignalized intersections on rural divided highways, HSM chapter 11 of the predictive method for rural multilane highways is adopted. This methodology is applicable to all rural multi-lane highways with partial access control and outside urban areas with a population of less than 5000 persons. Predictive method can be applied in different scenarios to estimate crashes for proposed new countermeasures, existing and alternative conditions (Kolody et al. 2014). Figure 3-1 shows the applicability of the predictive method under different scenarios.

In this study, the scenario of estimated effectiveness of countermeasures after a period of implementation was used to predict the crashes at the treated sites and are discussed further in the results chapter.

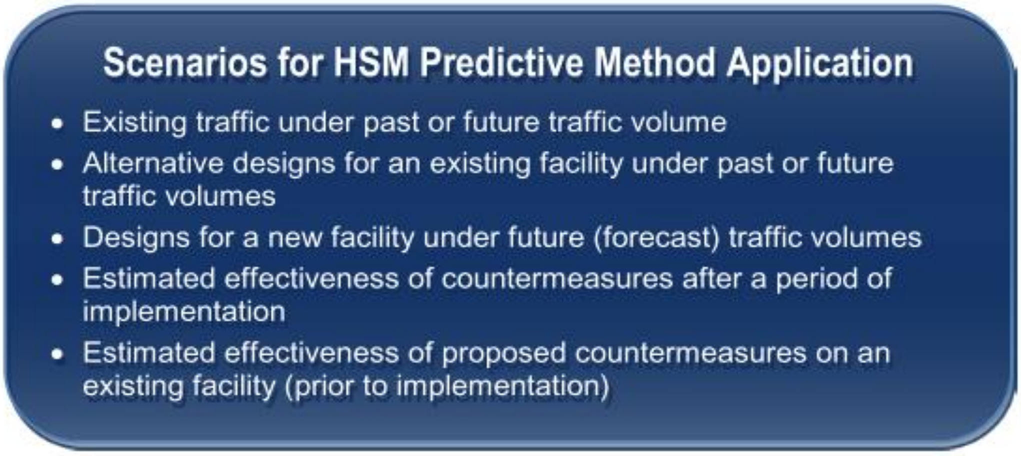

Figure 3- 1: Applicability of predictive method for different scenario (Kolody et al. 2014)

In general, the HSM predictive method involves three components (1) Base SPF (2) CMFs (3) Calibration Factor, C. The predicted average crash frequency at an intersection is determined by equation 3-1 (Sun et al. 2018)

$N_{Predicted\ intersection\ (adjusted)}$ = $N_{spf\ intersection\ x}$ C x $(CMF_1 x\ CMF_2 x \ldots \ldots \ldots . CMF_n)$ (3-1)

$N_{Predicted(adjusted)}$ = Adjusted total predicted crash frequency for an individual intersection for the selected year

$N_{spf\ intersection} =$ Predicted crash frequency for an intersection with base conditions

$N_{spf\ intersection}$ involves safety performance functions developed for three-legged and 4-legged stop-controlled intersections.

The base conditions for three and four-leg stop-controlled (3ST and 4ST) intersections are as follows:

- Intersection skew angle – 0 degrees
- Intersection left-turn lanes – 0, except on stop-controlled intersections
- Intersection right-turn lanes – 0, except on stop-controlled intersections
- Intersection lighting – Not present

$CMF_1 x\ CMF_2 x \ldots \ldots \ldots . CMF_n$ = Crash modification factors for intersections

Sometimes the geometric and traffic control features at an intersection vary from the above base conditions. In such cases, CMFs for intersection skew angle, intersection left-turn & right-turn lanes and intersection lighting are applied to account for the site conditions. As calibrating SPFs for unsignalized intersections on RDHs, is one of the objectives of this study, CMFs for the above mentioned geometric and traffic control features were used.

C = Calibration Factor for intersections of a specific type

The calibration factor is generally developed for use for a particular jurisdiction of geographical area. In this study, the calibration factor is developed for 3ST and 4ST intersections. Detail about the development of the calibration factor is presented in Section 3.3.

3.3 ESTIMATION OF LOCAL CALIBRATION FACTOR

Crash prediction models in HSM were developed using data from several state Departments of Transportation (DOT's) such as Oregon, Illinois, Virginia, Washington, Louisiana, and Missouri (Lyon et al 2016). HSM SPFs for Rural multilane highways were developed using crash data from a few selected states for a different time period (Lord et al, 2016). However, the crash frequencies vary from one jurisdiction to another, due to various factors like climate, driver population, crash reporting thresholds, and weather (Kolody et al. 2014). Hence it is necessary to calibrate SPFs when applied to a new jurisdiction to account for these regional and crash characteristics. Most studies in the literature estimated state-specific calibration factors for different facility types. A study done by Mehta and Lou estimated the calibration factor of value 1.863 for rural multilane segments in Alabama (Mehta and Lou 2013). No previous studies in the literature estimated the calibration factor for unsignalized intersections on rural divided highways in Alabama. Hence this study aims to develop local calibration factor for unsignalized intersections on rural divided highways.

A 5-step calibration procedure is outlined in Appendix A.1.1 of the HSM. This process involves the calculation of base SPF for the given facility type. Estimation of predicted crashes for the site conditions which involves crash modification factors (CMFs). The local calibration factor C is obtained by dividing the total number of observed crashes by the total predicted crashes. According to HSM, the sample sites necessary to develop a calibration factor for the predicted crash frequency is 30 to 50 sites. Data requirements for the intersections are shown in Table 3-2.

Intersections	**Units/Description**
Intersection Type	Unsignalized 3-leg (3ST) and unsignalized 4-leg (4ST)
Traffic flow major road	$AADT_{major}$
Traffic flow minor road	$AADT_{minor}$
Intersection skew angle	degrees
Number of uncontrolled approaches with a left-turn lane	From 0 to 4
Number of uncontrolled approaches with a right-turn lane	From 0 to 4
Intersection lighting	Present or not present
Calibration factor (C)	Derived from the calibration process
Observed crash data	Applicable only with the EB method. Crashes that occur at the intersection or on an intersection leg, and are related to the presence of an intersection during the period of study

Table 3- 2: Data requirements for unsignalized intersections for the predictive method (Kolody et al. 2014)

The unadjusted predicted crash frequency for each intersection is computed and then the sum for all intersections is used for the calculation of local calibration factor. The unadjusted predicted crash frequency for each intersection can be obtained using equation 3-2 (Sun et al. 2018)

$$N_{Predicted(unadjusted)} = N_{spf} x(CMF_1 x\ CMF_2 x \ldots \ldots \ldots . CMF_n) \text{ x C} \quad (3\text{-}2)$$

In the above equation, a nominal calibration factor of 1 was taken to calculate the unadjusted predicted crash frequency at an intersection. The sum of total unadjusted predicted crash frequencies for the considered sample intersections was generally represented as Σall sites unadjusted predicted crashes. Similarly, the observed crash frequency for a period of 5 years for the considered sample sites was also obtained from the CARE database. The sum of total observed crash frequencies for the considered sample sites was generally represented as Σall sites observed crashes.

In the estimation of local calibration factor for an intersection, the sum of total unadjusted predicted crash frequencies (Σall sites unadjusted predicted crashes) and the sum of the total observed crash frequencies (Σall sites observed crashes) were used.

The estimation of local calibration factor for an intersection can be obtained by the equation 3-3 (Shin et al 2014)

$$\text{Local Calibration Factor (LCF)} = \frac{\Sigma_{all}\, sites\ Observed\ crashes}{\Sigma_{all}\, sites\ unadjusted\ predicted\ crashes} \quad (3\text{-}3)$$

Figure 3-2 shows a flowchart with a sequence of steps involved in the estimation of local calibration factor for intersections of a specific type developed for use for a particular jurisdiction of geographical area.

As this study is specific to unsignalized intersections on RDHs, HSM predictive method for rural multilane highways was identified in predicting the crash frequencies at the intersections.

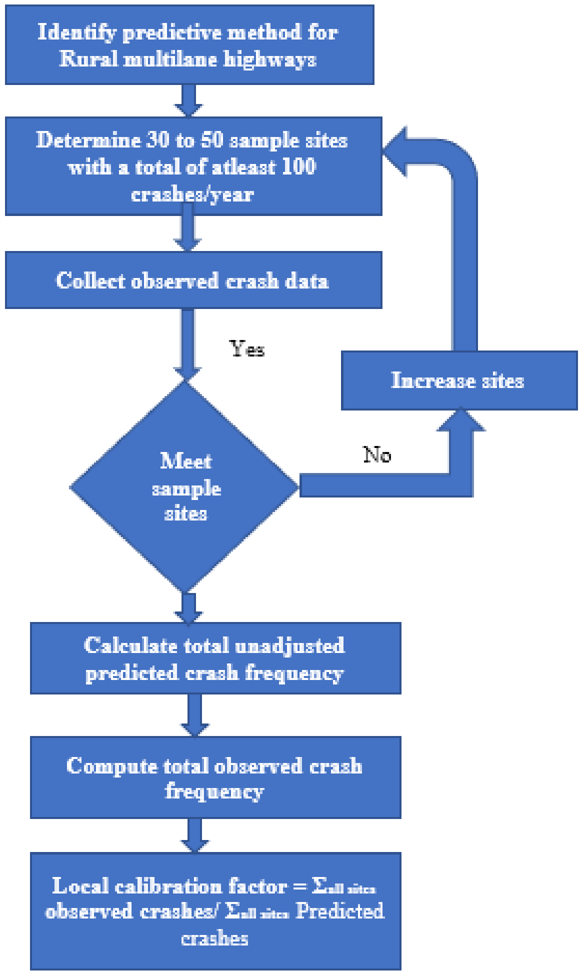

Figure 3- 2: Flowchart for the estimation of Local calibration factor used in this study

3.4 CALIBRATION OF STATE SPECIFIC SPFs

The Local calibration factor for Alabama calculated from the above procedure is used to calibrate the SPFs for unsignalized intersections with median width greater than 30 ft on rural divided highways in Alabama.

The SPFs for base conditions for rural multilane intersections is given by equation 3-4 (Kolody et al. 2013)

$$N_{spf\ intersection} = \exp\left[a + b \times Ln(AADT_{maj}) + c \times Ln(AADT_{min})\right] \qquad (3\text{-}4)$$

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

$AADT_{maj}$ = Major road traffic volume for the specified period

$AADT_{min}$ = Minor road traffic volume for the specified period

a, b, c are the regression coefficients for a specific facility type obtained from table 11-7 of the HSM (HSM 2010)

Intersection Type/Severity Level	a	b	c	Overdispersion Parameter (Fixed k)
Four-leg intersection (4ST) Total	-10.008	0.848	0.448	0.494
Four-leg intersection (4ST) Fatal and Injury	-11.554	0.888	0.525	0.742
Three-leg Intersection (3ST) Total	-12.526	1.204	0.236	0.460
Three-leg Intersection (3ST) Fatal and Injury	-12.664	1.107	0.272	0.569

Table 3- 3: SPF coefficients for 3ST and 4ST intersections with minor-road stop control for total and fatal-and-injury crashes (HSM 2010)

As the development of the calibration factor involves predicting the crash frequencies of 30 to 50 sample sites or more, it is apparent due to more number of intersections, calculation of predicted crash frequency manually at each of these intersections is time-consuming and potential for errors.

