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VALIDATION AND APPLICATION OF HIGHWAY SAFETY MANUAL (PART D) IN FLORIDA

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DISCLAIMER

The opinions, findings, and conclusions expressed in this publication are those of the authors and not necessarily those of the State of Florida Department of Transportation.

UNIT CONVERSION

SI*Modern Metric Conversion Factors as provided by the Department of Transportation, Federal Highway Administration http://www.fhwa.dot.gov/aaa/metricp.htm

LENGTH				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km

AREA				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	*square meters*	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2

LENGTH				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi

AREA				
SYMBOL	**WHEN YOU KNOW**	**MULTIPLY BY**	**TO FIND**	**SYMBOL**
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section4 of ASTME3

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16. Abstract

The Highway Safety Manual (HSM) Part D provides a comprehensive list of the effects of safety treatments (countermeasures). These effects are quantified by crash modification factors (CMF), which are based on compilation from past studies of the effects of various safety treatments. The HSM Part D provides CMFs for treatments applied to roadway segments (e.g., roadside elements, alignment, signs, rumble strips, etc.), intersections (e.g., control), interchanges, special facilities (e.g., highway-rail crossings), and road networks. Thus, an assessment of the applicability of the HSM in Florida is essential. The objectives of this study are (1) to develop CMFs for various treatments in Florida for the same setting (rural/urban), road type, crash type, and severity level, (2) to evaluate the difference between these Florida-specific CMFs and the CMFs in the HSM, and (3) to recommend whether the CMFs in the HSM can be applied to Florida or new Florida-specific CMFs are needed. Different methods of observational study – before-after (B-A) and cross-sectional (C-S) – were used to calculate CMFs for a total of 17 treatments applied to roadway segments, intersections and special facilities. The CMFs calculated using the before-after with comparison-group (C-G) and empirical Bayesian (EB) methods, only the CMF with lower standard error was selected. The methods of calculating CMFs were determined based on the availability of the data and the methods used in the HSM, if the CMFs were provided in the HSM. It was found that Florida-specific CMFs were generally statistically significant, and safety effects represented by the CMFs were intuitive, similar to the CMFs in the HSM. It was also found that Florida-specific CMFs for the treatments not included in the HSM showed significant positive effects in reducing crash frequencies.

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EXECUTIVE SUMMARY

The Highway Safety Manual (HSM) Part D provides a comprehensive list of the effects of safety treatments (countermeasures). These effects are quantified by crash modification factors (CMF), which are based on compilation from past studies of the effects of various safety treatments. The HSM Part D provides CMFs for treatments applied to roadway segments (e.g., roadside elements, alignment, signs, rumble strips, etc.), intersections (e.g., control), interchanges, special facilities (e.g., highway-rail crossings), and road networks. Thus, an assessment of the applicability of the HSM in Florida is essential. The objectives of this study are (1) to develop CMFs for various treatments in Florida for the same setting (rural/urban), road type, crash type, and severity level, (2) to evaluate the difference between these Florida-specific CMFs and the CMFs in the HSM, and (3) to recommend whether the CMFs in the HSM can be applied to Florida or new Florida-specific CMFs are needed.

In this study, the treatments included in the HSM were mainly analyzed for evaluating the validity of the CMFs in the HSM for Florida. However, other treatments not included in the HSM were also considered. Massive efforts have been made to collect the data for developing CMFs. Multiple data sets were obtained from the data sources maintained by FDOT. These data include Financial Management (FM) Database, the Roadway Characteristics Inventory (RCI), as-built plans, video logs, Straight Line Diagrams (SLD), the Transtat I-view aerial mapping system, Google Earth, and the Crash Analysis Reporting System (CARS) database. These data were used to identify the time and location of treatments, road geometric and traffic characteristics of the location before and after application of the treatments, and historical crash records at the location.

Different methods of observational study – before-after (B-A) and cross-sectional (C-S) – were used to calculate CMFs for a total of 17 treatments applied to roadway segments, intersections, and special facilities. The before-after method includes naïve before-after, before-after with comparison group (CG), and before-after with empirical Bayesian (EB) methods. A set of safety performance functions (SPFs), which predict crash frequency as a function of explanatory variables, were also developed. These Florida-specific SPFs were used to predict crash frequency for untreated sites in the after period in the before-after with EB method or derive CMFs for the treatment using the cross-sectional method. Both simple SPF (with traffic volume only as an explanatory variable) and full SPF (with traffic volume and additional explanatory variable(s)) were used to calculate CMFs and only the SPF which produces the CMF with lower standard error was selected. Similarly, between the CMFs calculated using the before-after with CG and EB methods, only the CMF with lower standard error was selected.

The methods of calculating CMFs were determined based on the availability of the data and the methods used in the HSM if the CMFs were provided in the HSM. The list of17 treatments and the methods used to calculate CMFs are as follows:

1. Roadway Segments (* denotes the treatment not included in the HSM)
   1) *adding a through lane** (B-A)
   2) *adding shoulder rumble strips on two-lane undivided roadways**(B-A)

3) *adding* shoulder *rumble strips*(B-A)
4) *widening shoulder width**(B-A)
5) *adding* shoulder *rumble strips*+ w*idening shoulder width on rural multilane highways**(B-A)
6) *converting a two-way left-turn lane to a raised median*(B-A)
7) *adding lighting*(B-A)
8) *adding a raised median*(C-S)
9) *increasing median width*(C-S)
10) *narrowing lane width*(C-S)
11) *converting4 to 3 lanes*(C-S)
12) *narrowing paved right shoulder width*(C-S)
13) *adding a bike lane**(C-S)

2. Intersections and Special Facilities (* denotes the treatment not included in the HSM)
    1) *signalization of stop-controlled intersections*(B-A)
    2) *adding left turn lanes*(B-A)
    3) *adding red light running cameras*(B-A)
    4) *converting traditional mainline toll plaza to hybrid mainline toll plaza**(B-A)

It was found that Florida-specific CMFs were generally statistically significant and safety effects represented by the CMFs were intuitive similar to the CMFs in the HSM. It was also found that Florida-specific CMFs for the treatments not included in the HSM show significant positive effects in reducing crash frequencies. Thus, these treatments need to be considered in addition to the treatments included in the HSM. In conclusion, Florida-specific CMFs developed in this study are recommended for application to Florida as long as they are statistically significant. However, if they are not significant, the CMFs in the HSM (if they are significant) are recommended.

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LIST OF ACRONYMS/ABBREVIATIONS

AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
CARS	Crash Analysis Reporting System
CG	Comparison Group
CMF	Crash Modification Factor
CMFunction	Crash Modification Function
EB	Empirical Bayes
FB	Full Bayes
F+I	Fatal and Injury
FDOT	Florida Department of Transportation
FM	Financial Management
HSM	Highway Safety Manual
HMTP	Hybrid Mainline Toll Plaza
NB	Negative Binomial
PDO	Property Damage Only
RCI	Roadway Characteristics Inventory
SE	Standard Error
SLD	Straight Line Diagram
SPF	Safety Performance Function

TMTP	Traditional Mainline Toll Plaza
TRB	Transportation Research Board
TWLTL	Two-Way Left-Turn Lane

CHAPTER 1. INTRODUCTION

The Highway Safety Manual (HSM) (AASHTO, 2010) is a result of extensive work spearheaded by the Transportation Research Board (TRB) Committee on Highway Safety Performance. HSM will enable officials to benefit from the extensive research in safety of highways as it bridges the gap between research and practice. The HSM's analytical tools and techniques provide quantitative information on crash analysis and evaluation for decision making in planning, design, operation, and maintenance. Thus, an assessment of the applicability of this manual in Florida is essential. Part D of the HSM provides a comprehensive list of crash modification factors (CMFs), which were compilation from past studies of the effects of various safety treatments (i.e., countermeasures). There is a need to validate the CMFs in the HSM Part D. Another issue with the HSM is that many practitioners find it difficult to use or need substantial statistical knowledge to implement. The challenges would be to how to simplify the HSM so practitioners can practically apply it.

For these reasons, the HSM has been a hot research topic since its publication. Researchers are keen to work on the application of HSM in different states, including Utah (Brimley, Saito et al. 2012), Kansas (Howard and Steven 2012), Oregon (Zhou and Dixon 2012), Florida (Gan et al., 2012), etc. They have already worked on calibrations and modifications of the Safety performance functions (SPFs) in the HSM on their own roadways.

The HSM Part D provides a methodology to evaluate the effects of safety treatments (countermeasures). These can be quantified by CMFs. The HSM Part D identifies CMFs based on literature review and experts or at least trends (or unknown effects) for each treatment. CMFs are expressed as numerical values to identify the percent increase or decrease in crash frequency together with the standard error. A standard error of 0.10 or less indicates that a CMF is sufficiently accurate. CMFs could also be expressed as a function or SPF (equation), graph or combination.

The HSM Part D provides CMFs for roadway segments (e.g., roadside elements, alignment, signs, rumble strips, etc.), intersections (e.g., control), interchanges, special facilities (e.g., Hwy-rail crossings), and road networks. CMFs could be applied individually if a single treatment is proposed or multiplicative if multiple treatments are implemented. Other possibilities are to divide or interpolate CMFs. In this study, the empirical Bayes (EB) approach to analysis before-after effects will be utilized. The EB method can overcome the limitations faced by simple before-after evaluation and compare group methods by not only accounting for regression to the mean effects, but also accounting for traffic volume changes when identifying the crash modification factors. This will increase the reliability of the CMF and increase the likelihood of achieving the same change in crash frequency if the treatment is implemented elsewhere.

Crash modification factors can therefore play a vital role as an important tool to enable practitioners in FDOT to estimate the safety effects of various countermeasures, identify the most cost-effective strategies to reduce the number of crashes (or severe crashes) at problematic locations, and check the validity of assumptions in cost-benefit analyses.

CHAPTER 2. LITERATURE REVIEW

The HSM was published in 2010 by the American Association of State Highway and Transportation Officials (AASHTO). This manual perfectly fills the gap between traffic safety researches and safety improvement applications for the highways. One of the key parts in this manual is the safety performance functions (SPFs) and the crash modification factors (CMFs), which can help local agencies and DOTs to discover the hot spots (locations with high crash occurrences) and suggest countermeasures for sites of concern. However, the basic method stated in the HSM was calibrated only based on several states and it need further calibration before applied to a specific area, the calibration factor should be calculated to develop jurisdiction specific models. This chapter provides a review of the HSM related papers in the latest TRB Annual Meetings, and these papers were summarized from the data aspect, methodology part and results of HSM's application.

2.1 HSM Crash Prediction Model for Highway Segments and Data Requirement

Crash prediction model for rural two-lane highways presented by Equations 10-1 in Chapter 10 of the HSM(AASHTO 2010) has the following forms:

where,

= predicted average crash frequency for an individual roadway segment for a specific year;

calibration factor for roadway segments of a specific type developed for a particular jurisdiction or geographical area, $\frac{\Sigma}{\Sigma}$;

= predicted average crash frequency for base conditions for an individual roadway segment;

= crash modification factors.

The calibration factor should be calculated by the above equation, this adjustment will help to address differences in weather, driver populations, animal populations, collision reporting thresholds, and other factors that are likely to influence reported crashes. Besides, the HSM calibration procedure suggests that at least 30 to 50 sites with at least 100 crashes per year. To avoid the site selection bias, the sites should be randomly selected and then the number of crashes should be determined.

2.2 Review of Research Papers

There have been many research papers on the calibration and validation of the crash prediction models used in the HSM. For instance, Sacchi, Persaud et al. (2012) studied the transferability of the HSM crash prediction algorithms on two-lane rural roads in Italy. The authors firstly estimated a local baseline model as well as evaluated each CMF based on the Italian data. Homogeneous segmentation for the chosen study roads has been performed just to be consistent with the HSM algorithms. In order to quantify the transferability, a calibration factor has been evaluated to represent the difference between the observed number of crashes and the predicted number of crashes by applying HSM algorithm.

With four-year crash data, the calibration factor came out to be 0.44 which indicates the HSM model has over-predicted the collisions. After investigating the predicted values with the observed values by different AADT levels, the authors concluded that the predicted ability of the HSM model for higher AADT is poor and a constant value of "calibration factor" is not appropriate. This effect was also proved from the comparison between the HSM baseline model and the local calculated baseline model. Furthermore, the authors evaluated CMFs for three main road features (Horizontal Curve, Driveway Density and Roadside Design). The calculation of CMFs has been grouped according to Original CMFs, and results of comparing the calculated CMFs to baseline CMFs indicated that the CMFs are not unsuitable for local Italian roadway characteristics since most of them are not consistent.

Finally, several well-known goodness-of-fit measures have been used to assess the recalibrated HSM algorithms as a whole, and the results are consistent as the results mentioned in the split investigation of HSM base model and CMFs. With these facts the authors concluded that the HSM is not suitable to transferable to Italy roads and Europe should orient towards developing local SPFs/CMFs.

Sun, Magri et al. (2012) calibrated the SPF for rural multilane highways in the Louisiana State roadway system. The authors investigated how to apply the HSM network screening methods and identified the potential application issues. Firstly the rural multilane highways were divided into sections based on geometric design features and traffic volumes, all the features are distinct within each segment. Then by computing the calibration factor, the authors found out that the average calibration parameter is 0.98 for undivided and 1.25 for divided rural multilane highways. These results turned out that HSM has underestimated the expected crash numbers.