A more robust and sophisticated data tool accounts for the errors as well as time-consuming. Many states had developed state-specific HSM predictive method spreadsheets for different facility types. Hence the research team coordinated with Federal Highway Administration to obtain Alabama specific HSM predictive method spreadsheets. During 2009 and 2010 Karen Dixon developed three spreadsheets to support the training efforts on the first edition of HSM. Later in 2011, Alabama extended spreadsheets were developed which were jointly funded by Alabama, Virginia, and Washington state DOT’s (Schalkwyk 2016). In the extended spreadsheet, functionality has been added using macros within Microsoft Excel 2007. This functionality added macros to spreadsheets support multiyear analysis and as well create automated reports which include results and graphical content.

Figures 3-3, 3-4, and 3-5 show the general, project information and crash modification factors information that had been entered in the spreadsheet to calculate the predicted crash frequency at an intersection.

Alabama extended spreadsheet consists of a series of steps to predict the crashes at an intersection. These steps are as follows

1. General information like project name, total number of intersections considered, crash history, etc are entered
2. Push the "update element table" button to set up the element Table. It should be noted that elements cannot be added to the analysis once this button is pushed. Figure 3-3 shows a total number of 69 4ST intersections considered for the analysis. Therefore, a total of 69 spreadsheets will be populated.
3. Location information like route, location description, and traffic control features like signalized or unsignalized were entered.
4. Once all of the information has been entered, push the "proceed to 1st element" button.
5. For each of the intersections, roadway geometry data like skew angle, number of non-stop-controlled approaches with left-turn & right-turn lanes, and intersection lighting were entered. Traffic volume data like major road and minor road volumes pertaining to the site conditions were also entered.
6. Results for CMFs and predicted crash frequency for a specific intersection is automatically generated and are shown in the worksheets 2B and 2C as shown in figure 3-5.

1	PROJECT SAFETY PERFORMANCE ANALYSIS INPUT SHEET			
2	General Information			
3	Project Name	Project Name	Contact Email	rzr0055@auburn.edu
4	Project Description	Project Description	Contact Phone	224-509-5648
5	Reference Number	Route and Project Name	Date Performed	12-28-19
6	Analyst	First and Last Name	Analysis Year	2019
7	Agency/Company	Auburn university	Multiple Year Analysis?	No
11	# of Segments in Analysis	0	Predicted/expected crashes?	Predicted
12	# of Intersections in Analysis	69	Crash history (years)	5
13	Element Table Updated			

14–16	INDIVIDUAL PROJECT ELEMENTS	LOCATION INFORMATION		JURISDICTION	INTERSECTIONS ONLY	SEGMENTS ONLY
		Route	Location Description		Signalized or Unsignalized?	Divided or Undivided?
19	INTERSECTIONS					
20	Intersection 1	AL 157	AL 157 at Al 101		Unsignalized	-
21	Intersection 2	US 80	US 80 at Al 17		Unsignalized	-
22	Intersection 3	US 43	US 43 at Al 178		Unsignalized	-

Figure 3- 3: Macro-Enabled spreadsheet general information used in this study (Schalkwyk 2016)

2	Worksheet 2A -- General Information and Input Data for Rural Multilane Highway Intersections			
3	General Information		Location Information	
4	Analyst	First and Last Name	Roadway	AL 157
5	Agency or Company	Auburn university	Intersection	AL 157 at Al 101
6	Date Performed	12-28-19	Jurisdiction	0
7	Intersection	Intersection 1	Intersection 1	2019
8	Signalized/Unsignalized	Unsignalized		

9	Input Data		Site Conditions	Base Conditions
10	Intersection type (3ST, 4ST, 4SG)		4ST	--
11	$AADT_{major}$ (veh/day)	$AADT_{MAX}$ = 78,300 (veh/day)	7,422	--
12	$AADT_{minor}$ (veh/day)	$AADT_{MAX}$ = 7,400 (veh/day)	2,184	--
13	Intersection skew angle (degrees)		15	0
14	Number of non-STOP-controlled approaches with left-turn lanes (0, 1, 2)		2	0
15	Number of non-STOP-controlled approaches with right-turn lanes (0, 1, 2, 3, or 4)		2	0
16	Intersection lighting (present/not present)		Not Present	Not Present
17	Calibration Factor, C_i		1.00	1.00

18	Average Annual Crash History (3 or 5-yr average)			
19	Intersection crashes	KABC	Fatal and Injury Only	0.0
20		PDO	Property Damage Only	0.0
21	NOTES: * AADT: It is important to remember that the AADT(major) = AADT(major approach1) + AADT(minor approach2) (refer to p.11-6 in Part C of the HSM)			

Next Element

Figure 3- 4: Macro-Enabled spreadsheet project information used in this study (Schalkwyk 2016)

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

(1)	(2)	(3)	(4)	(5)	(6)
Crash Severity Level	CMF for Intersection Skew Angle (CMF_{1i}) from Equations 11-18 or 11-20 and 11-19 or 11-21	CMF for Left-Turn Lanes (CMF_{2i}) from Table 11-22	CMF for Right-Turn Lanes (CMF_{3i}) from Table 11-23	CMF for Lighting (CMF_{4i}) from Equation 11-22	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** from (6) of Worksheet 2B	**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			(3)*(5)*(6)
Total	-10.008	0.848	0.448	2.703	0.494	0.52	1.00	1.411
Fatal and Injury (FI)	-11.554	0.888	0.525	1.487	0.742	0.37	1.00	0.553
Fatal and Injury[a] (FI^a)	-10.734	0.828	0.412	0.830	0.655	0.37	1.00	0.308
Property Damage Only (PDO)	--	--	--	--	--	--	--	$(7)_{TOTAL} - (7)_{FI}$ 0.859

Figure 3- 5: Macro-Enabled spreadsheet CMFs for Rural Multilane Highway intersections (Schalkwyk 2016)

3.5 SELECTION OF APPROPRIATE CMFs FOR THE TREATED SITES

CMFs represent the relative change in crash frequency for a specific countermeasure implemented at a site when all other conditions remain constant (Fletcher et al 2014). These can be used to compare safety effectiveness among various treatments and locations, Identify cost-effective strategies, check the cost-benefit analysis for a specific countermeasure, etc. (Carter et al. 2012). The main objective in the selection of appropriate CMFs for a specific countermeasure at a treated site rather than developing CMFs is due to poorness of data availability. There are four treated sites of which each of these countermeasures is not the same. Also, the countermeasures for these sites were recently implemented and lack of a minimum of 3-year after-period crash data. Insufficient crash data can result in biased results and does not serve as a factor to develop CMFs. Hence appropriate CMFs were selected from the resources like FHWA CMF clearinghouse and HSM part D CMFs. FHWA clearinghouse is a web data-based platform where 3,500 CMFs of varying quality with supporting documentation can be found. These CMFs are a collection of various sources like HSM, FHWA's desktop reference for crash reduction factors, studies from the Transportation Research Board, and other research efforts (Fletcher et al 2014). Based on the review process of CMF clearinghouse, crash modification factors were selected based on factors study design, sample size, Standard error, potential biases, and data source. The selection of an appropriate CMF for a specific countermeasure requires sound engineering judgment so that the predicted crashes are neither overestimated or underestimated (Kolody et al. 2014). The following steps were suggested in the selection of an appropriate CMF for a specific treatment (Fletcher, Bradley, and Santos 2014).

1. Determine available CMFs from sources like FHWA CMF clearinghouse, HSM part D and FHWA's desktop reference for crash reduction factors
2. Choose CMFs that best fit the analysis when performed.
3. Review various CMFs and choose with the best quality rating.

In this study, CMFs for RCUT, Left-in-Right-in-Right-out (LIRIRO), double yellow center line & yield bar markings, and Flashing beacons & stop ahead signs implemented at four treated sites were reviewed and selected from other states.

More detail about the selection of CMFs for the treated sites will be discussed in Section 4.5.

CHAPTER 4: DATA

4.1 INTRODUCTION

This chapter provides detailed information on data collection and overview of reference and treatment sites that are used in the analysis. The first section provides an overview of the sites that are initially considered in Alabama. The remaining sections also provide a detailed description of how different types of data pertaining to traffic volume, crashes, and roadway geometry are collected. A list of treatment and reference sites are provided which led to the development of state-specific calibration factor and CMFs explained further in the methodology. This chapter also explains how the data had been screened and processed.

4.2 OVERVIEW OF SITES AND DATA COLLECTION PLAN

Development of calibration factors for 3ST and 4ST intersections with wide medians (30ft or greater) based on current SPFs and CMFs from the HSM and support the safety analysis was the primary objective of this thesis. As such a review of field data plays a vital role in developing state-specific SPFs. Hence the research team coordinated with the (ALDOT) to identify potential locations with strong safety performance, better-than-typical safety performance, and poor safety performance. A total of 23 intersections were initially identified by ALDOT out of which 10 intersections have poor safety performance, 3 intersections corresponding to good safety performance and the remaining 10 intersections are recently modified. These intersections were categorized based on the number of crashes associated with the minor road turning and crossing movements. Intersections with good safety performance have none or few crashes associated with minor roads and intersections with poor safety performance have more crashes associated with the minor road turning and crossing movements. Recently modified intersections have their median openings modified physically, geometrically, or changes to signs/markings to restrict certain movements or provide guidance regarding the right-of-way assignment. Though many locations were collected from ALDOT, few of them were considered in the analysis. This is because of the data constraints associated with the crash data as well as the exact date of modifications of the intersections that were not available from ALDOT. Hence for the purpose of analysis, four recently modified intersections were named as treatment sites, and reference sites from different routes were collected.

S. No	Recently modified intersections	County	Route
1	US 82 at AL 219/ Birmingham Road	Bibb	AL0006
2	US 82 at County Road 140	Tuscaloosa	AL0006
3	US 11 at US 80	Sumter	AL0008
4	US 431 at AL 169	Russell	AL0001

Table 4- 1: Intersections with modifications obtained from ALDOT

4.3 CRASH DATA

Crash data from 2012 to 2016 on Alabama Rural divided highways were collected from Critical Analysis Reporting Environment (CARE) software. CARE is a database software package that contains information entered on traffic crash reports completed by corresponding law enforcement officers. Different crash data sets like public and private databases of Alabama were available at the Center for Advanced public safety at the University of Alabama. Public data sets can be accessed by anyone, but some of the variables like street names, GPS coordinates and personally identifiable information are restricted. Therefore, a private crash database was utilized to collect the crash records for the purpose of research.

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 4-1.

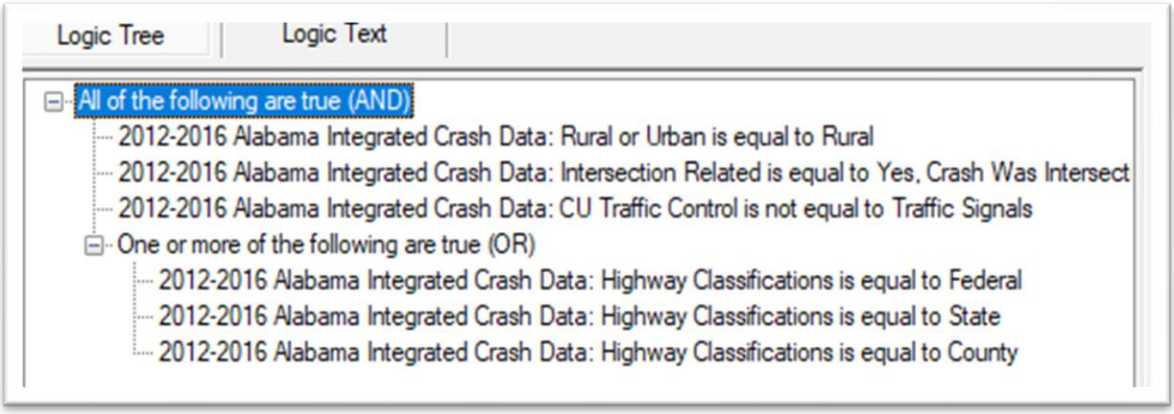

Figure 4- 1: Logic tree for the specific interest of crash records

A total of 18822 intersection-related crash records were initially identified. Intersections with depressed median widths 30 ft. or wider are the specific area of interest, hence data is further screened to meet this criterion. Two-way left-turn lane (TWLTLs) medians which were encountered during the screening process were also removed. This data processing yielded a total of 346 intersections with 982 crash records of the specific area of interest. 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.

4.4 REFERENCE SITES DATA

For the purpose of calibration homogeneous intersections whose geometric characteristics, ranges of traffic volume remain the same over the study period were initially identified. The Highway Safety Manual 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 was selected from routes like US-82, US-80, US-11, US-43, US-72, US-431, SR-157, SR-69, and SR-24 as a representative state-wide sample. These routes were selected from 32 counties. Most of these routes have four-lane divided highways with wider medians greater than 30 feet which were the focus of this study. The research team used these intersections as potential reference sites.

Figure 4-1 shows the locations of the reference sites/intersections as a representative state-wide sample considered in this study.

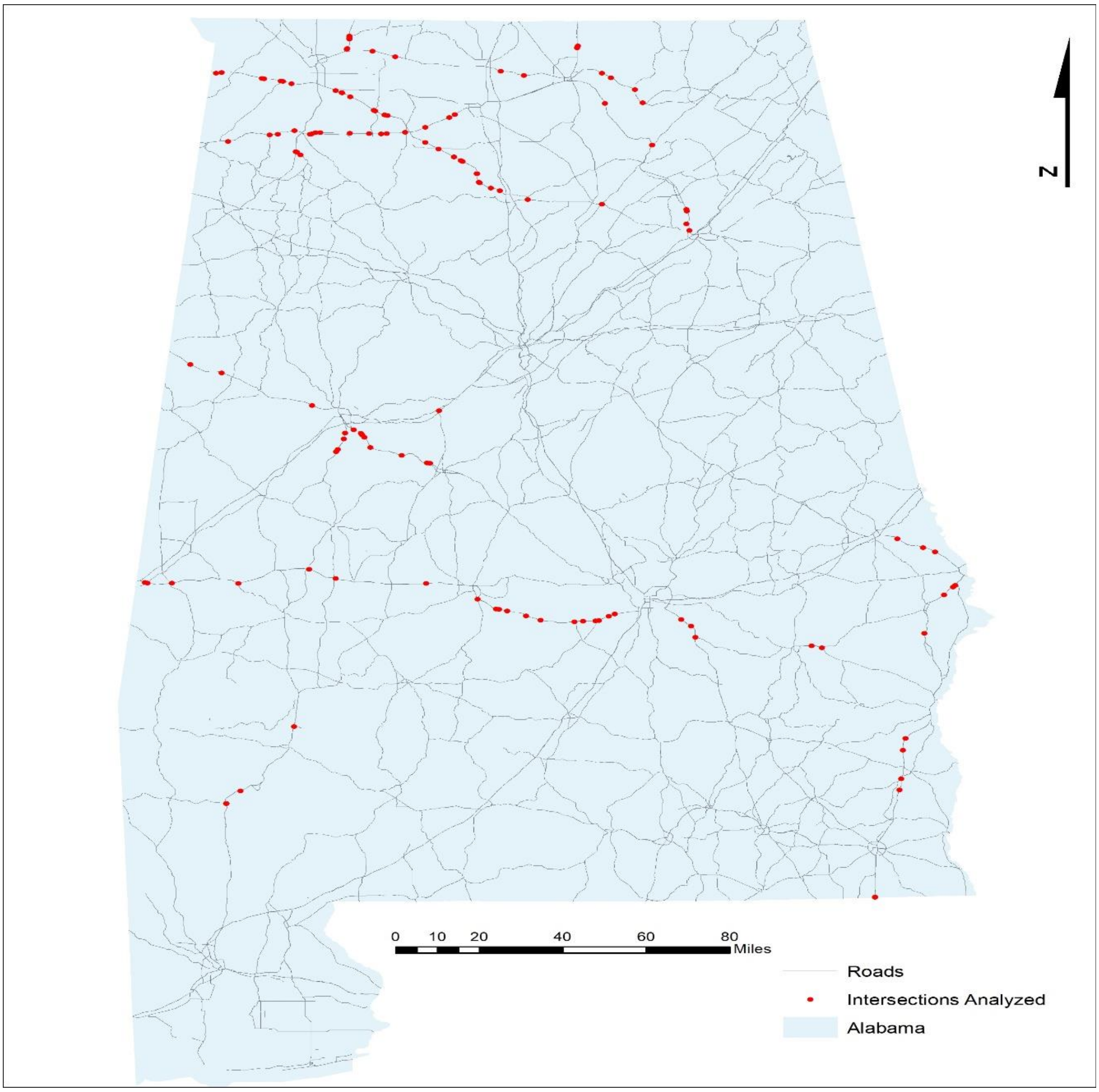

Figure 4- 2: A map showing potential reference sites considered in this study

The sample locations include a total of 128 three-legged and four-legged stop-controlled rural multilane intersections. There are a total of 59 three-legged (3ST) and 69 four-legged stop-controlled (4ST) intersections. Geometric characteristics like median width and skew angle were also collected for these 128 intersections. But the sample sites 59 for 3ST and 69 for 4ST intersections did not yield a total of at least 100 crashes per year due to few recorded crashes associated with each intersection. The observed crash frequency for all the reference sites for a period of 5 years (2012- 2016) was also collected from the CARE database.

Table 4-2 shows the frequency and percentage of reference sites based on their geometric characteristics' median width and skew angle.

Intersection Type	Geometric Characteristics	Frequency	Percentage
3ST	**Median Width (ft)**		
	30-50	32	48%
	51-70	29	44%
	71-130	5	8%
	Skew Angle (degrees)		
	0-15	42	64%
	16-31	13	20%
	32-47	8	12%
	48-63	3	5%
4ST	**Median Width (ft)**		
	30-50	41	55%
	51-70	31	42%
	71-100	3	4%
	Skew Angle (degrees)		
	0-15	44	59%
	16-31	20	27%
	32-47	10	14%

Table 4- 2: Classification of intersection type based on median width and skew angle

In case of 3ST intersections, 48% has a median width between 30-40 ft whereas 8% has a median width of 71-130 ft. For 4ST intersections, 55% has a median width of 30-50 ft whereas 4% has a median width of 71-100 ft. The skew angle of an intersection in between 0-15 degrees constitutes more than 50% in both three-legged and four-legged stop-controlled intersections.

Manner of Crash	Property Damage Only	Incapacitating Injury	Non-Incapacitating Injury	Possible Injury	Fatal Injury	Total Percentage
Single Vehicle Crash (all types)	20	5	7	5	0	7%
Side Impact (90 degrees)	91	60	59	19	9	47%
Side Impact (angled)	50	21	15	10	2	19%
Angle Oncoming (frontal)	3	4	3	1	0	2%

Angle (front to side) Opposite Direction	23	6	10	1	0	8%
Other	2	2	1	0	0	1%
Sideswipe - Same Direction	14	0	4	0	0	4%
Rear End (front to rear)	30	8	5	5	0	9%
Head-On (front to front only)	0	0	2	0	0	0%
Angle (front to side) Same Direction	9	0	0	1	0	2%
Sideswipe - Opposite Direction	1	0	0	0	0	0%
Causal Veh Backing: Rear to Side	1	0	0	0	0	0%
Non-Collision	1	0	0	0	0	0%

Table 4- 3: Crash severity distribution by manner of collision

Manner of Crash	2012	2013	2014	2015	2016
Single Vehicle Crash (all types)	10	4	6	6	11
Side Impact (90 degrees)	45	43	41	52	57
Side Impact (angled)	22	15	18	19	24
Angle Oncoming (frontal)	2	2	3	2	2
Angle (front to side) Opposite Direction	4	9	7	10	10
Other	1	1	0	3	0
Sideswipe - Same Direction	1	4	2	4	7
Rear End (front to rear)	9	12	10	8	9
Head-On (front to front only)	1	0	0	1	0
Angle (front to side) Same Direction	1	2	2	3	2
Sideswipe - Opposite Direction	0	1	0	0	0
Causal Veh Backing: Rear to Side	0	0	1	0	0
Non-Collision	0	1	0	0	0

Table 4- 4: Crash frequency distribution of manner of crash by year

Severity	2012	2013	2014	2015	2016	percentage
Property Damage Only	39	48	47	50	61	48%
Incapacitating Injury	17	19	17	25	28	21%
Non-Incapacitating Injury	25	17	18	22	24	21%
Possible Injury	9	9	5	10	9	8%
Fatal Injury	6	1	3	1	0	2%

Table 4- 5: Crash severity distribution by year

Tables 4-3, 4-4, and 4-5 shows the descriptive statistics of the crashes for the reference sites considered in this study.

From Table 4-3, it can be observed that fatal injury crashes are predominant and most of them are side-impact 90 degrees and side-impact angled. From Table 4-4, it can be observed that the crash frequency of side impact (90 degrees) and side-impact (angled) shows an increasing trend from 2012 to 2016. From Table 4-5, it can be observed that the crash severity also showed an increasing trend for all crashes except the fatal injury from 2012 to 2016.

4.5 TREATMENT SITES

Information on intersections that were modified physically, geometrically, or changes to signs/markings to restrict certain movements or provide guidance regarding the right-of-way assignment was obtained from ALDOT. Table 4-6 shows the list of intersections with modifications.