Besides the calibration factor evaluation, the authors investigated the network screening methods provided by HSM. 13 methods are promoted in the HSM, each of these methods required different data and data availability issue is the key part of HSM network screening methods application. In the paper, four methods have been adopted: crash frequency, crash rates, excess expected average crash frequency using SPFs (EEACF) and expected average crash frequency with EB Adjustment (EACF). Comparisons between these methods have been done by ranking the most hazardous segments and findings indicate that the easily used crash frequency method produced similar results to the results of the sophisticated models; however, crash rate method could not provide the same thing.

Xie, Gladhill et al. (2011) investigated the calibration of the HSM prediction models for Oregon State Highways. The authors followed the suggested procedures by HSM to calibrate the total crashes in Oregon. In order to calculate the HSM predictive model, the author identified the needed data and came up with difficulties in collecting the pedestrian volumes, the minor road AADT values and the under-represented crash locations. For the pedestrian volume issue, the authors assumed to have “medium” pedestrian when calculate the urban signalized intersections. While for the minor road AADT issue, the authors developed estimation models for the specific roadway types. Then the calibration factors have been defined for the variety types of highways and most of these values are below than 1. These findings indicate an overestimation for the crash numbers by the HSM. However, the authors attribute these results to the current Oregon crash reporting procedures which take a relative high threshold for the Property Damage Only (PDO) crashes. Then for the purpose of proving the crash reporting issue, the authors compared the HSM proportions of different crash severity levels and the Oregon oriented values. Furthermore, calibration factors for fatal and injury crashes have been proved to be higher than the total crash ones, which also demonstrated that Oregon crash reporting system introduce a bias towards the fatal and injury conditions. So the authors concluded that the usages of severity-based calibration factors are more suitable for the Oregon State highways.

Howard and Steven (2012) investigated different aspects of calibrate the predictive method for rural two-lane highways in Kansas State. Two data sets were collected in this study; one data set was used to develop the different model calibration methods and the other one was adopted for evaluating the models accuracy for predicting crashes.

At first, the authors developed the baseline HSM crash predictive models and calculated the Observed-Prediction (OP) ratios. Results showed a large range of OP ratios which indicate the baseline method is not very promising in predicting crash numbers. Later on, the author tried alternative ways to improve the model accuracy. Since crashes on Kansas rural highways have a high proportion of animal collision crashes which is nearly five times the default percentage presented in the HSM. The authors tried to come up with a (1) statewide calibration factor, (2) calibration factors by crash types, (3) calibration using animal crash frequency by county and (4) calibration utilizing animal crash frequency by section. The empirical Bayes (EB) method was introduced to see whether it would improve the accuracy and also a variety of statistical measures were performed to evaluate the performance.

Finally, the authors concluded that the applications of EB method showed consistent improvements in the model prediction accuracy. Moreover, it was suggested that a single statewide calibration of total crashes would be useful for the aggregate analyses while for the project-level analysis, the calibration using animal crash frequency by county is very promising.

Banihashemi (2011) performed a heuristic procedure to develop SPFs and CMFs for rural two-lane highway segments of Washington State and compared the developed models to the HSM model. The author utilized more than 5000 miles of rural two-lane highway data in Washington State and crash data for 2002-2004. Firstly the author proposed an innovative way to develop SPFs and CMFs, incorporating the segment length and AADT. Then CMFs for lane width, shoulder width, curve radius and grade have been developed. After all these procedures, the author came up with two self-developed SPFs and then compared them with the HSM model. The comparison was done at three aggregation levels: (1) consider each data as single observation (no aggregation), (2) segments level with a minimum 10 miles length and (3) aggregated based on geometric and traffic characteristics of highway segments. A variety of statistical measures were introduced to evaluate the performances and the author concluded that mostly the results are comparable, and there is no need to calibrate new models. Finally a sensitivity analysis was conducted to see the influence of data size issue on the calibration factor for the HSM model, and the conclusions indicated that a dataset with at least 150 crashes per year are most preferred for Washington State.

Later on, Banihashemi (2012) conducted a sensitivity analysis for the data size issue for calculating the calibration factors. Mainly five types of highway segment and intersection crash prediction models were investigated; Rural two-lane undivided segments, rural two-lane intersections, rural multilane segments, rural multilane intersections and urban/suburban arterials. Specifically, eight highway segment types were studied. Calibration factors were calculated with different subsets with variety percentages of the entire dataset. Furthermore, the probability that the calibrated factors fall within 5% and 10% range of the ideal calibration factor values were counted. Based on these probabilities, recommendations for the data size issue to calibrate reliable calibration factors for the eight types of highways have been proposed. With the help of these recommendations, the HSM predictive methods can be effectively applied to the local roadway system.

Brimley, Saito et al. (2012) evaluated the calibration factor for the HSM SPF for rural two-lane two-way roads in Utah. Firstly, the authors used the SPF model stated in the HSM and found out the calibration factor to be 1.16 which indicate a under estimate of crash frequency by the base model. Later on, under the guidance of the HSM, the authors developed jurisdiction-specific negative binomial models for the Utah State. More variables like driveway density, passing condition, speed limit and etc. were entered into the models with the p-values threshold of 0.25. Bayesian information criterion (BIC) was selected to evaluate the models and the finally chosen best promising model show that the relationships between crashes and roadway characteristics in Utah may be different from those presented in the HSM.

V.Zegeer, A.Sundstrom et al. (2012) worked on the validation and application issues of the HSM to analysis of horizontal curves. Three different data sets were employed in this study: all segments, random selection segments and non-random selection segments. Besides, based on the three data sets, calibration factors for curve, tangent and the composite were calculated. Results showed that the curve segments have a relative higher standard deviation than the tangent and composite segments. However, since the development of a calibration factor requires a large amount of data collecting work, a sensitivity analysis of each parameter's influence for the output results for curve segments have been performed. HSM predicted collisions were compared as using the minimum value and the maximum value for each parameter. The most effective variables were AADT, curve radius and length of the curve. Other variables like grade, driveway density won't affect the result much if the mean value were utilized when developing the models. Finally, validation of the calibration factor was performed with an extra data set. Results indicated that the calibrated HSM prediction have no statistical significant difference with the reported collisions.

Elvik (2011) examined whether accident modification functions could be transferred globally based on the data from Canada, Denmark, and Germany etc. Srinivasan et al. (2013) examined the safety effect of converting the signals to composite LED bulbs. The empirical Bayes before-after method was used for the evaluation and CMFs were estimated for 3 and 4 leg intersections for 8 different crash types. Persaud et al. (2013) evaluated SPFs of passing relief lanes using the empirical Bayes before-after method and cross-sectional method. Based on their results, state-specific CMFs were established for passing lanes. Simpson and Troy (2013) tried to evaluate safety effectiveness of intersection conflict warning system named "Vehicle Entering When Flashing" (VEWF) at stop-controlled intersection. CMFs were provided for all sites of study and each category using the empirical Bayes before-after evaluation.

Bauer and Harwood (2013) evaluated the safety effect of the combination of horizontal curvature and longitudinal grade on rural two-lane highways. Safety prediction models for fatal-and-injury and PDO crashes were evaluated, and CMFs representing safety performance relative to level tangents were developed from these models. Zeng and Schrock (2013) tried to address 10 shoulder design types' safety effectiveness between the winter and non-winter periods. For this, a cross-sectional approach was applied to develop SPFs of the winter and non-winter periods.

Lu et al. (2013) compared the results of two methods, the empirical Bayes (EB) approach adopted in the HSM and the Safety Analyst application for evaluating safety performance functions (SPFs). Models were estimated for both total crashes and fatal and injury (F+I) crashes, and the two models yielded very similar performance of crash prediction.

Kim et al. (2013) developed a four-step procedure for SPFs using categorical impact and clustering analysis. They claimed that their procedure can easily predict crash frequency more accurately. Mehta and Lu (2013) evaluated the applicability of the HSM predictive methods to develop state-specific statistical models for two facility types, two-lane two-way rural roads and four-lane divided highways. Nordback et al. (2013) presented for the first time specific SPFs for bicycle in Colorado. The developed SPFs demonstrated that intersections with more cyclists have fewer collisions per cyclist, illustrating that cyclists are safer at intersections with larger number of cyclists.

Cafiso et al. (2013) compared the effect of choosing different segmentation methods; they examined using short and long roadway segments to calibrate the SPF. In addition to the segment selection criteria, new treatment types have also been identified beside those which included in the HSM. Lan and Srinivasan (2013) focused on the safety performance on discontinuing late night flash operation at signalized intersections. The study also compared between empirical Bayes and full Bayes.

2.3 Implementation of the HSM and Safety Analyst in Florida

State of Florida is among other states that initiated a plan to implement and validate the HSM to its roadways. Figure 2-1 shows the FDOT timeline of the HSM implementation.

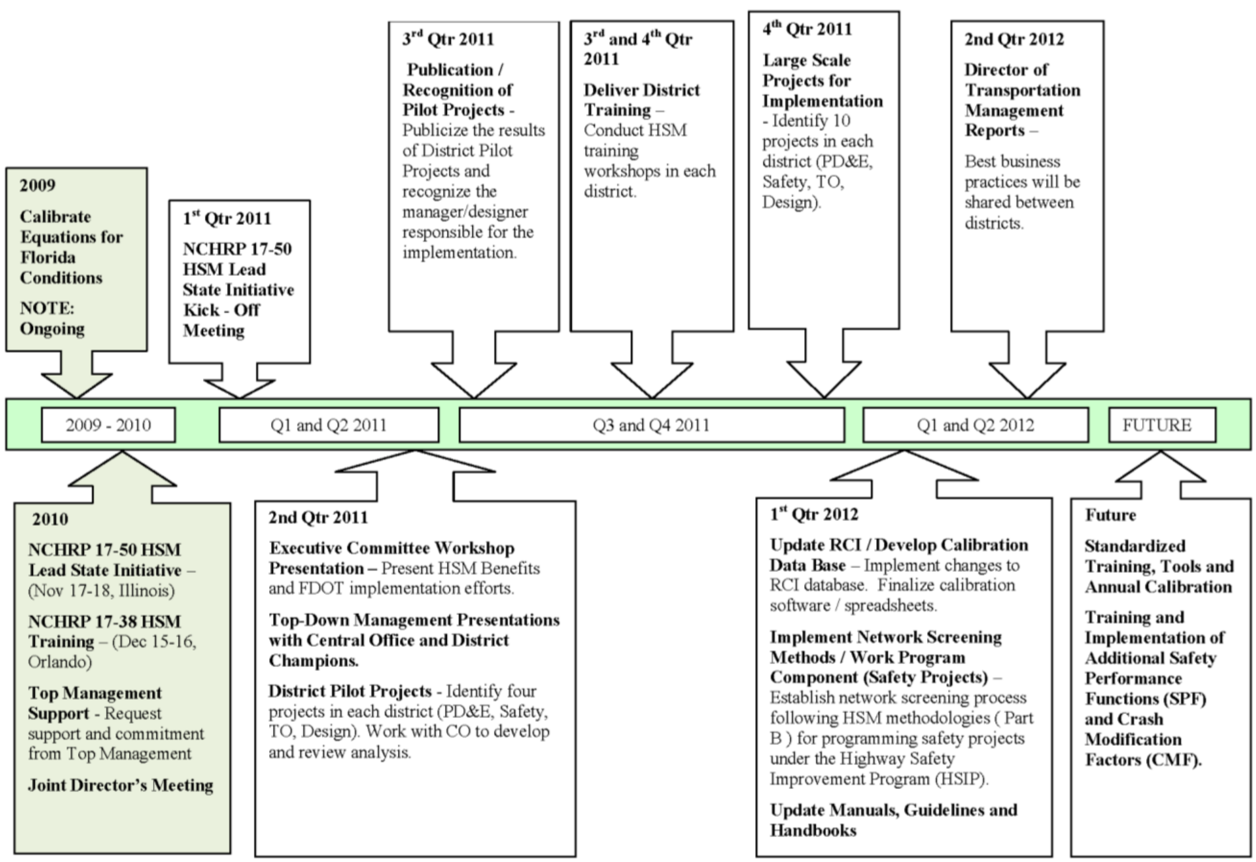


Figure 2-1: FDOT Implementation Plan Timeline for the HSM

The HSM is considered a turning point in the approach of analyzing safety data for practitioners and administrators throughout statistically proven quantitative analyses. States and local agencies are still examining ways to implement the HSM. The data requirement for the HSM and Safety Analyst is the most challenging task that all agencies are still struggling with.

Florida has been at the forefront of many states in implementing the HSM and deploying the Safety Analyst. A research project was sponsored by FDOT and conducted by the University of Florida to develop and calibrate of the HSM equations for Florida conditions. The study provided calibration factors at the segment- and intersection- level safety performance functions from the HSM for Florida conditions or the years 2005 through 2008 (Srinivasan et al., 2011).

Specifically, FDOT has sponsored two projects in its effort to implement Safety Analyst. The first of these projects was conducted by the University of South Florida (USF) which developed a program to map and convert FDOT's roadway and crash data into the input data format required by Safety Analyst (Lu et al., 2009).