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

Table 4- 6: List of modified intersections obtained from ALDOT

US 82 at AL 219/Birmingham Road:

The intersection US 82 at AL 219/Birmingham Road was modified from a typical crossover into an RCUT. Restricted crossing U-turn (RCUT) design prohibits the left-turn and crossing maneuvers from the minor road on to 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 one-way median opening 400 to 1000 ft after the intersection(Hughes and Jagannathan 2009)

This design is also known as J-turn in Maryland, Superstreet intersection in North Carolina, and Right-Turn U-Turn (RTUT) intersection in Florida (Maze et al 2010)

This project started in late 2016 and ended in early 2017. This intersection was a traditional TWSC expressway intersection in Bibb County and converted into an RCUT intersection. Aerial photographs of Before and After conditions are shown in Figures 4-3, and 4-4. At this intersection, US 82 is a four-lane divided highway with two lanes in each direction and separated by a depressed median of width 46 ft and a posted speed limit of 65 mph. 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, these properties remained the same and the RCUT design replaced a typical crossover. As this project was recently ended in early 2017, limited after crash data (2-years) was obtained from the CARE database. Before crash data was also not available in the CARE database, Therefore statistical comparisons of the annual crash frequencies for the before-after analysis cannot be made due to insufficient Before and after crash data. Therefore, the predictive method for rural multilane highways from the highway safety manual was used to predict the crash frequency at this intersection which was explained in detail in the methodology chapter.

Figure 4- 3: US 82 at AL 219/Birmingham Road Before Condition (Google Earth)

Figure 4- 4: 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 in Alabama was a standard crossover. At this intersection, US 82 is a four-lane divided highway with two lanes in each direction and separated by a depressed median of width 70ft and a posted speed limit of 65 mph. AL 219 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 but 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. Aerial photographs of Before and After modifications were shown in Figures 4-5 and 4-6 respectively.

This location does not have enough before and after crash data to compare annual crash frequencies for before and after data. Therefore, the HSM predictive method for rural divided highways was used to predict the crash frequency at this intersection. Crash modification factors (CMFs) for the site conditions were applied to estimate the predicted crash frequency. Then an appropriate CMF is selected from the FHWA CMF Clearinghouse, which provides a reasonable estimate of the countermeasure that has been deployed at the location. Selection of an appropriate CMF needs some engineering judgment so that the predicted crash frequency is neither underestimated nor overestimated (Fletcher et al 2014)

Figure 4- 5: US 82 at County Road 140 Before Condition (Google Earth)

Figure 4- 6: 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 a four-way stop-control located in Sumter County in Alabama. At this intersection, US 80 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. 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 four 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. Aerial photographs of Before and After modifications were shown in Figures 4-7 and 4-8 respectively.

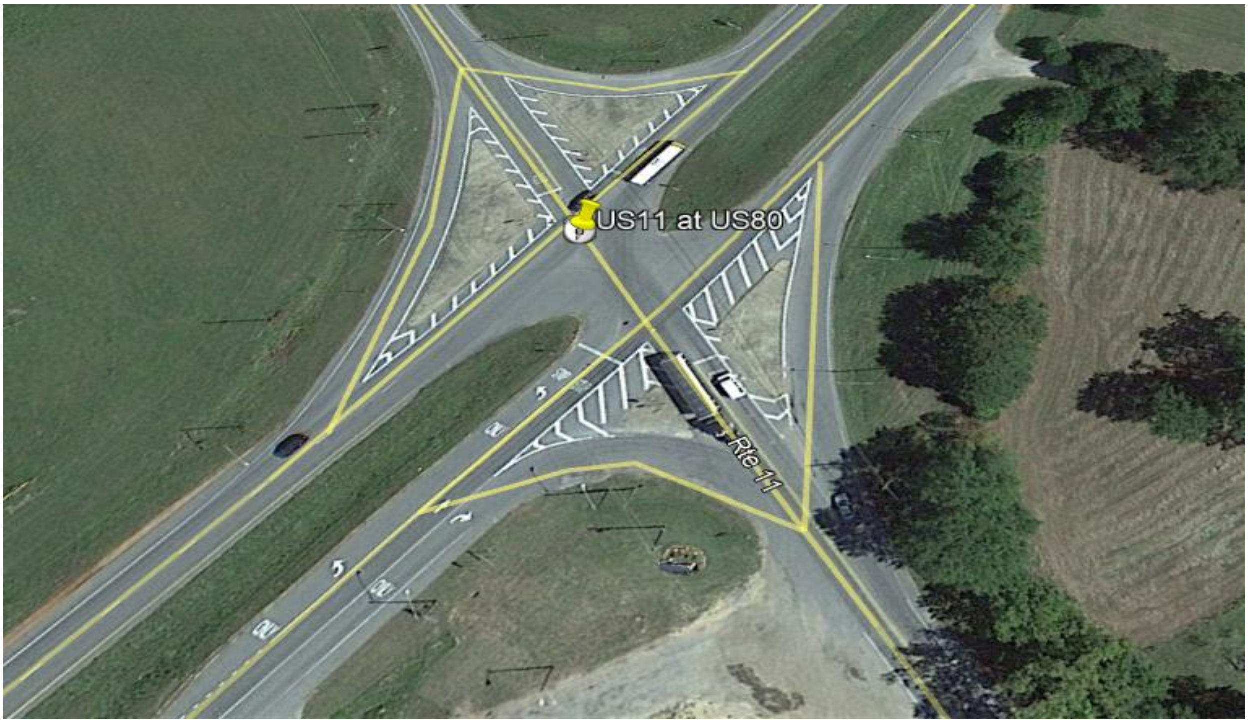

Figure 4- 7: US 11 at US 80 Before Condition (Google Earth)

Figure 4- 8: 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 Four-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. Aerial photographs of Before and After modifications were shown in Figures 4-9 and 4-10 respectively.

Figure 4- 9: US 431 at SR 169 Before Condition (Google Earth)

Figure 4- 10: US 431 at SR 169 After Condition (Google Earth)

4.6 TRAFFIC VOLUME DATA

Major and minor road traffic volumes were collected from the Alabama Traffic Data (ATD) website maintained by ALDOT. Data from 2012 to 2016 was collected for both major and minor roads. Most of the traffic data for the major road was readily available in the ATD. Some of the minor roads are county roads for which the traffic volume was not available. So, these minor roads were excluded from the sample sites. Out of 346 intersections with 982 crash records of the specific area of the interest, traffic volumes of the minor roads were not available for some intersections. Hence these intersections were excluded from the sample. This data screening included a total of 142 intersections with 573 crashes to meet the requirements of the HSM calibration procedure. Traffic volume data was further screened and excluded 14 intersections from the sample sites. At these 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 128 intersections with 59 3ST and 69 4ST with a total of 510 crashes.

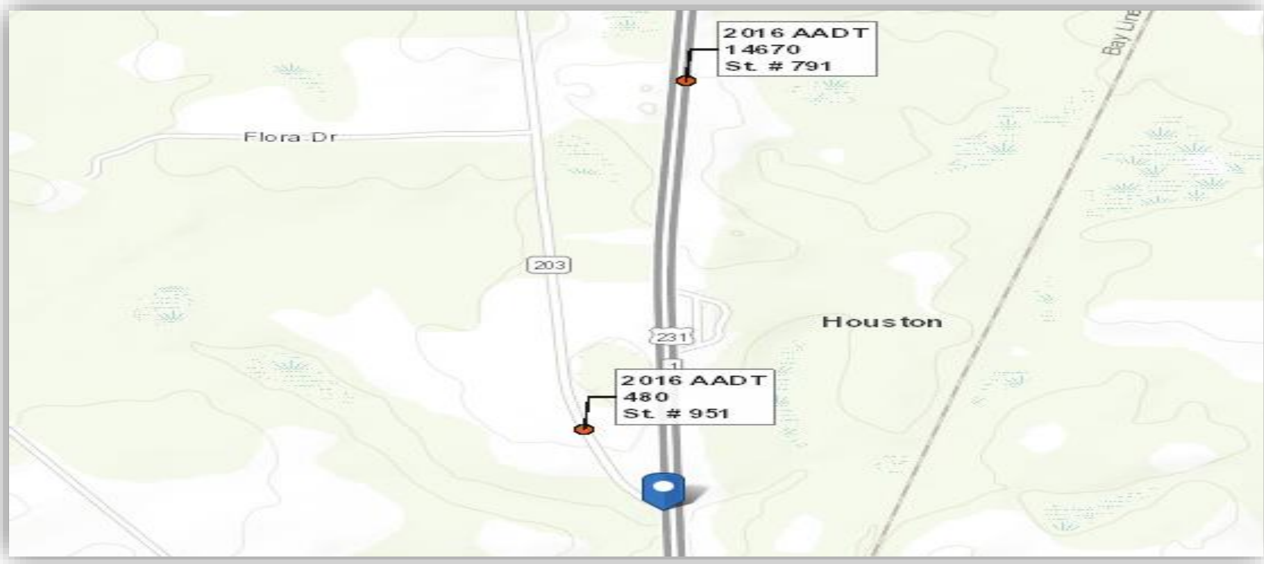

Figure 4- 11: Example of major and minor road AADT from Alabama Traffic Data

4.7 ROADWAY GEOMETRY DATA

Most of the roadway geometry data were collected from Google Earth and Google Maps. Variables like the presence of median, median width, speed limits of major and minor road, the total number of lanes on major and minor road, and facility type were collected. From the HSM, variables that were used for the predicted crash frequency of rural multilane intersections are intersection skew angle, intersection left-turn and right-turn lanes, and intersection lighting.

Intersection skew angle:

Ideally, intersecting roadways should be oriented as close to a 90-degree angle as possible. However, the orientation may diverge from the preferred configuration which results in a skewed intersection. There are many intersections in the sample sites that have a skewed configuration. The skewness of the intersection was measured in the Microstation v8i.

Figure 4- 12: Example of Intersection skew-angle estimation (Google Earth)

Intersection Left-turn and right-turn lanes

From HSM left-turn and right-turn lane, CMF’s are associated with the base conditions of the rural multilane intersections with minor road stop control. Hence it is necessary to collect the number of left-turn and right-turn lanes present on the number of uncontrolled major-road approaches. Street-view of the google earth pro was used manually to collect these figures.

Figure 4- 13: Example of intersection with left-turn and right-turn lanes (Google Earth)

Intersection Lighting

Intersection lighting is another variable which is considered in the SPF base condition. Hence every intersection in the sample sites was observed to find the presence or absence of intersection lighting.

Figure 4- 14: Intersection Lighting present at US-231 at Trotman road (Google Earth)

CHAPTER 5: RESULTS

5.1 INTRODUCTION

This chapter presents the key results from the analysis that was described in the methodology chapter. It also discusses how the available crash data was used for computing the predicted crash frequency. It further presents the results of the local calibration factor for the unsignalized intersections on rural divided highways following the HSM based Appendix A procedure. A discussion on the selection of appropriate CMFs for a specific countermeasure at the treated intersections was also presented.