A second related project was completed recently by Florida International University (FIU). The project successfully developed Florida-based safety performance functions (SPFs) for different types of segments, ramps, and signalized intersections. These SPFs were then applied to generate high crash locations in Safety Analyst. Additionally, the project also developed the first known GIS tool for Safety Analyst. However, the project was unable to develop SPFs, nor generate any Safety Analyst input files for non-signalized intersections due to the lack of the required data in FDOT's Roadway Inventory Characteristics (RCI). In addition, the SPFs and Safety Analyst input data files for signalized intersections could only be developed based on very limited data (Gan et al., 2012).

2.4 Crash Modification Factors

Crash modification factors are known also as collision modification factors or accident modification factors (CMFs or AMFs), all of which have exactly the same function. Crash reduction factors (CRFs) function in a very similar way as they represent the expected reduction in number of crashes for a specific treatment. The proper calibration and validation of crash modification factors will provide an important tool to practitioners to adopt the most suitable cost effective countermeasure to reduce crashes at hazardous locations. It is expected that the implementation of CMFs will gain more attention after the recent release of the HSM and the 2009 launch of the Clearinghouse website http://www.cmfclearinghouse.org (University of North Carolina Highway Safety Research Center, 2010).

2.5 Development of Crash Modification Factors

There are different methods to estimate CMFs, these methods vary from a simple before and after study and before and after study with comparison group to a relatively more complicated methods such as empirical Bayes and full Bayes methods.

2.5.1 The Simple (Naïve) Before-After Study

This method compares numbers of crashes before and after the treatment is applied. The main assumption of this method is that the number of crashes before the treatment would be expected without the treatment. This method tends to overestimate the effect of the treatment because of the regression to the mean problem (Hauer, 1997).

2.5.2 The Before-After Study with Comparison Group

This method is similar to the simple before and after study, however, it uses a comparison group of untreated sites to compensate for the external causal factors that could affect the change in the number of crashes. This method also does not account for the regression to the mean as it does not account for the naturally expected reduction in crashes in the after period for sites with high crash rates.

2.5.3 The Empirical Bayes Before-After Study

The empirical Bays (EB) method can account for the regression to the mean issue by introducing an estimated for the mean crash frequency of similar untreated sites using SPFs. Since the SPFs use AADT and sometimes other characteristics of the site, these SPFs also account for traffic volume changes which provides a true safety effect of the treatment (Hauer, 1997).

2.5.4 The Full Bayes Before-After Study

The full Bays (FB) is similar to the EB of using a reference population; however, it uses an expected crash frequency and its variance instead of using point estimate, hence, a distribution of likely values is generated.

2.6 Crash Modification Factors in the Safety Analyst

Safety Analyst has a tool c*ountermeasure selection tool* to assist practitioners in the selection of the appropriate countermeasure/s to reduce crash frequency and severity at specific sites. The tool has a feature to enable the users to select appropriate countermeasures for a particular site from lists based on the type of site, the observed crash patterns, and the specific safety concerns identified in the diagnostic step. One or more countermeasures can be selected by the user with the guide of the economic appraisal and priority-ranking tools.

2.7 Crash Modification Factors in the Canadian Manual

The Canadian Manual has less number of CMFs than those listed in the HSM. James et al. (2010) compared CMFs in the Canadian Manual to the HSM and Safety Analyst, they found that there is a limited number of published CMFs based on studies conducted in Canada. Additionally, it was concluded that there is a large similarity between the available CMFs in the Canadian manual.

Based on the literature review, the accuracies of the HSM prediction models are not very promising and the calibration factors vary for different data. These are due to different weather, driver populations, animal populations, and collision reporting thresholds in different locations. Thus, care must be taken to consider local conditions when the HSM is applied to different locations.

CHAPTER 3. DEVELOPMENT OF CRASH MODIFICATION FACTORS

Crash modification factors (CMFs) or Functions (CMFunctions) express the safety consequences of some treatment or intervention that has been implemented on a roadway facility. A CRF (Crash Reduction Factor) is the percentage crash reduction after implementing a given treatment at a specific site. It is also known as "safety effectiveness" of the treatment. Both CMF and CRF are commonly applied in traffic safety field and they can be estimated by a simple formula: CMF = 1- (CRF/100).One of the main methodologies to examine the effect of highway and traffic engineering measures on safety is the 'observational study'. Observational studies can be categorized into two main groups; 1) before-after and 2) the cross-sectional.

The before-after study is more advantageous over the cross-sectional study since it can capture the safety implications of a certain improvement or operational change where many of the attributes (e.g., geometry and other site characteristics) of a study facility remain unchanged. For example, the evaluation of safety effect associated with installing traffic signal control at an all-way stop-controlled intersection falls under the observational before-after study category. In contrast, in the cross-sectional study, the safety implications of one group of entities having some common feature (e.g., stop-controlled intersection) are compared to the safety of a different group of entities not having that feature (e.g., signal-controlled).The method is determined based on data availability. The HSM Part D uses both methods for different treatments.

3.1 Observational Before-After Studies

As discussed earlier, one of the main methodologies to examine the effect of highway and traffic engineering measures on safety is the 'observational before-after study'. There are four most commonly used approaches to perform an 'observational before-after' study; 1) naïve before-after study, 2) before-after study with yoked comparison, 3) before-after study with comparison group (CG) and 4) before-after study with the empirical Bayes (EB) approach.

Generally, all before-after studies are designed to answer questions about "What would have been the safety of the entity in the after period had treatment not been implemented?" and "What the safety of the treated entity in the after period was?" (Hauer, 1997)

In this study, CMFs were estimated using naïve before-after study (only for illustration), before-after with comparison group, and before-after with EB method (the last two approaches are more reliable). Moreover, the cross-Sectional study was used for the treatments where data were not sufficient for the before-after study.

3.1.1 Naïve Before-After Study

The naïve before-after approach is the simplest approach. Crash counts in the before period are used to predict the expected crash rate and, consequently, expected crashes had the treatment not been implemented. This basic naïve approach assumes that there was no change from the 'before' to the 'after' period that affected the safety of the entity under scrutiny; hence, this approach is unable to account for the passage of time and its effect on other factors such as exposure, maturation, trend and regression-to-the-mean bias. Despite the many drawbacks of the basic naïve before-after study, it is still quite frequently used in the professional literature because; 1) it is considered as a natural starting point for evaluation, and 2) its easiness of collecting the required data, and 3) its simplicity of calculation. The basic formula for deriving the safety effect of a treatment based on this method is shown in Equation 3-1:

$$CMF = \frac{N_a}{N_b} \tag{3-1}$$

where N_a and N_b are the number of crashes at a treated site in the after and before the treatment, respectively. It should be noted that with a simple calculation, the exposure can be taken into account in the naïve before-after study. The crash rates for both before and after the implementation of a project should be used to estimate the CMFs which can be calculated as:

$$\text{Crash Rate} = \frac{\text{Total Number of Crashes}}{\text{Exposure}} \tag{3-2}$$

where the 'Exposure' is usually calculated in million vehicle miles (MVM) of travel, as indicated in Equation 3-3:

$$\text{Exposure} = \frac{\text{Project Section Length in Miles} \times \text{Mean ADT} \times \text{Number of Years} \times 365\ \text{Days}}{1{,}000{,}000} \tag{3-3}$$

Each crash record would typically include the corresponding average daily traffic (ADT). For each site, the mean ADT can be computed by Equation 3-4:

$$\text{Mean ADT} = \frac{\text{Summation of Individual ADTs Associated with each Crash}}{\text{Total Number of Crashes}} \tag{3-4}$$

3.1.2 Before-After with Comparison Group

To account for the influence of a variety of external causal factors that change with time, the before-after with comparison group study can be adopted. A comparison group is a group of control sites that remained untreated and that are similar to the treated sites in trend of crash history, traffic, geometric, and geographic characteristics. The crash data at the comparison group are used to estimate the crashes that would have occurred at the treated entities in the 'after' period had treatment not been applied. This method can provide more accurate estimates of the safety effect than a naïve before-after study, particularly, if the similarity between treated and comparison sites is high. The before-after with comparison group method is based on two main assumptions (Hauer, 1997):

1. The factors that affect safety have changed in the same manner from the 'before' period to 'after' period in both treatment and comparison groups, and

2. These changes in the various factors affect the safety of treatment and comparison groups in the same way.

Based on these assumptions, it can be assumed that the change in the number of crashes from the 'before' period to 'after' period at the treated sites, in case of no countermeasures had been implemented, would have been in the same proportion as that for the comparison group. Accordingly, the expected number of crashes for the treated sites that would have occurred in the 'after' period had no improvement applied ($N_{expected, T,A}$) follows (Hauer, 1997):

$$N_{expected,T,A} = N_{observed,T,B} \times \frac{N_{observed,C,A}}{N_{observed,C,B}} \quad (3\text{-}5)$$

If the similarity between the comparison and the treated sites in the yearly crash trends is ideal, the variance of $N_{expected,\ T,A}$ can be estimated from Equation 3-6:

$$Var(N_{expected,T,A}) = N_{expected,T,B}{}^{2}(1/N_{observed,T,B} + 1/N_{observed,C,B} + 1/N_{observed,C,A}) \quad (3\text{-}6)$$

It should be noted that a more precise estimate can be obtained in case of using non-ideal comparison group as explained in Hauer (1997), Equation 3-7:

$$Var(N_{expected,T,A}) = N_{expected,T,B}{}^{2}(1/N_{observed,T,B} + 1/N_{observed,C,B} + 1/N_{observed,C,A} + Var(\omega)) \quad (3\text{-}7)$$

$$\omega = \frac{r_c}{r_t} \quad (3\text{-}8)$$

where $$r_c \cong \frac{N_{expected,c,A}}{N_{expected,c,B}} \quad (3\text{-}9)$$

and $$r_t \cong \frac{N_{expected,t,A}}{N_{expected,t,B}} \quad (3\text{-}10)$$

The CMF and its variance can be estimated from Equations 3-11 and 3-12.

$$CMF = (N_{observed,T,A}/N_{expected,T,A})/(1 + (Var(N_{expected,T,A})/N_{expected,T,A}{}^{2})) \quad (3\text{-}11)$$

$$Var(CMF) = \frac{CMF^{2}[(1/N_{observed,T,A}) + ((Var(N_{expected,T,A})/N_{expected,T,A}{}^{2})]}{[1 + (Var(N_{expected,T,A})/N_{expected,T,A}{}^{2}]^{2}} \quad (3\text{-}12)$$

where,

$N_{observed,T,B}$= the observed number of crashes in the before period for the treatment group;

$N_{observed,T,A}$= the observed number of crashes in the after period for the treatment group;

$N_{observed,C,B}$= the observed number of crashes in the before period in the comparison group;

$N_{observed,C,A}$= the observed number of crashes in the after period in the comparison group;

ω = the ratio of the expected number of crashes in the 'before' and 'after' for the treatment and the comparison group;

r_c = the ratio of the expected crash count for the comparison group;

r_t = the ratio of the expected crash count for the treatment group.

There are two types of comparison groups with respect to the matching ratio; 1) the before-after study with yoked comparison which involves a one-to-one matching between a treatment site and a comparison site, and 2) a group of matching sites that are few times larger than treatment sites. The size of a comparison group in the second type should be at least five times larger than the treatment sites as suggested by Pendleton (1991). Selecting matching comparison group with similar yearly trend of crash frequencies in the 'before' period could be a daunting task. In this study a matching of at least 4:1 comparison group to treatment sites was conducted. Identical length of three years of the before and after periods for the treatment and the comparison group was selected.

3.1.3 Before-After with Empirical Bayes

In the before-after with empirical Bayes method, the expected crash frequencies at the treatment sites in the 'after' period had the countermeasures not been implemented is estimated more precisely using data from the crash history of a treated site, as well as the information of what is known about the safety of reference sites with similar yearly traffic trend, physical characteristics, and land use. The method is based on three fundamental assumptions (Hauer, 1997):

1. The number of crashes at any site follows a Poisson distribution.
2. The means for a population of systems can be approximated by a Gamma distribution.
3. Changes from year to year from sundry factors are similar for all reference sites.

Figure 3-1 illustrates the conceptual approach used in the EB method (Harwood et al., 2003).

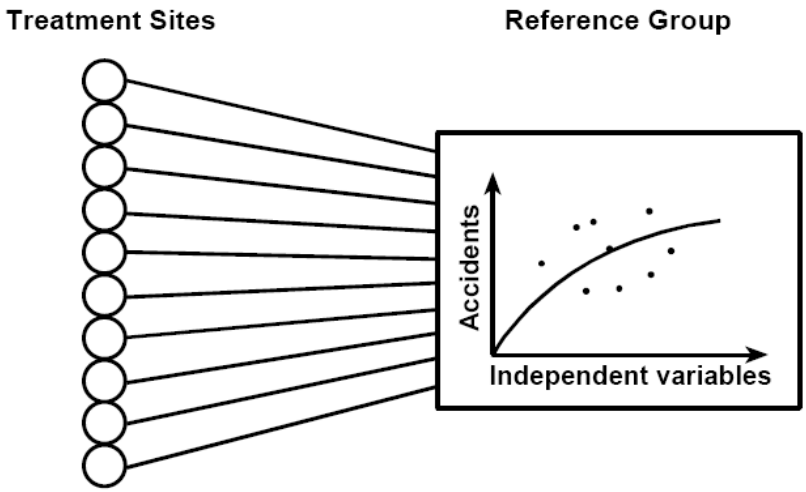


Figure 3-1: Conceptual Approachof the Empirical Bayesian Method
(Source: Harwood et al., 2003)

One of the main advantages of the before-after study with empirical Bayes is that it accurately accounts for changes in crash frequencies in the 'before' and in the 'after' periods at the treatment sites that may be due to regression-to-the-mean bias. It is also a better approach than the comparison group for accounting for influences of traffic volumes and time trends on safety. The estimate of the expected crashes at treatment sites is based on a weighted average of information from treatment and reference sites as given in (Hauer, 1997):

$$\hat{E}_i = (\gamma_i \times y_i \times n) + (1 - \gamma_i)\eta_i \qquad (3\text{-}13)$$

where γ_i is a weight factor estimated from the over-dispersion parameter of the negative binomial regression relationship and the expected 'before' period crash frequency for the treatment site as shown in Equation 3-14:

$$\gamma_i = \frac{1}{1 + k \times y_i \times n} \tag{3-14}$$

where,

y_i= Number of average expected crashes of given type per year estimated from the SPF (represents the 'evidence' from the reference sites).

η_i = Observed number of crashes at the treatment site during the 'before' period

n = Number of years in the before period,

k = Over-dispersion parameter

The 'evidence' from the reference sites is obtained as output from the SPF. SPF is a regression model which provides an estimate of crash occurrences on a given roadway section. Crash frequency on a roadway section may be estimated using negative binomial regression models (Abdel-Aty and Radwan, 2000; Persaud, 1990), and therefore it is the form of the SPFs for negative binomial model is used to fit the before period crash data of the reference sites with their geometric and traffic parameters. A typical SPF will be of the following form:

$$y_i = e^{(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n)} \tag{3-15}$$

where,

β_i*'s* = Regression Parameters;

x_1, x_2= logarithmic values of AADT and section length, respectively;

x_i*'s*(i> 2) = Other traffic and geometric parameters of interest.

Over-dispersion parameter, denoted by k is the parameter which determines how widely the crash frequencies are dispersed around the mean. The standard deviation (σ_i) for the estimate in Equation 3-16 is given by:

$$\hat{\sigma}_i = \sqrt{(1-\gamma_i)\times \hat{E}_i} \tag{3-16}$$

It should be noted that the estimates obtained from equation 3-16 are the estimates for number of crashes in the before period. Since, it is required to get the estimated number of crashes at the treatment site in the after period; the estimates obtained from Equation 3-16 are adjusted for traffic volume changes and different before and after periods (Hauer, 1997; Noyce et al., 2006). The adjustment factors are given as below:

$$\rho_{AADT} = \frac{AADT_{after}^{\alpha_1}}{AADT_{before}^{\alpha_1}} \tag{3-17}$$

where,

ρ_{AADT} = adjustment factor for AADT;

$AADT_{after}$ = AADT in the after period at the treatment site;

$AADT_{before}$ = AADT in the before period at the treatment site;

α_1 = regression coefficient of AADT from the SPF.

$$\rho_{time} = \frac{m}{n} \tag{3-18}$$

where,

ρ_{time} = Adjustment factor for different before-after periods;

m = Number of years in the after period;

n = Number of years in the before period.

Final estimated number of crashes at the treatment location in the after period ($\hat{\pi}_i$) after adjusting for traffic volume changes and different time periods is given by:

$$\hat{\pi}_i = \hat{E}_i \times \rho_{AADT} \times \rho_{time} \tag{3-19}$$

The index of effectiveness (θ_i) of the treatment is given by:

$$\hat{\theta}_i = \frac{\hat{\lambda}_i / \hat{\pi}_i}{1 + \left(\hat{\sigma}_i^{\,2} \Big/ \hat{\pi}_i^{\,2} \right)} \tag{3-20}$$

where,

$\hat{\lambda}_i$ = Observed number of crashes at the treatment site during the after period.

The percentage reduction (τ_i) in crashes of particular type at each site i is given by:

$$\hat{\tau}_i = (1 - \hat{\theta}_i) \times 100\% \tag{3-21}$$

The Crash Reduction Factor or the safety effectiveness ($\hat{\theta}$)of the treatment averaged over all sites would be given by (Persaud et al., 2004):

$$\hat{\theta} = \frac{\sum_{i=1}^{m} \hat{\lambda}_i \Big/ \sum_{i=1}^{m} \hat{\pi}_i}{1 + \left(\operatorname{var}(\sum_{i=1}^{m} \hat{\pi}_i) \Big/ (\sum_{i=1}^{m} \hat{\pi}_i)^2 \right)} \quad (3\text{-}22)$$

where

m = total number of treated sites;

$$\operatorname{var}(\sum_{i=1}^{k} \hat{\pi}_i) = \sum_{i=1}^{k} \rho_{AADT}{}^2 \times \rho_{time}{}^2 \times \operatorname{var}(\hat{E}_i) \quad \text{(Hauer, 1997)} \quad (3\text{-}23)$$

The standard deviation ($\hat{\sigma}$) of the overall effectiveness can be estimated using information on the variance of the estimated and observed crashes, which is given by Equation 3-24.

$$\hat{\sigma} = \sqrt{\frac{\theta^2 \left[\left(\operatorname{var}(\sum_{i=1}^{k} \hat{\pi}_i) \Big/ (\sum_{i=1}^{k} \hat{\pi}_i)^2 \right) + \left(\operatorname{var}(\sum_{i=1}^{k} \hat{\lambda}_i) \Big/ (\sum_{i=1}^{k} \hat{\lambda}_i)^2 \right) \right]}{\left[1 + \left(\operatorname{var}(\sum_{i=1}^{k} \hat{\pi}_i) \Big/ (\sum_{i=1}^{k} \hat{\pi}_i)^2 \right) \right]^2}} \quad (3\text{-}24)$$

where, $\operatorname{var}(\sum_{i=1}^{k} \hat{\lambda}_i) = \sum_{i=1}^{k} \lambda_i$ (Hauer, 1997) (3-25)

Equation 3-25 is used in the analysis to estimate the expected number of crashes in the after period at the treatment sites, and then the values are compared with the observed number of crashes at the treatment sites in the after period to get the percentage reduction in number of crashes resulting from the treatment.

3.1.4 Safety Performance Functions (SPFs)

Data from the untreated reference group are used to first estimate a safety performance function (SPF) that relates crash frequency of the sites to their traffic and geometrical characteristics. Generally, a safety performance function (SPF) is a crash prediction model, which relates the frequency of crashes to traffic (e.g., annual average daily traffic) and the roadway characteristics (e.g., number of lanes, width of lanes, width of shoulder, etc.). There are two main types of SPFs in the literature: (1) full SPFs and (2) simple SPFs. Full SPF is a mathematical relationship that relates both traffic parameters and geometric parameters as explanatory variables, whereas simple SPF includes annual average daily traffic (AADT) as the sole explanatory variable in predicting crash frequency on a roadway entity. It is worth mentioning that the calibrated CMFs in the HSM are based only on the simple 'SPF'.

As mentioned earlier, the weight in Equation 3-13 is calculated using the over-dispersion parameter obtained from the negative binomial (NB) model. In this project, simple and full SPFs will be developed for different roadway entities. Moreover, different SPFs will be estimated separately by land use (rural/urban) for various crash type and severity levels.

3.1.4.1 Negative Binomial Models

Crash data have a gamma-distributed mean for a population of systems, allowing the variance of the crash data to be more than its mean (Shen, 2007). Suppose that the count of crashes on a roadway section is Poisson distributed with a mean λ, which itself is a random variable and is gamma distributed, then the distribution of frequency of crashes in a population of roadway sections follows a negative binomial probability distribution (Hauer, 1997).

$y_i|\lambda_i \approx$ Poisson (λ_i)

$\lambda \approx$ Gamma (a,b)

Then, P(y_i) ≈ Negbin (λ_i, k)

$$= \frac{\Gamma(1/k + y_i)}{y_i!\,\Gamma(1/k)} \left(\frac{k\lambda_i}{1+k\lambda_i}\right)^{y_i} \left(\frac{1}{1+k\lambda_i}\right)^{1/k} \quad (3\text{-}26)$$

where,

y = number of crashes on a roadway section per period;

λ = expected number of crashes per period on the roadway section;

k= over-dispersion parameter.

The expected number of crashes on a given roadway section per period can be estimated by Equation 3-27.

$$\lambda = \exp(\beta^T X + \varepsilon) \quad (3\text{-}27)$$

where,

β = a vector of regression of parameter estimates;

X= a vector of explanatory variables;

exp(ε) = a gamma distributed error term with mean one and variance k.

Because of the error term the variance is not equal to the mean, and is given by Equation 3-28.

$$\text{var}(y) = \lambda + k\lambda^2 \qquad (3\text{-}28)$$

As $k \rightarrow 0$, the negative binomial distribution approaches Poisson distribution with mean λ. The parameter estimates of the binomial regression model and the dispersion parameter are estimated by maximizing the likelihood function given in Equation 3-29.

$$l(\beta, k) = \prod_i \frac{\Gamma\left(1/k + y_i\right)}{y_i!\,\Gamma\left(1/k\right)} \left(\frac{k\lambda_i}{1 + k\lambda_i}\right)^{y_i} \left(\frac{1}{1 + k\lambda_i}\right)^{1/k} \qquad (3\text{-}29)$$

Using the above methodology negative binomial regression models were developed and were used to estimate the number of crashes at the treated sites.

3.2 Cross-Sectional Studies

It should be noted that the CMF for certain treatments (e.g., median width) can only be estimated using the cross-sectional method, but not before-after method. This is because it is difficult to isolate the effect of the treatment from the effects of the other treatments applied at the same time using the before-after method (Harkey et al., 2008).

The method is used in the following conditions (AASHTO, 2010): 1) the date of the treatment installation is unknown, 2) the data for the period before treatment installation are not available, and 3) the effects of other factors on crash frequency must be controlled for creating a crash modification function (CMFunction).

The cross-sectional method requires the development of crash prediction models (i.e., SPFs) for calculation of CMFs. The models are developed using the crash data for both treated and untreated sites for the same time period (3-5 years). According to the HSM, 10~20 treated and 10~20 untreated sites are recommended. However, the cross-sectional method requires much more samples than the before-after study, say 100~1000 sites (Carter et al., 2012). Sufficient sample size is particularly important when many variables are included in the SPF. This ensures large variations in crash frequency and variables, and helps better understand their inter-relationships. The treated and untreated sites must have comparable geometric characteristics and traffic volume (AASHTO, 2010).

The research developed a generalized linear model (GLM) with a negative binomial distribution (NB) using these crash data as it is the most common type of function which accounts over-dispersion. The model describes crash frequency in a function of explanatory variables including geometric characteristics, AADT and length of roadway segments as follows:

$$F_i = \exp(\alpha + \beta_1 * \ln AADT_i + \beta_2 * Length_i + \cdots + \beta_k * x_{ki}) \tag{3-30}$$

where,

F_i = crash frequency on a road segment i;

$Length_i$= length of roadway segment i (mi);

$AADT_i$ = average annual daily traffic on a road segment i (veh/day);

x_{ki} = geometric characteristic k (i.e., treatment) of a road segment i (k> 2);

α = constant;

$\beta_1, \beta_2, \ldots, \beta_k$ = coefficient for the variable *k*.

In the above equation, length and AADT are control variables to identify the isolated effect of the treatment(s) on crash frequency. Since the above model form is log-linear, the CMFs can be calculated as the exponent of the coefficient associated with the treatment variable as follows (Lord and Bonneson, 2007; Stamatiadis et al., 2009; Carter et al., 2012):

$$CMF = \exp(\beta_k * (x_{kt} - x_{kb})) = \exp(\beta_k) \tag{3-31}$$

where,

x_{kt}= geometric characteristic *k* of treated sites;

x_{kb}= geometric characteristic *k* of untreated sites (baseline condition).

The above model can be applied to prediction of total crash frequency or frequency of specific crash type or crash severity. The standard error (SE) of the CMF is calculated as follows (Bahar, 2010):

$$SE = \frac{\exp(\beta_k * (x_{kt} - x_{kb}) + SE_{\beta_k}) - \exp(\beta_k * (x_{kt} - x_{kb}) - SE_{\beta_k})}{2} \tag{3-32}$$

where,

SE = standard error of the CMF;

$SE_{\beta k}$ = standard error of the coefficient β_k.

CHAPTER 4. DATA COLLECTION

The data were collected from multiple sources maintained by FDOT to identify locations with treatments/upgrades for different categories of roadway segments, intersections, and special facilities. The data include Financial Management (FM) Database, Transtat I-view aerial mapping system, video log viewer, the Roadway Characteristic Inventory (RCI), as-built plans, and Straight Line Diagrams (SLD). Each data source is described in detail in Section 4.1.

4.1 Description of Data

4.1.1 Financial Management Database

Road facility construction projects are recorded in the FM database. The database offers a search system named "Financial Project Search" as shown in Figure 4-1.Through this system, specific financial project and its relevant information can be identified. Also, the system provides a function to search financial projects by various conditions such as district, status, work types and year. The information provided in the FM database was too general in which other data sources have to be utilized to collect more information about the treated sites.