5.2 PREDICTED CRASH FREQUENCIES FOR THE REFERENCE SITES

Crash frequency was predicted for the reference intersections. A total of 128 intersections with a total of 510 observed crashes were present at the reference sites. A nominal calibration factor value of 1 was used in the calculation of predicted crash frequencies. Tables 5-1 and 5-2 shows 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 A-1 and Table A-2 of Appendix A shows the predicted crash frequencies of 59 3ST and 69 4ST reference sites that were used in the computation of the calibration factor.

Crash Severity Level	$N_{spf\ int}$	Predicted Average Crash Frequency ($N_{predicted\ int}$)
Total	2.703	1.411
Fatal and Injury (FI)	1.487	0.553
Fatal and Injury (FI^a)[1]	0.830	0.308
Property Damage only (PDO)	1.216	0.878

Table 5- 1: Predicted average crash frequency by crash severity level at AL-157 at AL-101

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

$N_{spf\ int}$ = 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

From Table 5-1, it was observed that the predicted average crash frequency for total crashes is greater than other crash severity levels.

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	0.023	0.010	0.007	0.013
Sideswipe collision	0.151	0.023	0.012	0.134
Rear-end collision	0.322	0.118	0.033	0.206
Angle collision	0.558	0.295	0.176	0.251
Single-vehicle collision	0.285	0.082	0.061	0.209
Other collision	0.073	0.025	0.018	0.046

Table 5- 2: Predicted average crash frequency by collision type at AL-157 at AL-101

Table 5-2 shows the distribution of crash frequency severity and collision type. A detailed explanation of crash frequency distribution was mentioned in section 5.4

5.3 LOCAL CALIBRATION FACTOR RESULTS

This section illustrates the predicted average crash frequencies obtained from the extended HSM 1 predictive method spreadsheets. Table A-3 and A-4 of Appendix A shows the predicted and observed crash frequencies for the 59 3ST and 69 4ST reference intersections. Detailed calculation of the calibration factor was also presented in this Table.

The sum of predicted crashes for all 59 3ST intersections was estimated to be 345 but the total number of actual observed crashes was 212. A calibration factor of 0.61 was obtained by dividing the total number of observed crashes by the total number of predicted crashes.

Local Calibration Factor = $\Sigma_{\text{all sites}}$ observed crashes/ $\Sigma_{\text{all sites}}$ Predicted crashes

= 212/345.705

= 0.613

Similarly, the sum of predicted crash frequencies for all 69 4ST intersections was estimated to be 522 but the total number of actual observed crashes was 298. A calibration factor of 0.57 was obtained by dividing the total number of observed crashes by the total number of predicted crashes.

Local Calibration Factor = $\Sigma_{\text{all sites}}$ observed crashes/ $\Sigma_{\text{all sites}}$ Predicted crashes

= 298/522.46

= 0.570

A calibration factor of 0.61 and 0.57 was obtained for 3-leg stop-control (3ST) and 4-leg stop-control (4ST) intersections. This means for a 3ST and 4ST intersections on a rural multilane highway, predicted crash frequency using a corresponding SPF should be adjusted by multiplying with a calibration factor of value 0.61 and 0.57 respectively. It is also observed that a calibration factor of values 0.61 and 0.57 less than one indicates that the observed crashes for the 3ST and 4ST intersections on rural divided highways for Alabama are fewer than the base model crash frequencies.

5.4 CALIBRATION OF INTERSECTION SPFs FOR TREATED INTERSECTIONS

The developed calibration factors of 0.61 and 0.57 can be used to calibrate SPFs for 3ST and 4ST intersections with wider medians greater than 30 feet on RDHs in Alabama. The treated sites considered in this study were not included in the reference sites. Therefore, the developed calibration factors were used in predicting the crashes at these four treated intersections before the application of countermeasure. The predicted crash frequency at these intersections was calculated using a corresponding SPF with adjusted calibration factors of 0.61 and 0.57 for the

3ST and 4ST treated sites. Tables 5-3 to 5-10 presents the values of predicted crash frequencies for the treated intersections by severity and collision type.

Crash Severity Level	**$N_{spf\ int}$**	**Predicted average Crash Frequency ($N_{predicted\ int}$)**
Total	2.372	0.898
Fatal and Injury (FI)	1.350	0.455
Fatal and Injury (FI^a)	0.717	0.242
Property Damage only (PDO)	1.022	0.443[2]

Table 5- 3: Predicted crash frequency by severity level at US 82 at AL 219

Table 5-3 presents the predicted average crash frequencies of base and site conditions of the intersection US 82 at AL 219 after applying a calibration factor of value 0.57.

$N_{predicted}$ (PDO) = $N_{predicted\ int}$ (Total) - $N_{predicted\ int}$ (FI) = 0.898-0.455

= 0.443 crashes/year

A Calibration factor of value 0.57 yielded a greater reduction in the predicted average crash frequencies by severity level of intersection US 82 at AL 219 was observed when compared to the HSM default SPFs. This means that the SPF provided in the HSM overpredicts the crashes at this intersection. A similar trend was observed in the case of remaining treatment sites and applicable to Tables 5-5, and 5-7 respectively.

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	0.014	0.008	0.006	0.007
Sideswipe collision	0.096	0.019	0.010	0.069
Rear-end collision	0.205	0.097	0.026	0.106
Angle collision	0.355	0.243	0.138	0.129
Single-vehicle collision	0.181	0.067	0.048	0.108
Other collision	0.047	0.020	0.014	0.024

Table 5- 4: Predicted crash frequency by collision type at US 82 at AL 219

[2] $N_{predicted}$ (PDO) = $N_{predicted\ int}$ (Total) - $N_{predicted\ int}$ (FI).

Table 5-4 presents the values of the predicted crash frequencies by collision type of intersection US 82 at AL 219. It also shows the distribution of crash frequency by collision and crash severity scale presented in Table 5-3. An example of the predicted average crash frequency of total crashes by collision type of US 82 at AL 219 is shown below.

$N_{predicted}$ (Total) = $N_{predicted\ (Head\text{-}on\ collision)}$ + $N_{predicted\ (Sideswipe)}$ + $N_{predicted\ (Rear\text{-}end)}$ + $N_{predicted\ (Angle)}$ + $N_{predicted\ (Single\ vehicle)}$ + $N_{predicted\ (other\ collision)}$

0.898 = 0.014+0.096+0.205+0.355+0.181+0.047

A similar distribution was applicable to Tables 5-6, 5-8, and 5-9 respectively. From the analysis, a greater reduction in angle collisions for total, Fatal-injury, and PDO crashes was observed when compared to other collision types.

Crash Severity Level	**$N_{spf\ int}$**	**Predicted average Crash Frequency ($N_{predicted\ int}$)**
Total	2.602	0.729
Fatal and Injury (FI)	1.375	0.274
Fatal and Injury (FI[a])	0.814	0.162
Property Damage only (PDO)	1.227	0.455

Table 5- 5: Predicted crash frequency by severity level at US 431 at SR 169

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	0.012	0.005	0.004	0.007
Sideswipe collision	0.078	0.011	0.006	0.071
Rear-end collision	0.166	0.058	0.017	0.109
Angle collision	0.288	0.146	0.092	0.133
Single-vehicle collision	0.147	0.040	0.032	0.111
Other collision	0.038	0.012	0.010	0.025

Table 5- 6: Predicted crash frequency by collision type at US 431 at SR 169

Crash Severity Level	$N_{spf\ int}$	Predicted average Crash Frequency ($N_{predicted\ int}$)
Total	1.174	0.699
Fatal and Injury (FI)	0.939	0.336
Fatal and Injury (FI^a)	0.532	0.190
Property Damage only (PDO)	0.235	0.363

Table 5- 7: Predicted crash frequency by severity level at US 80 at US 11

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	0.011	0.006	0.004	0.005
Sideswipe collision	0.075	0.014	0.008	0.057
Rear-end collision	0.159	0.072	0.021	0.087
Angle collision	0.276	0.179	0.109	0.106
Single-vehicle collision	0.141	0.050	0.038	0.088
Other collision	0.036	0.015	0.011	0.020

Table 5- 8: Predicted crash frequency by collision type at US 80 at US 11

Crash Severity Level	$N_{spf\ int}$	Predicted average Crash Frequency ($N_{predicted\ int}$)
Total	2.350	0.961
Fatal and Injury (FI)	0.966	0.352
Fatal and Injury (FI^a)	0.573	0.209
Property Damage only (PDO)	1.384	0.609

Table 5- 9: Predicted crash frequency by severity level at US 82 at County Road 140

Table 5-9 presents the predicted average crash frequencies of base and site conditions of the intersection US 82 at County Road 140 after applying a calibration factor of value 0.61.

$N_{predicted}$ (PDO) = $N_{predicted\ int}$ (Total) - $N_{predicted\ int}$ (FI)

= 0.961-0.352

= 0.609 crashes/year

A Calibration factor of value 0.61 yielded a greater reduction in the predicted average crash frequencies by severity level of intersection US 82 at County Road 140 was observed when compared to the HSM default SPFs. This means that the SPF provided in the HSM overpredicts the crashes at this intersection.

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	0.028	0.015	0.011	0.012
Sideswipe collision	0.128	0.020	0.012	0.109
Rear-end collision	0.278	0.087	0.030	0.192
Angle collision	0.253	0.130	0.080	0.120
Single-vehicle collision	0.225	0.077	0.059	0.148
Other collision	0.050	0.023	0.018	0.027

Table 5- 10: Predicted crash frequency by collision type at US 82 at County Road 140

Table 5-10 presents the values of the predicted crash frequencies by collision type of intersection US 82 at County Road 140. It also shows the distribution of crash frequency by collision and crash severity scale presented in Table 5-9. An example of the predicted average crash frequency of total crashes by collision type of US 82 at County Road 140 is shown below.

$N_{predicted}$ (Total) = $N_{predicted\ (Head\text{-}on\ collision)}$ + = $N_{predicted\ (Sideswipe)}$ + $N_{predicted\ (Rear\text{-}end)}$ + $N_{predicted\ (Angle)}$ + $N_{predicted\ (Single\ vehicle)}$ + $N_{predicted\ (other\ collision)}$

0.961 = 0.028+0.128+0.278+0.253+0.225+0.050

5.5 SELECTION OF APPROPRIATE CMFs FOR TREATED SITES

From the data obtained from ALDOT, the research team collected data for four treated sites for which the countermeasures were deployed at these locations. As the countermeasures applied at each of the treated locations were different, it was difficult to develop CMFs for these specific treatments. This is because there were sample size issues pertaining to each of these treatment sites deployed. There was only one sample site specific to each of these countermeasures. Therefore, literature related to these treatments that were implemented on these types of rural settings at different states were reviewed to select an appropriate CMF.