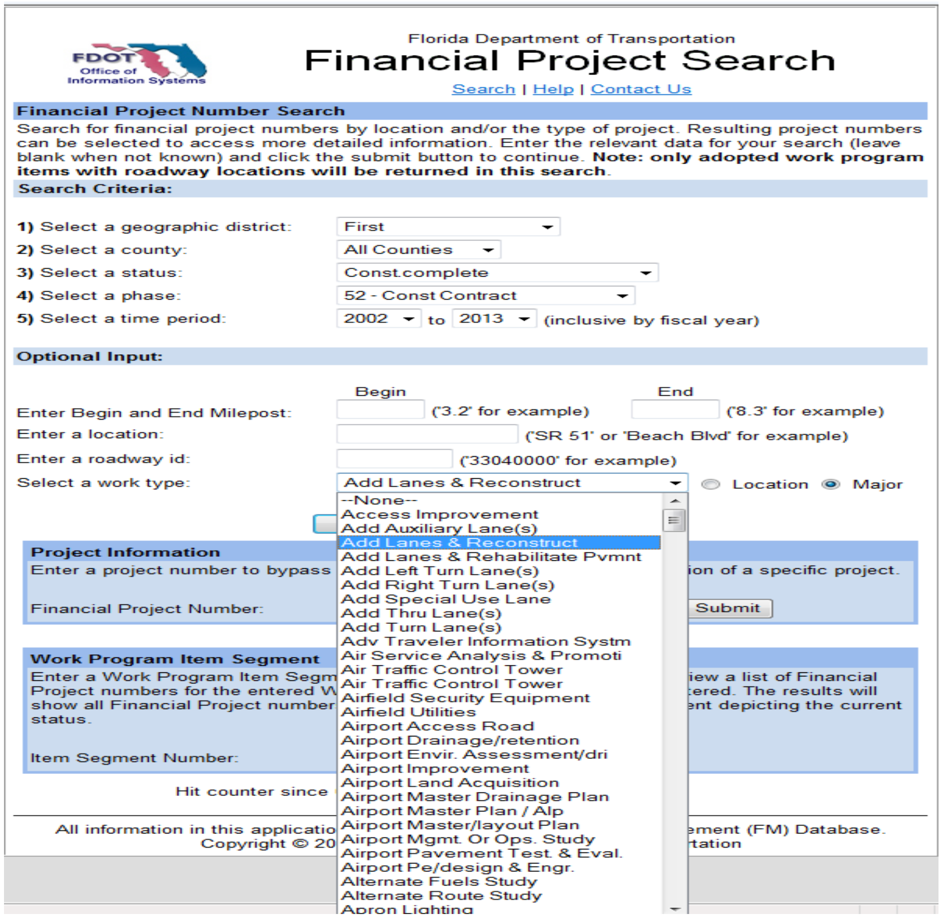


Figure 4-1: Financial Project Search from the Financial Management Database

4.1.2 Transtat I-view Aerial Mapping System

Transtat I-view is a Geographical Database System provided by FDOT Transtat Department. The system was used to verify information collected from the FM. Figure 4-2 shows a location with beginning and end mileposts for an identified project in the FM.

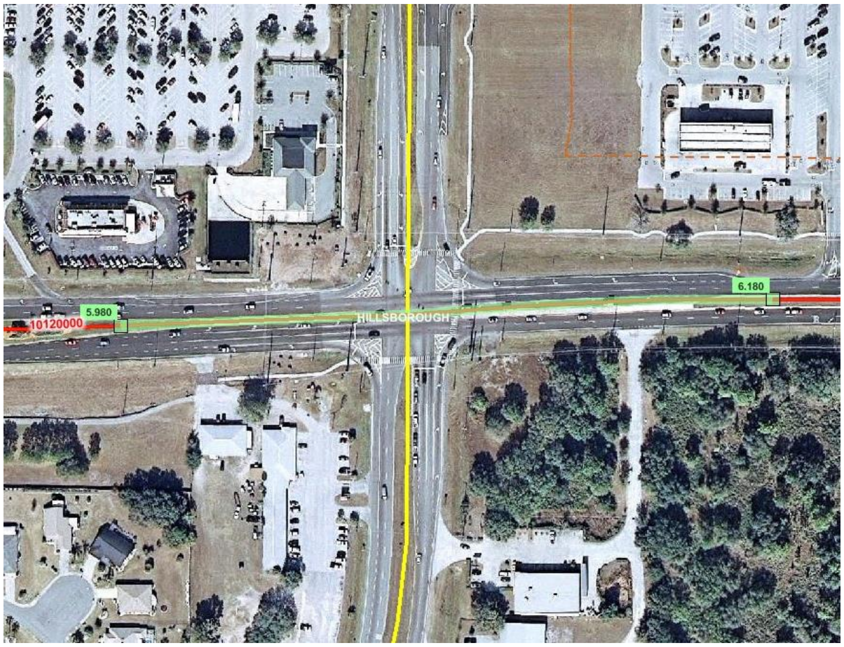


Figure 4-2: Example of Transtat I-view Map

Although that the treated site can be specified in the Transtat I-view, it does not provide detailed historical geometry of the site. Therefore, Google Earth was used as an additional source to verify data collected from the FM. Google Earth provides historical satellite imagery layers for different years. This feature enabled us to compare the before and after geometrical characteristics more precisely. Although that Google Earth provided valuable information and helped to identify various problems in the FM database, this process could be extremely tedious and time consuming.

4.1.3 Video Log Viewer Application

Video Log Viewer Application was also used to check the validity and accuracy of the collected data. Figure 4-3 shows a screenshot of the results of one of the treated sites.

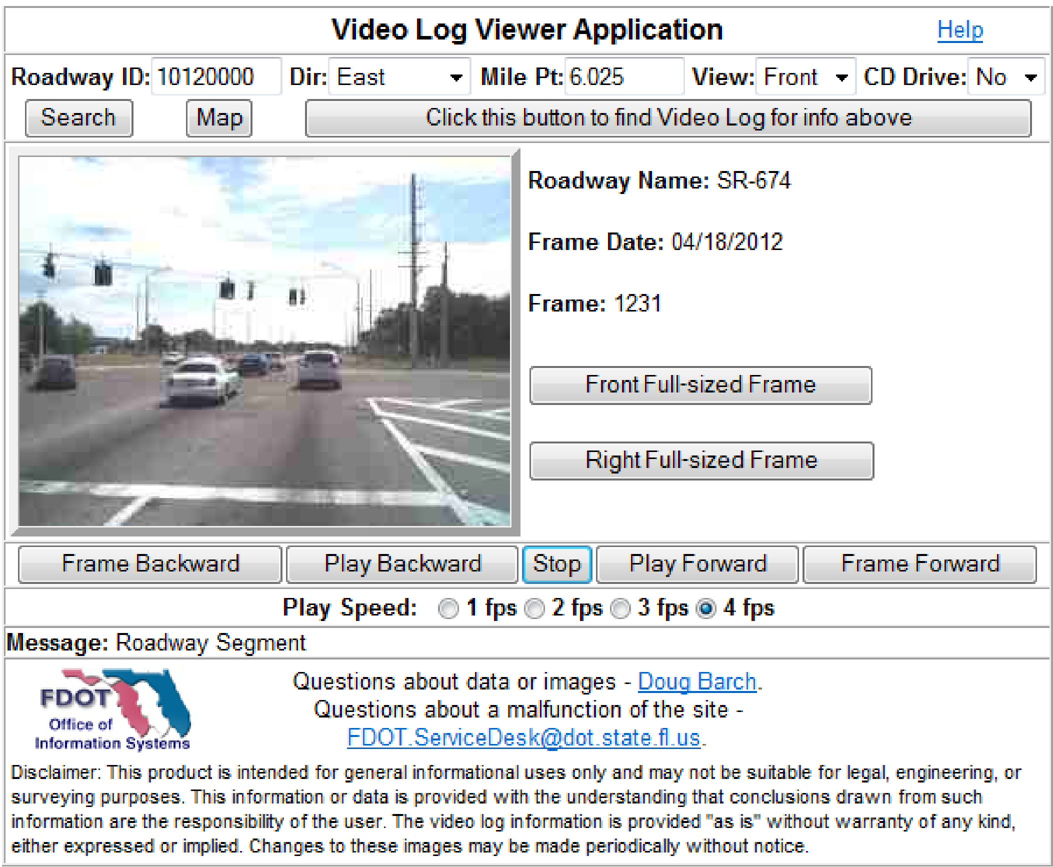
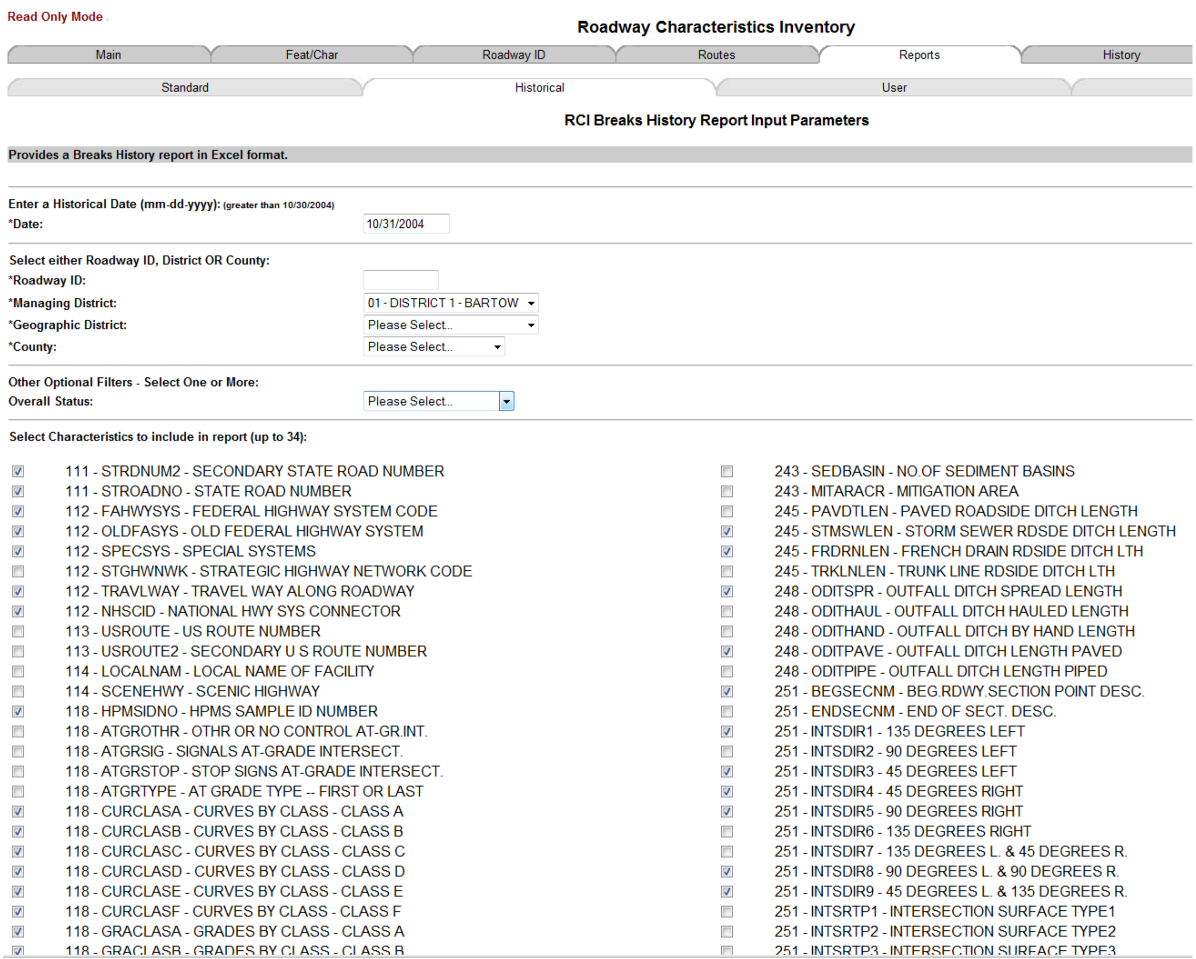


Figure 4-3: Screenshot from Video Log Viewer Application

4.1.4 Roadway Characteristics Inventory (RCI)

The Roadway Characteristics Inventory (RCI) is mainly used to identify the type of road configuration, geometrics of roadway segments and intersections, e.g., overall surface lane width, number of lanes, shoulder type and width, median width, maximum speed limit and other roadway and traffic characteristics.


Read Only Mode

Roadway Characteristics Inventory

Main | Feat/Char | Roadway ID | Routes | Reports | History

Standard | Historical | User

RCI Breaks History Report Input Parameters

Provides a Breaks History report in Excel format.

Enter a Historical Date (mm-dd-yyyy): (greater than 10/30/2004)
*Date: 10/31/2004

Select either Roadway ID, District OR County:
*Roadway ID:
*Managing District: 01 - DISTRICT 1 - BARTOW
*Geographic District: Please Select..
*County: Please Select..

Other Optional Filters - Select One or More:
Overall Status: Please Select..

Select Characteristics to include in report (up to 34):

- [x] 111 - STRDNUM2 - SECONDARY STATE ROAD NUMBER
- [x] 111 - STROADNO - STATE ROAD NUMBER
- [x] 112 - FAHWYSYS - FEDERAL HIGHWAY SYSTEM CODE
- [x] 112 - OLDFASYS - OLD FEDERAL HIGHWAY SYSTEM
- [x] 112 - SPECSYS - SPECIAL SYSTEMS
- [ ] 112 - STGHWNWK - STRATEGIC HIGHWAY NETWORK CODE
- [x] 112 - TRAVLWAY - TRAVEL WAY ALONG ROADWAY
- [x] 112 - NHSCID - NATIONAL HWY SYS CONNECTOR
- [ ] 113 - USROUTE - US ROUTE NUMBER
- [ ] 113 - USROUTE2 - SECONDARY U S ROUTE NUMBER
- [ ] 114 - LOCALNAM - LOCAL NAME OF FACILITY
- [ ] 114 - SCENEHWY - SCENIC HIGHWAY
- [x] 118 - HPMSIDNO - HPMS SAMPLE ID NUMBER
- [ ] 118 - ATGROTHR - OTHR OR NO CONTROL AT-GR.INT.
- [ ] 118 - ATGRSIG - SIGNALS AT-GRADE INTERSECT.
- [ ] 118 - ATGRSTOP - STOP SIGNS AT-GRADE INTERSECT.
- [ ] 118 - ATGRTYPE - AT GRADE TYPE -- FIRST OR LAST
- [x] 118 - CURCLASA - CURVES BY CLASS - CLASS A
- [x] 118 - CURCLASB - CURVES BY CLASS - CLASS B
- [x] 118 - CURCLASC - CURVES BY CLASS - CLASS C
- [x] 118 - CURCLASD - CURVES BY CLASS - CLASS D
- [x] 118 - CURCLASE - CURVES BY CLASS - CLASS E
- [x] 118 - CURCLASF - CURVES BY CLASS - CLASS F
- [x] 118 - GRACLASA - GRADES BY CLASS - CLASS A
- [x] 118 - GRACLASB - GRADES BY CLASS - CLASS B
- [ ] 243 - SEDBASIN - NO.OF SEDIMENT BASINS
- [ ] 243 - MITARACR - MITIGATION AREA
- [ ] 245 - PAVDTLEN - PAVED ROADSIDE DITCH LENGTH
- [x] 245 - STMSWLEN - STORM SEWER RDSDE DITCH LENGTH
- [x] 245 - FRDRNLEN - FRENCH DRAIN RDSIDE DITCH LTH
- [ ] 245 - TRKLNLEN - TRUNK LINE RDSIDE DITCH LTH
- [x] 248 - ODITSPR - OUTFALL DITCH SPREAD LENGTH
- [ ] 248 - ODITHAUL - OUTFALL DITCH HAULED LENGTH
- [ ] 248 - ODITHAND - OUTFALL DITCH BY HAND LENGTH
- [x] 248 - ODITPAVE - OUTFALL DITCH LENGTH PAVED
- [ ] 248 - ODITPIPE - OUTFALL DITCH LENGTH PIPED
- [x] 251 - BEGSECNM - BEG.RDWY.SECTION POINT DESC.
- [ ] 251 - ENDSECNM - END OF SECT. DESC.
- [x] 251 - INTSDIR1 - 135 DEGREES LEFT
- [ ] 251 - INTSDIR2 - 90 DEGREES LEFT
- [x] 251 - INTSDIR3 - 45 DEGREES LEFT
- [x] 251 - INTSDIR4 - 45 DEGREES RIGHT
- [x] 251 - INTSDIR5 - 90 DEGREES RIGHT
- [ ] 251 - INTSDIR6 - 135 DEGREES RIGHT
- [ ] 251 - INTSDIR7 - 135 DEGREES L. & 45 DEGREES R.
- [x] 251 - INTSDIR8 - 90 DEGREES L. & 90 DEGREES R.
- [x] 251 - INTSDIR9 - 45 DEGREES L. & 135 DEGREES R.
- [ ] 251 - INTSRTP1 - INTERSECTION SURFACE TYPE1
- [ ] 251 - INTSRTP2 - INTERSECTION SURFACE TYPE2
- [ ] 251 - INTSRTP3 - INTERSECTION SURFACE TYPE3

Figure 4-4: Screenshot of Historical RCI Query List

The research team identified the implemented treatments in the RCI to verify the data collected from the FM. It should be noted that RCI provides data only starting from 2004, and hence the identified treatment projects from 2000 to 2003 cannot be verified from RCI. Table 4-1 lists the 49 major variables related to crash frequency.

Table 4-1: List of Variables in the Road Characteristics Inventory Data

Variable	Variable Name	Description
111	STROADNO	State Road Number
113	USROUTE	US Route Number
118	TURNLANL	Turn Lane Left
118	GRACLASA	Grade by Class
118	GRACLASB	Grade by Class
118	GRACLASC	Grade by Class
118	GRACLASD	Grade by Class
118	GRACLASE	Grade by Class
118	GRACLASF	Grade by Class
118	TURNLANR	Turn Lane Right
118	TYPEOP	Type of Operation
120	TYPEROAD	Type of Road
121	FUNCLASS	Functional Classification
122	RDACCESS	Access Control Type
212	NOLANES	Number of Roadway Lanes
212	SURWIDTH	Total Through Lanes Surface Width
213	AUXLNTYP	Auxiliary Lane Type
213	AUXLWTH	Width of Auxiliary Lane
213	AUXNUM	Number of Auxiliary Lanes
214	SHLDTYPE 3	Highway Shoulder Type
214	SHLDTYPE	Highway Shoulder Type
214	SHLDTYPE 2	Highway Shoulder Type
214	SLDWIDTH	Highway Shoulder Width
214	SLDWIDTH 2	Highway Shoulder Width
214	SLDWIDTH 3	Highway Shoulder Width
215	MDBARTYP	Type of Median
215	MEDWIDTH	Highway Median Width
215	RDMEDIAN	Highway Median Type
216	BIKELNCD	Bicycle Lane

Table 4-1: List of Variables in the Road Characteristics Inventory Data (Continued)

Variable	Variable Name	Description
219	ISLDTYPE	Inside Shoulder Type
219	ISLDTYPE 2	Inside Shoulder Type
219	ISLDTYPE 3	Inside Shoulder Type
219	ISLDWDTH	Inside Shoulder Width
219	ISLDWDTH 2	Inside Shoulder Width
219	ISLDWDTH 3	Inside Shoulder Width
221	HRZCANGL	Horizontal Curve Central Angle
221	HRZDGCRV	Horizontal Degree of Curve
311	MAXSPEED	Maximum Speed Limit
313	DTEPKIMP	DTE Parking Restriction Implement
331	SECTADT	Section Average AADT
453	CRWALK24	No. of 24-ft Crosswalks
453	CRWALK36	No. of 36-ft Crosswalks
453	CRWALK48	No. of 48-ft Crosswalks
453	CRWALK60	No. of 60-ft Crosswalks
453	CRWALK72	No. of 72-ft Crosswalks
455	PAVTMARK	Number of raised pavement markers
456	CL	Centerline
456	EL	Edge Line
457	FINPROJ	Financial Project No.

4.2 Data Collection for Roadway Segments

In this study, each roadway segment has uniform geometric characteristics within the road section. A segment is represented by roadway ID, and beginning and end mile points. But segments do not necessarily have equal length. Each roadway consists of one or more segments with the same roadway IDs.

4.2.1 Adding a Through Lane

Table 4-2 presents an overall summary for a*dding a through lane*, urban (U) or rural (R), from 2 to 4 and from 4 to 6 lanes. The total identified a*dding a through lane* lengths are about 106.345 miles.

Table 4-2: Treated and Comparison Groups for *Adding a Through Lane*

Roadway Types	Treated Group				Comparison Group		
	Total Length (mile)	Number of Projects (RD_IDs)	Number of Segments	Average Length of Segments (mile)	Total Length (mile)	Number of Segments	Average Length of Segments (mile)
U2 to U4	8.578	10	41	0.209	67.814	381	0.178
U4 to U6	53.561	25	164	0.327	365.913	1015	0.361
R2 to R4	32.808	5	43	0.763	230.331	370	0.623
R4 to R6	11.398	3	28	0.407	91.213	32	2.85
Total	106.345	43	276	0.385	755.271	1798	0.420

4.2.2 RCI Data Collection for Installing Shoulder Rumble Strips

RCI data from 2007 to 2010 for the whole state were used for finding s*houlder rumble strips* (SRS) projects and comparison group data. The RCI data were compared for multiple years for same locations to check whether there was s*houlder rumble strips* treatment or not. Transtat I-view and Google Earth were used to validate the RCI data. Table 4-3 presents the overall summary of data collection for installation of s*houlder rumble strips* projects, and Figure 4-5 shows the types of shoulder in the RCI data. Shoulder type 1 means 'paved with or without hatching (including paved parking and bike slots)', type 2 is 'paved with warning device (raised or indented strips)', and type 3 represents 'lawn (number of feet to support road bed)'.

Table 4-3: Numbers and Length of Road Segments for Evaluating Safety Effectiveness of *Adding Shoulder Rumble Strips*

Type of Road	SRS Types	Number of RD_IDs	Number of Segments	Total Length (mile)
Two-lane (No median)	1 to 2	31	74	60.54
	3 to 2	6	15	25.679
Multilane Divided (Median exists)	1 to 2	28	78	32.427
Total		65	167	118.646

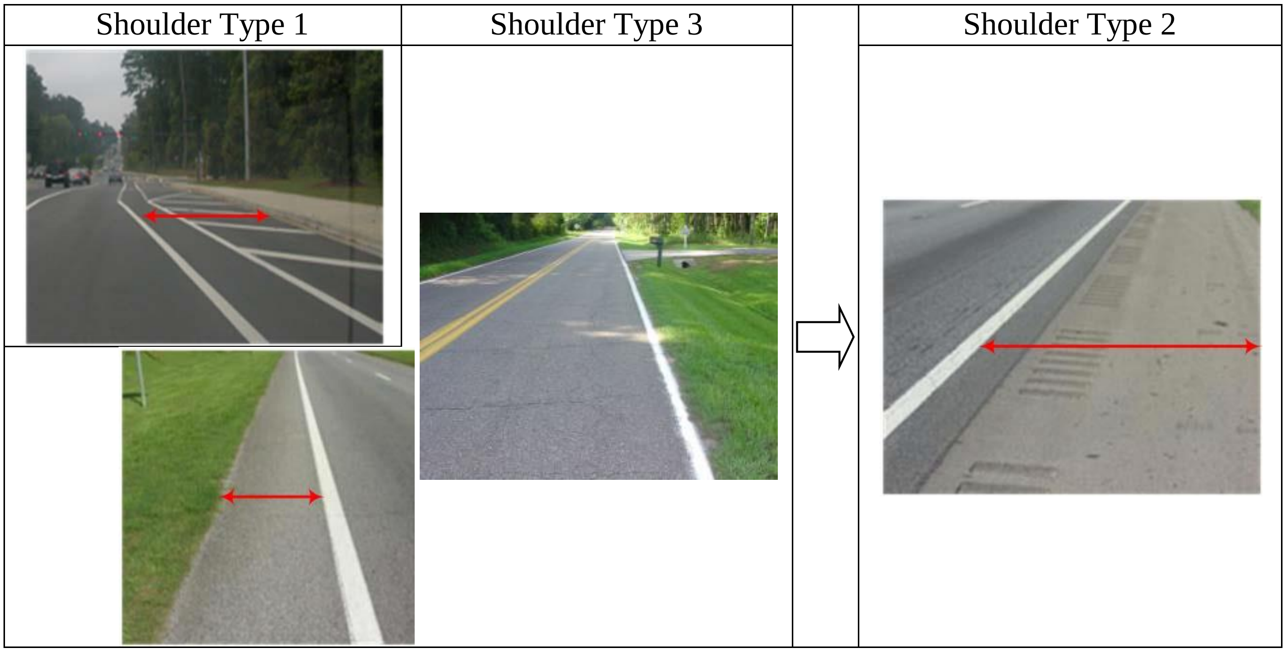


Figure 4-5: Identification of Intersection Locations

Different RCI characteristics were selected for each type of roads which are two-lane and multilane roadways. For two-lane undivided roadway, milepost, type of road, functional class, number of lane, shoulder width, shoulder type, surface width, maximum speed limit, and section ADT were chosen. Moreover, inside shoulder width, inside shoulder type, median width, and median type were added for multilane divided roadway. Since each RCI characteristic could be considered as a treatment, the research team tried to find combination of treatments including installation of *shoulder rumble strips*. Thirty-five combinations of treatments were found from RCI data and due to the sample size limitation, only 5 combinations are selected for analysis as shown in Table 4-4.

Table 4-4: Selected Combination of Treatments

Case No.	Category	Types	No. of segments	Total length (mi)
1	Undivided / 1 to 2	rumble strip only	56	47.942
2	Undivided / 1 to 2	rumble strip + narrow surface width	3	7.204
3	Undivided / 3 to 2	rumble strip + narrow shoulder width	12	24.82
4	Divided / 1 to 2	rumble strip only	23	9.528
5	Divided / 1 to 2	rumble strip + widen shoulder width + widen surface width + narrow median width + adding a thru lane + widen inside shoulder width	5	6.702
		Total	99	96.196

In order to evaluate CMF using before-after studies, it is needed to collect comparison group for each site. Comparison group data was collected from RCI data for case 1, which is 'two-lane undivided roadway and type 1 to 2' case. Table 4-5 presents data description of Case 1.