The following are the countermeasures that are being deployed:

- RCUT at US 82 at AL 219/ Birmingham Road

The number of treated sites (RCUT) implemented in Alabama were only two. An estimate of the safety effectiveness of this countermeasure at the treated intersections is evaluated by selecting an appropriate CMF of the RCUTs deployed in different states.

From Table 2-1 it can be observed that RCUT implementation had yielded a reduction in total, fatal, injury, and angle crashes. Therefore, a CMF range of 0.56 to 0.85 for total crashes was assumed to predict the expected crash frequency after the countermeasure has applied at the treated intersection. This means the reduction in total crashes is estimated to be 15% and 44% respectively.

From table 5-3, the predicted average crash frequency at the intersection of US 82 at AL 219 for base conditions is 2.372.

N_{spf} = 2.372   Combined CMF for site conditions = 0.66

C = 0.57   CMF range for the RCUT countermeasure (0.56-0.85)

$N_{Predicted(adjusted)}$ = 2.732 x 0.57 x 0.66 x 0.85 to = 2.732 x 0.57 x 0.66 x 0.56

= 0.873 to 0.575 crashes/year

Table 5-11 shows the predicted average crash frequencies of the RCUT countermeasure with an assumed CMF range of 0.56 to 0.85 at the intersection of US 82 at AL 219. The predicted crash frequency for the total crashes with these assumed CMFs is estimated to be 0.873 and 0.575 crashes/year.

Predicted average crash frequency, Npredicted int Crashes/year		
Without countermeasure	With countermeasure (Minimum)	With countermeasure (Maximum)
0.898	0.873	0.575

Table 5- 11: Range of predicted average crash frequencies for US 82 at AL 219/ Birmingham Road with and without countermeasure

- Installation of double yellow center line and yield bar markings at the intersection of US 431 at SR 169

From Table 2-2, it can be observed that a specific combination of countermeasures such as double yellow center line and yield bar markings were not implemented. Basic signing and pavement markings were implemented in the study by Le et., al which yielded a crash reduction of 8.3 percent for total crashes. Therefore, a CMF of 0.917 was assumed in calculating the predicted crash frequency at US 431 at SR 169.

N_{spf} = 2.602   Combined CMF for site conditions = 0.49

C = 0.57   CMF for total crashes = 0.917

$N_{Predicted(adjusted)}$ = 2.602 x 0.57 x 0.49x 0.917

= 0.66 crashes/year

Table 5-12 shows the predicted average crash frequencies of the basic signing and pavement markings countermeasures with an assumed CMF of 0.917 at the intersection of US 431 at SR 169. The predicted crash frequency for the total crashes with the assumed CMF is estimated to be 0.66 crashes/year.

Predicted average crash frequency, Crashes/year	
Without countermeasure	With countermeasure
0.729	0.66

Table 5- 12: Predicted average crash frequencies for the intersection US 431 at SR 169 with and without countermeasure.

As mentioned in section 4.5, a total of 2 crashes was observed in the before data. This indicates that a calibration factor of 0.57 underpredicts the predicted before crash data by almost 45% when compared to observed before data.

- Flashing beacons and stop ahead signs at the intersection US 11 at US 80

Table 2-3, it can be observed that a specific combination of countermeasure such as flashing beacons and stop ahead signs was not implemented in the previous studies. Basic low-cost safety improvements at stop-controlled intersections like signing and pavement markings were implemented in South Carolina. Applying these basic countermeasures to the intersection is estimated to reduce future crashes by 30 percent(Bahar et al. 2008)

N_{spf} = 1.724   Combined CMF for site conditions = 0.71

C = 0.57   CMF for total crashes = 0.917

$N_{Predicted(adjusted)}$ = 1.724 x 0.57 x 0.71 x 0.917

= 0.64 crashes/year

Table 5-13 shows the predicted average crash frequencies of the basic low-cost safety countermeasure with an assumed CMF of 0.917 at the intersection of US 11 at US 80. The predicted crash frequency for the total crashes with the assumed CMF is estimated to be 0.66 crashes/year.

Predicted average crash frequency, Crashes/year	
Without countermeasure	With countermeasure
0.70	0.64

Table 5- 13: Predicted average crash frequencies for the intersection US 11 at US 80 with and without countermeasure

As mentioned in section 4.5, a total of 2 crashes was observed in the before data. This indicates that a calibration factor of 0.57 underpredicts the predicted before crash data by almost 35% when compared to observed before data.

- Two new pavements with changes in movements allowed were added at US 82 at county road 140. One pavement allows left turns in and another pavement allows for the right turns into the driveway were added at the intersection. This countermeasure can be typically called as Left-in Right-in Right-out operation (LIRIRO).

A traditional rural expressway intersection design with 42 conflict points(Maze, Hochstein, and Souleyrette 2010). The possible maneuvers at these intersections are left turns from the minor road on to the major road, through movements from the minor road crossing the major road, and left turns from the major road on to the minor road.

There are very limited studies pertaining to LIRIRO countermeasure. A study related to median treatment evaluated the safety and economic performance of longitudinal channelizers in Florida. An empirical bayes before-after crash data was used in evaluating the safety effectiveness of full median opening to a left-in only median opening in urban and suburban settings. A total of 4 sites were included as treated sites. This countermeasure yielded a crash reduction factor of 0.95 for total crashes (Zhou et al. 2013)

From table 5-11, the predicted average crash frequency of the intersection US 82 at County Road 140 for base conditions is 2.350

N_{spf} = 2.350   Combined CMF for site conditions = 0.67

C = 0.61   CMF for total crashes = 0.95

$N_{Predicted(adjusted)}$ = 2.350 x 0.61 x 0.67 x 0.95

= 0.912 crashes/year

Table 5-14 shows the predicted average crash frequencies of the longitudinal channelizers countermeasure with an assumed CMF of 0.95 at the intersection of US 82 at County Road 140. The predicted crash frequency for the total crashes with the assumed CMF is estimated to be 0.912 crashes/year.

Predicted average crash frequency, Crashes/year	
Without countermeasure	With countermeasure
0.961	0.912

Table 5- 14: Predicted average crash frequencies for the intersection US 82 at County Road 140 with and without countermeasure

CHAPTER 6: CONCLUSIONS AND RECOMMENDATIONS

6.1 INTRODUCTION

The goal of this research was to develop an Alabama-specific calibration factor at unsignalized intersections on rural divided highways. Calibration of intersection specific safety performance functions for treated sites and selection of appropriate crash modification factors are the secondary goals. These objectives were served by collecting data pertaining to crashes, roadway geometry, and volume, Predicting the crash frequencies for the reference sites and computation of calibration factor, calibration of intersection specific SPFs for the countermeasures deployed at those locations. Selected appropriate crash modification factors for the specific countermeasure from various states. Also, compared the predicted average crash frequencies for the treated locations with and without countermeasure.

6.2 CONCLUSIONS

The major findings of the analysis are stated below

- The calibration factor developed for Alabama at 3-legged stop-controlled and 4-legged stop-controlled intersections on rural divided highways had yielded a value of 0.61 and 0.57 respectively. This indicates that the SPF provided in the HSM overpredicts crashes at intersections on rural divided highways in Alabama. Therefore, multiplying the calibration factor increases the predictions to match the observed crash frequencies.
- From the calibration of intersection safety performance functions for the treated locations, a greater reduction in total crashes was observed when compared to fatal and injury crashes.
- A reduction of 7 % and 6.9 % for total crashes was estimated to be predicted after the application of basic low-cost countermeasures at the intersections of US 11 at US 80 and US 431 at SR 169 respectively.

- A reduction of 4.9% for total crashes was estimated to be predicted after the application of longitudinal channelizers treatment at the intersection of US 82 at County Road 140.
- The development of the calibration factor in this study provides more insights about crash frequency thresholds at the intersections on RDHS in Alabama. An estimate of predicted crash frequencies at these intersections could assist the roadway engineers to implement countermeasures in order to reduce crash frequency.

6.3 RECOMMENDATIONS FOR FUTURE RESEARCH

This thesis is a component of ongoing research related to the development of guidance at unsignalized type configurations on rural divided highways. In continuation of this study, the development of calibration factor and calibration of intersection specific safety performance functions assess the safety performance of unsignalized intersections and quantify the crash reduction effects of safety countermeasures. Future research includes the following recommendations

- Based on the literature review of the safety evaluation of different countermeasures that are been deployed at different states. A good sample size of at least 5 treated sites should be collected to develop crash modification factors for the countermeasures deployed.
- Most of the countermeasures deployed at the treated locations do not have enough after crash data i.e.(three- or five-year data). Therefore, crash data of at least 3 to 5 years before and after crash data should be collected to account for regression to the mean bias.
- Although the HSM calibration procedure suggests a sample size of 30 to 50 sites with a total of 100 crashes per year, it does not apply to rural divided highways considered in this study. This is because a sample size of 30 to 50 intersections on these rural

settings did not yield a total of 100 crashes per year. Therefore, sample size of the intersections should be increased to meet a total of 100 crashes per year.

- An Empirical Bayes before-after analysis can be used as a statistical tool to estimate the safety effectiveness of the deployed countermeasures at the treated sites.

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APPENDIX A

Tables A-1 and A-2 shows the predicted average crash frequencies of 59 3ST and 69 4ST reference sites included in the study. This includes the predicted crash frequencies of base conditions and site conditions. The values obtained under the column base SPF represents the predicted crash frequency of the base conditions. The extreme right end of the column represents the predicted average crash frequencies for the site conditions.

S.NO	County	Route	IntersectingStreet1	Avg AADT major	Avg AADT minor	Base SPF	Intersection Skew angle (CMF1)	Left turn lanes on Major Road (CMF2)	Right turn lanes on Major Road (CMF3)	Lighting (CMF4)	Predicted Average Crash Frequency(Npredicted 3ST int)
1	Lowndes	US 80	AL 21	6722	3464	1.009	1.45	0.56	0.86	0.9	0.634
2	Colbert	US 72	AL 247	11190	1870	1.611	1	0.56	0.86	1	0.776
3	Jackson	US72	AL 35	14394	2066	2.233	1	0.56	0.86	1	1.075
4	Washington	US 43	AL 56	8920	2452	1.307	1	0.56	0.86	1	0.629
5	Jackson	US 72	AL 65	14874	1558	2.173	1.29	0.56	1	1	1.57
6	Hale	US 80	AL69	6982	2256	0.967	1	0.56	1	1	0.542
7	Etowah	US 431	AL 74	11660	5508	2.184	1.36	1	1	1	2.97
8	Marshall	US 431	AL79	15528	4804	2.985	1	1	1	1	2.985
9	Lowndes	US 80	Benton Road	8170	228	0.671	1	1	1	1	0.671
10	Madison	US 72	Brock Road	17188	2574	2.912	1.29	0.56	0.86	1	1.809
11	Morgan	AL 157	Campground Road	5550	1715	0.678	1	1	1	1	0.678
12	Montgomery	US 80	Cantelou Road	12825	384	1.306	1.24	0.56	0.86	1	0.78

13	Washington	US 43	Cortelyou Road	8920	2452	1.307	1	0.56	0.86	1	0.629
14	Cullman	AL 157	County Road 1114	8968	1032	1.072	1.14	0.56	1	1	0.684
15	Cullman	AL 157	County Road 1188	8364	908	0.957	1	0.56	1	1	0.536
16	Lawrence	AL 24	County Road 120	6014	856	0.634	1.2	0.56	1	1	0.426
17	Franklin	US 43	County Road 17	9215	4344	1.555	1.13	0.56	0.86	1	0.846
18	Houston	US 231	County Road 203	13920	588	1.594	1.36	0.56	0.86	1	1.044
19	Lowndes	US 80	County Road 37	12356	1120	1.608	1	0.56	0.86	1	0.774
20	Dallas	US 80	County road 41	26306	4498	5.545	1.27	0.56	0.86	0.9	3.052
21	Dallas	US 80	County Road 43	7634	264	0.64	1.36	0.56	1	1	0.487
22	Franklin	AL 24	County Road 44	6988	371	0.624	1	0.56	0.86	1	0.301
23	Lauderdale	US 72	County Road 51	12941	1019	1.663	1.16	0.56	1	1	1.08
24	Morgan	AL 157	County Road 55	5550	1715	0.678	1.37	1	1	1	0.929
25	Bibb	US 82	County Road 58	4610	832	0.457	1.26	0.56	0.86	1	0.277
26	Colbert	AL 157	County Road 63	7856	615	0.809	1	0.56	1	1	0.453
27	Lauderdale	US 43	County Road 65	8866	432	0.861	1.36	1	1	1	1.171
28	Barbour	US 431	County Road 79	8785	966	1.03	1.27	0.56	1	1	0.733
29	Tuscaloosa	US 82	Curry Road	8298	247	0.697	1	1	1	1	0.697
30	Tuscaloosa	US 82	Daffron Road	8298	956	0.959	1	1	1	1	0.959
31	Colbert	US 72	Hawk Pride Mountain Road	13892	1038	1.819	1.22	0.56	0.86	1	1.069
32	Lauderdale	US 72	Houstontown Road	17776	533	2.091	1	0.56	0.86	1	1.007
33	Washington	US 43	Hwy 56	8920	2452	1.307	1	0.56	0.86	1	0.629

34	Colbert	AL 157	J Mcgee Road	7856	297	0.681	1	0.56	1	1	0.381
35	Tuscaloosa	US 82	Jug Factory Road	15612	1396	2.245	1.4	1	1	1	3.143
36	Lauderdale	US 43	Lannes W Dr	8866	1558	1.166	1	1	1	1	1.166
37	Lee	US 431	Lee Road 391	17438	698	2.177	1.36	0.56	1	1	1.658
38	Lee	US 431	Lee Road 430	22495	4232	4.527	1	0.56	1	1	2.535
39	Pickens	US 82	Loop Road	6732	724	0.727	1	0.56	1	1	0.407
40	Montgomery	US 231	Meriwether Road	25259	1167	3.84	1.26	0.56	0.86	0.9	2.097
41	Montgomery	US 80	Mitchell Young Road	16725	2830	2.881	1.2	0.56	0.86	1	1.665
42	Tuscaloosa	US 82	Monticello Dr	12388	1330	1.68	1.13	1	1	1	1.898
43	Colbert	US 72	Mulberry Lane	10295	298	0.944	1	1	1	1	0.944
44	Franklin	AL 24	old AL 24	6988	300	0.593	1	0.56	0.86	1	0.286
45	Montgomery	US 82	Old Carterhill Road	18385	1960	2.961	1	1	1	1	2.961
46	Madison	US 431	Old Hwy 431	17664	890	2.342	1	0.56	0.86	1	1.128
47	Bibb	US 82	Pleasant Hill Church Road	5425	827	0.556	1	0.56	1	1	0.311
48	Etowah	US 431	Sand Valley Road	16235	310	1.65	1.22	1	1	1	2.013
49	Russell	US 431	South Seale Road	13674	1077	1.8	1.45	1	1	1	2.61
50	Washington	US 43	St Stephens Road	8710	1314	1.096	1.33	0.56	1	1	0.816
51	Houston	US 231	State Line Road	13920	711	1.667	1	0.56	0.86	0.9	0.723
52	Madison	US 231	Steeger Road	27155	2194	4.863	1	0.56	0.86	0.9	2.108
53	Lowndes	US 80	Steel Haven Road	8476	1120	1.021	1	0.56	1	1	0.572

54	Montgomery	US 231	Trotman Road	25259	3858	5.092	1	0.56	0.86	0.9	2.207
55	Bullock	AL 51	US 82	3132	1262	0.317	1.28	0.56	0.86	1	0.195
56	Franklin	AL 24	W Lawrence St	4644	1396	0.521	1.25	0.56	0.86	1	0.314
57	Madison	US 72	Wall Road	19666	636	2.462	1.5	0.56	1	0.9	1.861
58	Tuscaloosa	US 82	Westwood School Road	15334	2536	2.529	1.2	0.56	0.86	1	1.462
59	Lowndes	US 80	County Road 37	12356	1120	1.608	1	0.56	0.86	1	0.774

Table A- 1: Predicted average crash frequencies of 59 3ST reference sites

S.NO	County	Route	Intersecting Street	Avg AADT major	Avg AADT minor	Base SPF	Intersection Skew angle (CMF1)	Left turn lanes on Major Road (CMF2)	Right turn lanes on Major Road (CMF3)	Lighting (CMF4)	Predicted Average Crash Frequency(Npredicted 4ST int)
1	Lawrence	AL 157	AL 101	7422	2184	2.703	1.36	0.52	0.74	1	1.415
2	Sumter	US 80	AL 17	3296	1204	1.04	1	0.52	0.74	1	0.4
3	Clarke	US 43	AL 178	8688	2284	3.151	1.27	0.52	0.74	0.9	1.386
4	Franklin	AL 24	AL 187	3966	1420	1.31	1.21	1	0.74	1	1.173
5	Marengo	US 80	AL 25	5446	1616	1.816	1.27	0.52	0.74	1	0.887
6	Marengo	US 80	AL 28	5944	2212	2.251	1.4	0.52	0.74	0.9	1.091
7	Lawrence	AL 157	AL 36	5618	960	1.477	1.46	0.52	0.74	1	0.83
8	Lauderdale	US 43	AL64	8433	2632	3.274	1	0.52	0.74	1	1.26
9	Blount	US 278	AL 79	6865	2340	2.609	1.53	0.52	0.74	1	1.536
10	Lowndes	US 80	AL 97	8754	1462	2.597	1	0.52	0.74	0.9	0.899
11	Colbert	US 72	Allsboro Road	8256	596	1.653	1.56	0.52	0.74	1	0.992
12	Colbert	US 72	Asphalt Rock Road	8256	233	1.083	1.53	0.52	1	1	0.862
13	Etowah	US 431	Balenger Ln	16044	1660	4.595	1	1	1	1	4.595
14	Tuscaloosa	US 82	Bearmont Road.	13236	818	2.843	1	1	1	1	2.843
15	Limestone	US 72	Burgreen Road	20905	1720	5.843	1	0.52	1	1	3.038
16	Limestone	US 72	Cambridge Ln	20060	453	3.104	1	1	1	1	3.104
17	Russell	US 431	Clark Road	9890	820	2.223	1.56	0.52	0.74	1	1.334
18	Colbert	AL 157	County Line Road	6234	1079	1.7	1.45	0.52	0.74	1	0.949
19	Tuscaloosa	US 82	County Road 1	6916	2127	2.515	1.23	0.52	1	1	1.609
20	Lawrence	AL 24	County Road 108	5206	634	1.15	1	0.52	0.74	1	0.443
21	Lawrence	AL 157	County Road 108	8934	480	1.604	1.23	0.52	0.74	1	0.759

22	Cullman	AL 157	County Road 1101	7750	1518	2.382	1.36	0.52	1	1	1.685
23	Cullman	AL 157	County Road 1212	7750	799	1.787	1.56	0.52	1	1	1.45
24	Cullman	AL 157	County Road 1218	8959	1032	2.266	1.53	0.52	1	1	1.803
25	Cullman	AL 157	County Road 1246	12440	183	1.379	1.48	0.52	1	1	1.061
26	Lawrence	AL 157	County Road 136	7422	230	0.986	1.63	0.52	1	1	0.836
27	Lawrence	AL 157	County Road 150	8934	472	1.592	1.27	0.52	0.74	1	0.778
28	Lowndes	US 80	County Road 17	8430	2830	3.381	1.63	0.52	0.74	1	2.121
29	Lee	US 280	County Road 179	18850	1321	4.756	1.27	0.52	0.74	1	2.324
30	Lawrence	AL 157	County Road 184	6980	536	1.367	1	0.52	0.74	1	0.526
31	Franklin	AL 13	County Road 20	5128	540	1.056	1.53	1	1	1	1.616
32	Lawrence	AL 24	County Road 217	11706	1323	3.177	1.36	0.52	1	1	2.247
33	Franklin	US 43	County Road 22	9215	838	2.114	1.48	1	1	1	3.129
34	Franklin	AL 24	County Road 23	3606	575	0.806	1.43	0.52	1	1	0.599
35	Bullock	US 82	County Road 30	4375	203	0.596	1.47	0.52	0.74	1	0.337
36	Colbert	US 72	County road 33	10295	533	1.896	1	0.52	1	1	0.986
37	Lawrence	AL 24	County Road 358	15300	785	3.156	1.53	0.52	1	1	2.511
38	Franklin	AL 24	County Road 36	3966	218	0.566	1	0.52	0.74	1	0.218
39	Henry	US 431	County Road 41	10598	207	1.272	1.33	0.52	0.74	0.9	0.586
40	Henry	US 431	County Road 45	11590	253	1.501	1.6	0.52	1	1	1.249
41	Dallas	US 80	County Road 45	5455	237	0.77	1.27	0.52	1	1	0.509
42	Lawrence	AL 24	County Road 50	6014	856	1.486	1.29	0.52	0.74	1	0.738
43	Colbert	US 72	County road 53	11190	290	1.549	1.23	0.52	0.74	1	0.733
44	Henry	US 431	County Road 54	10346	119	0.973	1.23	0.52	0.74	1	0.461
45	Dallas	US 80	County Road 69	9942	283	1.386	1.4	0.52	1	1	1.009
46	Dallas	US 80	County Road 7	7702	235	1.207	1	1	1	1	1.207