Table 4-5: Data Description of 'Two-lane Undivided Roadway and Type 1 to 2' Case

	Treated Group		ComparisonGroup	
Setting	Number of segments	Total length (mi)	Number of segments	Total length (mi)
Rural	48	43.451	126	162.990
Urban	8	4.491	36	17.449
Total	56	47.942	162	180.439

Due to crash data availability and consistency between the before and after periods, 2 years crash data before treatment and 2 years crash data after treatment were matched. Moreover, crash severity and crash type information were included in this crash data. Tables 4-6 ~ 4-9 present All crash type (all severity) & (fatal + injury), and single vehicle run-off-road (SVROR) (all severity) & (fatal + injury) of 'two-lane undivided roadway and type 1 to 2' case.

Table 4-6: All Crash Type (All Severities) Crash Counts of 'Two-lane Undivided Roadway and Type 1 to 2' Case

Setting	Treated Group		Comparison Group	
	Before Crashes	After Crashes	Before Crashes	After Crashes
Rural	100	73	253	261
Urban	14	7	64	49
Total	114	80	317	310

Table 4-7: All Crash Types (Fatal +Injury) Crash Counts of 'Two-lane Undivided Roadway and Type 1 to 2' Case

Setting	Treated group		Comparison group	
	Before Crash	After Crash	Before Crash	After Crash
Total	82	51	211	161
Rural	73	46	164	137
Urban	9	5	47	24

Table 4-8: Single Vehicle Run-Off -Road (all severity) Crash Counts of 'Two-lane Undivided Roadway and Type 1 to 2' case

Setting	Treated group		Comparison group	
	Before Crash	After Crash	Before Crash	After Crash
Total	25	12	67	52
Rural	23	12	56	43
Urban	2	0	11	9

Table 4-9: Single Vehicle Run Off Road (Fatal +Injury) Crash Counts of 'Two-lane Undivided Roadway and Type 1 to 2' case

Setting	Treated group		Comparison group	
	Before Crash	After Crash	Before Crash	After Crash
Total	18	9	50	36
Rural	17	9	40	30
Urban	1	0	10	6

4.2.3 Shoulder Rumble Strips, Widening Shoulder Width, Shoulder Rumble Strips + Widening Shoulder Width on Rural Multilane Highways

The six-year (2005-2010) RCI data of Florida were used for identifying 3 treatments, s*houlder rumble strips, widening shoulder width*, and s*houlder rumble strips + widening shoulder width*. The same data were also used to identify comparison sites. The RCI dataset were validated using Transtat I-view and Google Earth. Table 4-10 presents the summary of data collection for installation of s*houlder rumble strips,* w*idening shoulder width*, and s*houlder rumble strips + widening shoulder width* projects. Comparison group data were also collected using the RCI data based on roadway characteristics of the treated group such as functional class, type of road, number of lanes, section ADT, median width, median type, shoulder width, shoulder type, maximum speed limit, and lane width. The total lengths of treated sites for s*houlder rumble strips*, w*idening shoulder width*, and s*houlder rumble strips* + *widening shoulder width* are 38.684, 102.071, and 39.967 miles, respectively. The total lengths of comparison groups for the 3 treatments are 160.621, 361.079, and 177.392 miles, respectively.

Table 4-10: Treated and Comparison Groups for *Shoulder Rumble Strips, Widening Shoulder Width, and Shoulder Rumble Strips + Widening Shoulder Width*

	Treated Group			Comparison Group	
Combination of treatments	Number of Sites	Number of Segments	Length(mile)	Number of Segments	Length(mile)
Shoulder Rumble Strip	27	60	38.684	115	160.621
Widening Shoulder Width	30	75	102.071	367	361.079
Rumble + Widening Shoulder Width	30	122	39.967	194	177.392
- AADT: 2,000 to 50,000veh/day - Widening Shoulder Width (0.5 ~ 10 feet)					

Crash data for these treated and comparison groups during before and after periods were obtained from the CARS database. Considering availability of crash data and consistency between before and after period, the crash data were extracted from each site for 2-year before and after periods. The crash data include crash severity and crash type. Intersection-related crashes were excluded from the dataset based on the value of the variable 'SITELOCA' in the crash data.

4.2.4 Converting a TWLTL to a Raised Median

The two-year RCI data (2004 and 2012) for the whole state were used as a way to find the treated and comparison groups for this treatment. By matching the milepost for the two years, the sites where a TWLTL was converted to a raised median were identified as the treated group. The influence areas of the intersection were excluded using Transtat I-view, and Google Earth was used to validate the RCI data. Also, the beginning and end dates of construction were checked using Google Earth. The segments where median type (TWLTL) remains unchanged in the after period were identified as the comparison group if they have the same traffic volume and geometric characteristics as the treated segments. The RCI data for the comparison group were collected in the same way as the treated group. Table 4-11 presents the overall summary of data collection for converting a TWLTL to a raised median.

Table 4-11: Treated and Comparison Groups for *Converting a TWLTL to a Raised Median*

	No. of roadways	No. of segments	Length of segments (mi)
Treated Group	12	33	9.27
Comparison Group	28	109	30

Then, the RCI data were matched to the crash data for the treated and comparison sites. Table 4-12 presents the summary of crashes by severity levels (all, and fatal and injury (F+I)), and crash type (head-on) during the before and after periods for the treated and comparison groups.

Table 4-12: Numbers of Crashes for Treated and Comparison Sites (*Converting a TWLTL to a Raised Median*)

Crash/Severity Type	Treated Group		Comparison Group	
	Before Period	After Period	Before Period	After Period
All	1127	681	1967	2087
F+I	559	406	1215	1117
Head-on	43	13	63	71

4.2.5 Adding Lighting

The research team identified the sites where lighting treatments were implemented between 2006 and 2010 using Transtat I-view and Google Earth. Only roadway segments were also selected, and the influence areas of the intersection were excluded using Transtat I-view and Google Earth. The beginning and end dates of construction were checked again using Google Earth images' histories. Crash data for three years before (2003, 2004, and 2005) and two years after (2011 and 2012) the implementation of the lighting treatment were used to examine the safety impact of lighting. AADTs in 2004 and 2011 were used as average traffic volumes for the before and after periods, respectively, for the segments with missing AADT. In this study, nighttime crashes were defined as the crashes that occurred in dark conditions (LIGHTCND = 5) from the CARS database. It should be noted that data in the period six months before and after the implementation of the lighting treatments were excluded from the analysis. The data for the comparison and reference sites were also collected. Tables 4-13 and 4-14 present the overall summary of data collection for *adding lighting* for (1) all road types with all number of lanes and

(2) urban 4-lane/6-lane principal and minor arterials (the main roadway type where the lighting treatment was applied), respectively.

Table 4-13: Treated, Comparison and Reference Groups for *Adding Lighting* on All Road Types with All Number of Lanes

	No. of roadways	No. of segments	Length of segments (mi)
Treated sites	31	45	131.7
Comparison Group	31	45	132.4
Reference sites	95	230	683.6

Table 4-14: Treated, Comparison and Reference Groups for *Adding Lighting* on Urban 4-lane/6-lane Principal and Minor Arterials

	No. of roadways	No. of segments	Length of segments (mi)
Treated sites	22	33	70.2
Comparison Group	22	33	71.4
Reference sites	117	164	408.3

4.2.6 Adding a Raised Median and Increasing Median Width

The road geometry data and crash records for roadway segments were collected for 3 years (2010-2012) from the RCI and CARS databases, respectively. The data were collected from only the "divided" roadway segments where median type and median width have not been changed during the 3-year period. Annual average daily traffic volume (AADT) in 2011 was used as an average AADT in 2010-2012.

Presence of a raised median on a given roadway segment was determined based on the median type (RDMED) specified in RCI data. Raised medians include curb, guard rail, fence and concrete wall. Depressed median, canal, and ditch are classified as non-raised medians. For evaluation of safety effectiveness of a raised median, the data were collected from the following three road types specified in the HSM: 1) urban two-lane roads (one lane in each direction), 2) urban multi-lane roads, and 3) rural multi-lane roads. In this study, only non-intersection-related crashes were analyzed except urban two-lane roads where crashes at driveways were also analyzed. This is because a raised median can reduce left-turn crashes by restricting left-turns from driveways or access points on urban two-lane roads (Elvik and Vaa, 2004). Table 4-15 shows the total numbers and length of roadway segments with and without a raised median. As shown in the table, a majority of roadway segments do not have a raised median on urban two-lane road whereas more roadway segments have a raise median on urban/rural multi-lane roads due to higher traffic volume.

Table 4-15: Numbers and Length of Road Segments for Evaluating Safety Effectiveness of *Adding a Raised Median*

Road type	Raised median		Non-raised median		Total	
	No. of segments	Length (mi)	No. of segments	Length (mi)	No. of segments	Length (mi)
Urban two-lane road	15	4.18	101	41.64	116	45.82
Urban multi-lane	666	426.13	167	99.87	833	526.00
Rural multi-lane	301	168.00	117	98.90	418	266.90

For evaluation of safety effectiveness of *increasing median width*, the data were collected from the following five road types as specified in the HSM: 1) rural 4 lanes with full access control, 2) rural 4 lanes with partial or no access control, 3) urban 4 lanes with full access control, 4) urban 5 or more lanes with full access control, and 5) urban 4 lanes with partial or no access control. The number of lanes in these road types denotes the total number of lanes in both directions. Table 4-16 shows the total numbers and length of roadway segments with and without a raised median for 5 different road types. As shown in the table, a majority of roadway segments do not have a raised median except for rural 4 lanes with partial or no access control.

Table 4-16: Numbers and Length of Road Segments for Evaluating Safety Effectiveness of *Increasing Median Width*

Road type	Raised median		Non-raised median		Total	
	No. of segments	Length (mi)	No. of segments	Length (mi)	No. of segments	Length (mi)
Rural 4lanes with full access control	146	158.86	0	-	146	158.86
Rural 4lanes with partial or no access control	493	355.02	215	162.48	833	517.50
Urban 4lanes with full access control	110	103.33	0	-	110	103.33
Urban 5 or more lanes with full access control	143	123.65	0	-	143	123.65
Urban 4lanes with partial or no access control	989	656.55	22	12.53	1,011	669.08

4.2.7 Narrowing Lane Width

Similar to a*dding a raised median* and i*ncreasing median width*, 3-year (2010-2012) road geometry data and crash records for roadway segments were collected for evaluating safety effectiveness of *narrowing lane width*. The data were collected from both divided and undivided roadway segments where lane width has not been changed during the 3-year period.

The data were collected from the following three road types as specified in the HSM: 1) rural two-lane roadway segments (one lane in each direction); 2) undivided rural multi-lane roadway segments; and 3) divided rural multi-lane roadway segments. Tables 4-17 ~ 4-19 show the total numbers and length of roadway segments for rural two-lane and multi-lane roads. As suggested in the HSM, only single-vehicle run-off-the-road, head-on, and sideswipe crashes were analyzed since these crash types are closely related to lane width. As shown in the tables, a majority of roadway segments have lane width of 12 feet or more except for rural undivided multi-lane roads. There were very few roadway segments with lane width greater than 12 feet. It should be noted that average speed limit was the highest for lane width of 12 feet or more than narrower lane width except for rural undivided multi-lane roads as shown Table 4-20.

Table 4-17: Numbers and Length of Road Segments for Evaluating Safety Effectiveness of *Narrowing Lane Width*

Road type	Undivided		Divided		Total	
	No. of segments	Length (mi)	No. of segments	Length (mi)	No. of segments	Length (mi)
Rural two-lane	798	844.36	172	59.95	970	904.31
Rural multi-lane	41	17.95	415	262.72	456	280.67

Table 4-18: Numbers and Length of Road Segments for Evaluating Safety Effectiveness of *Narrowing Lane Width*

Road type	Undivided		Divided		Total	
	No. of segments	Length (mi)	No. of segments	Length (mi)	No. of segments	Length (mi)
Rural two-lane	798	844.36	172	59.95	970	904.31
Rural multi-lane	41	17.95	415	262.72	456	280.67

Table 4-19: Characteristics of Road Segments on Rural Two-Lane Roads

(a) Undivided

Lane Width	Number of segments	Number of crashes	Length (mi)	Average Speed Limit (mph)
9-ft or less	45	1	66.66	43.0
10-ft	131	8	130.26	38.2
11-ft	125	6	121.33	43.2
12-ft or more	497	232	526.11	47.5

(b) Divided

Lane Width	Number of segments	Number of crashes	Length (mi)	Average Speed Limit (mph)
9-ft or less	0	-	-	-
10-ft	1	0	0.25	30.0
11-ft	12	0	3.82	43.4
12-ft or more	159	22	55.88	48.0

Table 4-20: Characteristics of Road Segments on Rural Multi-Lane Roads

(a) Undivided

Lane Width	Number of segments	Number of crashes	Length (mi)	Average Speed Limit (mph)
9-ft or less	2	0	0.74	37.5
10-ft	7	1	2.96	37.1
11-ft	23	4	10.49	36.3
12-ft or more	9	1	3.76	36.7

(b) Divided

Lane Width	Number of segments	Number of crashes	Length (mi)	Average Speed Limit (mph)
9-ft or less	0	-	-	-
10-ft	21	9	12.57	41.4
11-ft	89	32	57.59	41.0
12-ft or more	305	637	192.56	49.5

4.2.8 Converting 4 to 3 Lanes and Narrowing Paved Right Shoulder Width

The three-year (2010-2012) roadway geometric characteristics data and crash records were collected from the RCI and CARS database, respectively. The RCI dataset were validated using Transtat I-view and Google Earth. The data were collected for urban undivided roadways and rural multilane roadways where roadway geometric conditions of each segment have not been changed during the 3-year period. The average of AADT in 2010-2012 was calculated and used as AADT of each segment.