47	Lauderdale	US 43	County Road 73	8433	540	1.61	1.27	0.52	0.74	1	0.787
48	Franklin	AL 24	County Road 75	4644	861	1.197	1.36	0.52	1	1	0.847
49	Franklin	AL 24	County Road 77	4644	438	0.884	1.36	0.52	0.74	1	0.463
50	Franklin	AL 24	County Road 99	4488	404	0.828	1	0.52	1	1	0.431
51	Morgan	AL 157	Danville Road	5688	1622	1.888	1	1	1	1	1.888
52	Russell	US 431	Freeman Road	10772	2070	3.618	1	0.52	1	1	1.881
53	Tuscaloosa	US 11	Giles Road	10920	228	1.363	1.61	1	1	1	2.194
54	Morgan	AL 24	Hudson Road	14812	2776	5.406	1	0.52	1	1	2.811
55	Lauderdale	US 43	Lauderdale County 394	8433	540	1.61	1.27	0.52	1	1	1.063
56	Etowah	US 431	Lawson Gap Road	16044	345	2.273	1.53	1	1	1	3.478
57	Tuscaloosa	AL 69	Lower Hull Road	16318	350	2.321	1.46	0.52	0.74	1	1.304
58	Lawrence	AL 24	Old Florence Road	6594	230	0.892	1.53	0.52	1	1	0.71
59	Tuscaloosa	AL 69	old Greenboro Road	33758	1674	8.667	1.55	0.52	1	1	6.986
60	Tuscaloosa	AL 69	Patriot Pkway	33758	5142	14.33	1	0.52	0.74	0.9	4.963
61	Madison	US 231	Patterson Lane	31250	4212	12.274	1	0.52	0.74	1	4.723
62	Pickens	US 82	Pickens County Road 75	4872	394	0.878	1.56	0.52	0.74	1	0.527
63	Russell	US 431	Prudence Road	7779	701	1.69	1	0.52	0.74	1	0.65
64	Colbert	AL 157	Ricks Lane	7856	296	1.158	1.31	0.52	1	1	0.789
65	Sumter	US 80	Sheep Skin Road	3496	474	0.72	1.36	1	1	1	0.979
66	Tuscaloosa	AL 69	Upper Hull Road	16318	238	1.953	1.61	0.52	0.74	1	1.21
67	Sumter	US 80	Us 11	3496	3052	1.658	1.53	0.52	0.74	0.9	0.879
68	Cullman	AL 157	Us-278	5244	6912	3.373	1	0.52	1	1	1.754
69	Lawrence	AL 24	County Road 120	6014	856	1.486	1.36	0.52	1	1	1.051

Table A- 2: Predicted average crash frequencies of 69 4ST reference sites

Table A-3 shows the predicted and observed crash frequencies of the 59 3ST and 69 4ST reference sites. The values obtained under the column predicted average crash frequency represents a 5-year total crash frequency. This is obtained by multiplying the predicted average crash frequency values in Tables A-1 and A-2 with a 5-year period. The cumulative of predicted and observed crash frequencies of all sites was also presented which was used in the calculation of calibration factor.

S.NO	County	Route	IntersectingStreet1	predicted avg crash frequency	observed crash frequency
1	Lowndes	US 80	AL21	3.171	10
2	Colbert	US 72	AL 247	3.879	10
3	Jackson	US72	AL 35	5.377	1
4	Washington	US 43	AL 56	3.147	8
5	Jackson	US 72	AL 65	7.849	5
6	Hale	US 80	AL 69	2.708	2
7	Etowah	US 431	AL 74	14.851	2
8	Marshall	US 431	AL 79	14.925	10
9	Lowndes	US 80	Benton Road	3.355	2
10	Madison	US 72	Brock road	9.046	7
11	Morgan	AL 157	Campground Road	3.39	1
12	Montgomery	US 80	Cantelou Road	3.9	4
13	Washington	US 43	Cortelyou Road	3.147	1
14	Cullman	AL 157	County Road 1114	3.422	1
15	Cullman	AL 157	County Road 1188	2.68	2
16	Lawrence	AL 24	County Road 120	2.13	1
17	Franklin	US 43	County Road 17	4.231	6
18	Houston	US 231	County Road 203	5.22	1
19	Lowndes	US 80	County Road 37	3.872	9
20	Dallas	US 80	County road 41	15.262	1
21	Dallas	US 80	County Road 43	2.437	1
22	Franklin	AL 24	County Road 44	1.503	2
23	Lauderdale	US 72	County road 51	5.401	3
24	Morgan	AL 157	County Road 55	4.644	2
25	Bibb	US 82	County Road 58	1.387	1
26	Colbert	AL 157	County Road 63	2.265	1
27	Lauderdale	US 43	County Road 65	5.855	4
28	Barbour	US 431	County Road 79	3.663	1
29	Tuscaloosa	US 82	Curry Road	3.485	2
30	Tuscaloosa	US 82	Daffron Road	4.795	4
31	Colbert	US 72	Hawk Pride Mountain Road	5.344	6
32	Lauderdale	US 72	Houstontown Road	5.035	3
33	Washington	US 43	Hwy 56	3.147	1
34	Colbert	AL 157	J Mcgee Road	1.907	1
35	Tuscaloosa	US 82	Jug Factory Road	15.715	4
36	Lauderdale	US 43	Lannes W Dr	5.83	5
37	Lee	US 431	Lee Road 391	8.29	2

38	Lee	US 431	Lee Road 430	12.676	1
39	Pickens	US 82	Loop Road	2.036	1
40	Montgomery	US 231	Meriwether Road	10.486	6
41	Montgomery	US 80	Mitchell Young Road	8.325	16
42	Tuscaloosa	US 82	Monticello Dr	9.492	3
43	Colbert	US 72	Mulberry Lane	4.72	1
44	Franklin	AL 24	old AL 24	1.428	6
45	Montgomery	US 82	Old Carterhill Road	14.805	2
46	Madison	US 431	Old Hwy 431	5.64	1
47	Bibb	US 82	Pleasant Hill Church Road	1.557	1
48	Etowah	US 431	Sand Valley Road	10.065	2
49	Russell	US 431	South Seale Road	13.05	4
50	Washington	US 43	St Stephens Road	4.082	2
51	Houston	US 231	State Line Road	3.613	2
52	Madison	US 231	Steeger Road	10.539	14
53	Lowndes	US 80	Steel Haven Road	2.859	2
54	Montgomery	US 231	Trotman Road	11.035	9
55	Bullock	AL 51	US 82	0.977	2
56	Franklin	AL 24	W Lawrence St	1.568	2
57	Madison	US 72	Wall Road	9.306	4
58	Tuscaloosa	US 82	Westwood School Road	7.308	3
59	Lowndes	US 80	County Road 37	3.872	1
				Σ_{all} Predicted	Σ_{all} Observed
				345.704	212

Table A- 3: Predicted and observed crash frequencies of 59 3ST reference sites

S.NO	County	Route	Intersecting Street	predicted avg crash frequency	observed crash frequency
1	Lawrence	AL 157	Al 101	7.075	11
2	Sumter	US 80	Al 17	2	4
3	Clarke	US 43	Al 178	6.93	6
4	Franklin	AL 24	AL 187	5.865	7
5	Marengo	US 80	Al 25	4.435	13
6	Marengo	US 80	Al 28	5.455	3
7	Lawrence	AL 157	Al 36	4.15	15
8	Lauderdale	US 43	Al 64	6.3	14
9	Blount	US 278	AL 79	7.68	4
10	Lowndes	US 80	Al 97	4.495	7
11	Colbert	US 72	Allsboro road	4.96	2
12	Colbert	US 72	Asphalt Rock Road	4.31	2
13	Etowah	US 431	Balenger Ln	22.975	1
14	Tuscaloosa	US 82	Bearmont Road.	14.215	7
15	Limestone	US 72	Burgreen Road	15.19	15
16	Limestone	US 72	Cambridge Ln	15.52	5
17	Russell	US 431	Clark Road	6.67	2
18	Colbert	AL 157	County Line Road	4.745	18
19	Tuscaloosa	US 82	County Road 1	8.045	2
20	Lawrence	AL 24	County Road 108	2.215	1
21	Lawrence	AL 157	County Road 108	3.795	1
22	Cullman	AL 157	County Road 1101	8.425	3
23	Cullman	AL 157	County Road 1212	7.25	1
24	Cullman	AL 157	County Road 1218	9.015	1
25	Cullman	AL 157	County Road 1246	5.305	2
26	Lawrence	AL 157	County Road 136	4.18	4
27	Lawrence	AL 157	County Road 150	3.89	1
28	Lowndes	US 80	County Road 17	10.605	1
29	Lee	US 280	County Road 179	11.62	1
30	Lawrence	AL 157	County Road 184	2.63	4
31	Franklin	AL 13	County Road 20	8.08	2

32	Lawrence	AL 24	County Road 217	11.235	16
33	Franklin	US 43	County Road 22	15.645	5
34	Franklin	AL 24	County Road 23	2.995	2
35	Bullock	US 82	County Road 30	1.685	2
36	Colbert	US 72	County road 33	4.93	3
37	Lawrence	AL 24	County Road 358	12.555	1
38	Franklin	AL 24	County Road 36	1.09	1
39	Henry	US 431	County Road 41	2.93	1
40	Henry	US 431	County Road 45	6.245	3
41	Dallas	US 80	County Road 45	2.545	3
42	Lawrence	AL 24	County Road 50	3.69	1
43	Colbert	US 72	County road 53	3.665	1
44	Henry	US 431	County Road 54	2.305	1
45	Dallas	US 80	County Road 69	5.045	1
46	Dallas	US 80	County Road 7	6.035	1
47	Lauderdale	US 43	County Road 73	3.935	8
48	Franklin	AL 24	County Road 75	4.235	2
49	Franklin	AL 24	County Road 77	2.315	15
50	Franklin	AL 24	County Road 99	2.155	2
51	Morgan	AL 157	Danville Road	9.44	4
52	Russell	US 431	Freeman Road	9.405	2
53	Tuscaloosa	US 11	Giles Road	10.97	13
54	Morgan	AL 24	Hudson Road	14.055	3
55	Lauderdale	US 43	Lauderdale County 394	5.315	1
56	Etowah	US 431	Lawson Gap Road	17.39	4
57	Tuscaloosa	AL 69	Lower Hull Road	6.52	4
58	Lawrence	AL 24	Old Florence Road	3.55	4
59	Tuscaloosa	AL 69	old Greenboro Road	34.93	1
60	Tuscaloosa	AL 69	Patriot Pkway	24.815	2
61	Madison	US 231	Patterson Lane	23.615	3
62	Pickens	US 82	Pickens County Road 75	2.635	2
63	Russell	US 431	Prudence Road	3.25	1
64	Colbert	AL 157	Ricks Lane	3.945	9
65	Sumter	US 80	Sheep Skin Road	4.895	1
66	Tuscaloosa	AL 69	Upper Hull Road	6.05	4
67	Sumter	US 80	Us 11	4.395	4

68	Cullman	AL 157	Us-278	8.77	1
69	Lawrence	AL 24	County Road 120	5.255	6
				Σ_{all} Predicted	Σ_{all} Observed
				522.46	298

Table A- 4: Predicted and observed crash frequencies of 69 4ST reference sites