Converting 4-lanes (2-lanes in each direction) to 3-Lanes (1-lane in each direction and TWLTL (two-way left-turn lane)) was determined based on the number of lanes (NOLANES) and median type (RDMED) in the RCI data. *Narrowing paved right shoulder width* was determined based on the shoulder type (SHLDTYPE) and shoulder width (SHLDWIDTH) in the

RCI data. For evaluation of safety effectiveness of different severity levels, all severities (KABCO) and injury crashes (KABC) were analyzed. Moreover, only non-intersection-related crashes were identified based on location of crash (SITELOCA) in the CARS data. Table 4-21 shows the numbers and length of roadway segments and total length of urban 4-lane undivided roadways and urban 3-lane roadways including TWLTL for c*onverting 4 to 3 lanes including TWLTL*. Table 4-22 presents the total numbers and length of road segments on rural multi-lane roadways for *narrowing paved right shoulder width*.

Table 4-21: Numbers and Length of Road Segments for Evaluating Safety Effectiveness of *Converting 4 to 3 Lanes*

Urban 4-lane Undivided Roadways		Urban 3-lane roadways (including TWLTL)	
Number of Segments	Total Length (mi)	Number of Segments	Total Length (mi)
122	49.977	219	77.632
AADT: 2,000 ~ 28,500veh/day			

Table 4-22: Numbers and Length of Road Segments on Rural Multi-Lane Roadways for Evaluating Safety Effectiveness of *Narrowing Paved Right Shoulder Width*

Shoulder Width	Number of Segments	Total Length (mi)
2-ft	2	1.809
3-ft	12	4.133
4-ft	132	57.277
5-ft	78	40.732
6-ft	38	10.374
7-ft	18	6.149
8-ft	37	14.852
Total	317	135.326
AADT: 5,000 ~ 35,000veh/day		

4.2.9 Adding a Bike Lane

The five-year (2008-2012) roadway geometric characteristics data and crash records were collected from the RCI and CARS database, respectively. The RCI dataset were validated using Transtat I-view and Google Earth. Annual average daily traffic volume (AADT) in 2010 was used as an average AADT in 2008-2012.

Adding a bike lane was determined based on the bike lane (BIKELNCD) in the RCI data. For evaluation of safety effectiveness of different severity levels, all severities (KABCO) and injury crashes (KABC) were analyzed. All crash types and Bike-related crashes were identified in order to estimate CMFs for specific crash types. Moreover, only non-intersection-related crashes were identified based on location of crash (SITELOCA) in the CARS data. Table 4-23 shows the numbers and length of road segments on urban multilane roadways with bike lane and without bike lane for *adding a bike lane.* The AADT is also shown in the table.

Table 4-23: Numbers and Length of Road Segments for Evaluating Safety Effectiveness of *Adding a Bike Lane*

Urban Multilane Roadways with Bike Lane		Urban Multilane Roadways without Bike Lane	
Number of Segments	Total Length (mi)	Number of Segments	Total Length (mi)
226	29.509	291	43.658
AADT: 2,900 ~ 59,500veh/day			

4.3 Data Collection for Intersections and Special Facilities

4.3.1 Signalization of Stop-Controlled Intersections

A total of 84 *signalization* projects were identified and these intersections were verified using Google Earth and Transtat I-view. Most of these sites were originally s*ignalized* intersections and they had only minor adjustment, either signal timing and/or phasing. Some of these intersections had signal type upgrade from cables to poles. It should be noted that the FM database does not provide information about the specific type of treatment and hence Google Earth and Transtat I-view were used to verify the exact treatment type at each intersection. A total of 32 intersections with a new signal installation were identified: 8 intersections in rural area (4-leg and 3-leg) and 24 intersections in urban area (fifteen 3-leg intersections and nine 4-leg intersections).

4.3.2 Adding Left-Turn Lanes

Adding Left-Turn Lanes was considered as another intersection-related treatment. A total 105 sites were identified using the FM database. Similar procedure was followed to validate the collected data using Transtat I-view and Google Earth. Figures 4-6 and 4-7 show examples of *Added Left-Turn Lanes* at intersections.

Start MP	End MP	Roadway ID	Minor Work	Road Name
3.06	3.373	46630000	Left turn Pocket added 0.064 miles	Cr 2321 at Kingswood Road

Figure 4-6: Example of Verifying Adding Left-Turn Lanes at Intersections Using Google Earth (Roadway ID: 46630000)

Start MP	End MP	Roadway ID	Minor Work	Road Name
10.338	10.683	48205000	Left turn pocket added 0.061 miles	Sr blue angel parkway at Bellview Avenue

Figure 4-7: Example of Verifying Adding Left-Turn Lanes at intersections Using Google Earth (Roadway ID: 48205000)

A total of 25 and 20 a*dding left-turn lanes* projects at 3-leg and 4-leg intersections, respectively, were verified. Roadway characteristics and crash data were collected for all treated sites and comparison group sites. It should be noted that left-turn lanes were added only on major roads at one- or two-way stop-controlled intersections. Table 4-24 shows the number of a*dding left-turn lanes* projects at urban/rural 3-leg and 4-leg intersections.

Table 4-24: Numbers of Intersections for Evaluating Safety Effectiveness of *Adding Left-Turn Lanes*

Intersection Type	Area Type	Number of Approaches	Traffic Control	Number of Intersections
3-Leg	Rural		Stop Controlled	18
			Signal Controlled	0
	Urban		Stop Controlled	7
			Signal Controlled	0
4-Leg	Rural	Single Approach	Stop Controlled	1
			Signal Controlled	0
		Two Approaches	Stop Controlled	9
			Signal Controlled	2
	Urban	Single Approach	Stop Controlled	1
			Signal Controlled	0
		Two Approaches	Stop Controlled	2
			Signal Controlled	5

4.3.3 Adding Red-Light Cameras

Since the start of the photo enforcement program in 2007 in Florida, 38 signalized intersections were equipped with one, two, or three surveillance camera systems in Orange County. It should be noted that since the installation and operation dates vary greatly among these intersections with active red-light cameras, at least three-year crash data in the before and after periods were considered in this study.

Crash data, traffic volume data, and roadway characteristics data were collected to perform observational before-after study. Crash data include date (year), crash type, severity level, location of crashes with respect to intersection (at-intersection, intersection related, not intersection related), and distance from the intersection. The traffic volume data include the entering average annual daily traffic (AADT) at the major and minor streets. Detailed geometric characteristics and traffic volumes (AADT) were also obtained from the RCI and automated traffic counter stations maintained by cities.

It should be noted that the presence of red-light cameras (RLCs) is not reported in the RCI data. While the identification of RLC-equipped intersections was relatively easy through Google Maps and city and county websites, the determination of the accurate installation and operation dates was a challenging task. In the State of Florida, the photo enforcement programs are typically operated by city police departments. The actual dates of installation and operation and the status of each camera were obtained from the corresponding city, county, or police agency. It is worth mentioning that not all identified photo-enforced intersections currently have active red light cameras, and intersections with terminated or inactive RLCs were removed from consideration in this analysis. In addition, Orange County officials tend to rotate and relocate RLCs from intersections that become safer to more dangerous intersections. As a result, 25 active RLC-equipped intersections in Unincorporated Orange County, and the cities of Orlando and Apopka in the State of Florida are considered in this study as shown in Figure 4-8. It is worth mentioning that the choice of these jurisdictions was based on the availability of installation/operation dates.

Since drivers are generally sensitive to the possibility of the presence of RLCs at other intersections, RLCs tend to change drivers' behavior in dealing with yellow time and red-light dilemma zone (Persaud et al., 2005; Shin and Washington, 2007). Thus, effects of RLCs might spill over to adjacent non-RLC-equipped intersections or sometimes throughout the whole jurisdiction. To examine such "spill-over" effects for each treated site, two untreated intersections immediately upstream and downstream of each active RLC-equipped intersection were also located. No RLCs were installed at these untreated intersections over the study period. A total number of 50 non-RLC-equipped intersections in the vicinity of the treated sites (located mostly on the same travel corridors) were identified. These intersections are similar to the RLC-equipped intersections in terms of intersection type and configuration, and traffic volume.

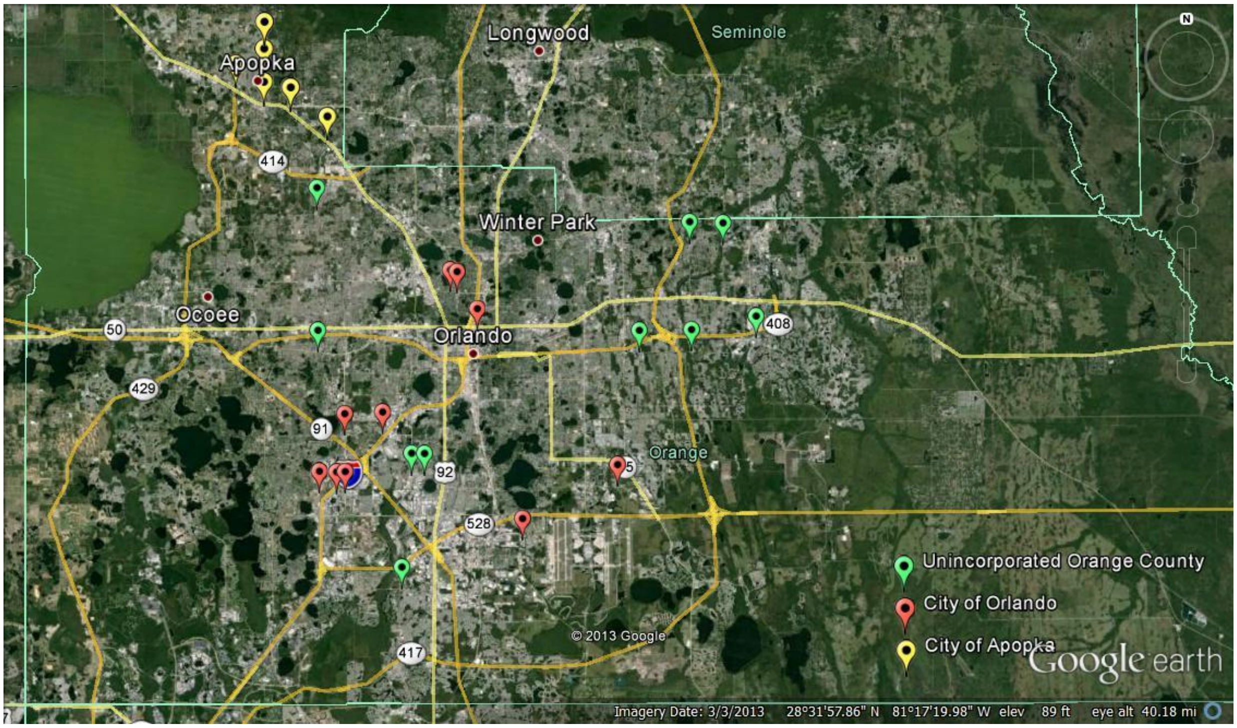


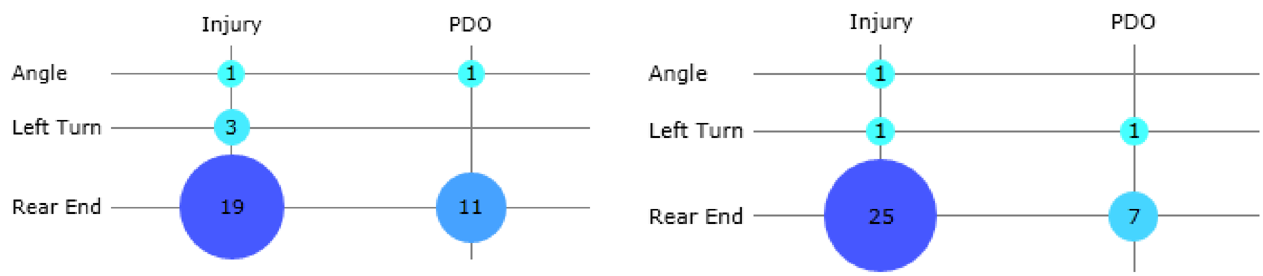
Figure 4-8: Road Network and Geo-coded Red-Light-Camera-Equipped Intersections in Orange County, Florida

The total number of crashes for an intersection was collected by combining both at-intersection and intersection-related crashes. Safety influence areas were manually identified in this study instead of using the areas within 250 feet from the center of intersections. It should be noted that the selection of fixed distance of influence area has no justified theoretical grounds in the literature. In order to identify crashes relate to red light running only at signalized intersections, crash reports were randomly selected and carefully reviewed. The preliminary investigation revealed that some crash cases that were recorded as intersection-related crashes were within very close distance (50 – 150 feet) of intersections are in fact not intersection-related; these crashes were related mostly to entry/exit movements to shopping areas in the vicinity of intersections. Therefore, angle and left-turn crashes were considered at the intersection area only (not the approaches) (Shin and Washington, 2007). Moreover, crashes dominated by driving under the influence of alcohol or drugs, illness, and sleep deprivation/fatigue and distraction by texting were removed from the crash dataset to examine only the effect of the presence of RLCs. Table 4-25 provides summary for selected RLC-equipped and non-RLC-equipped intersections.

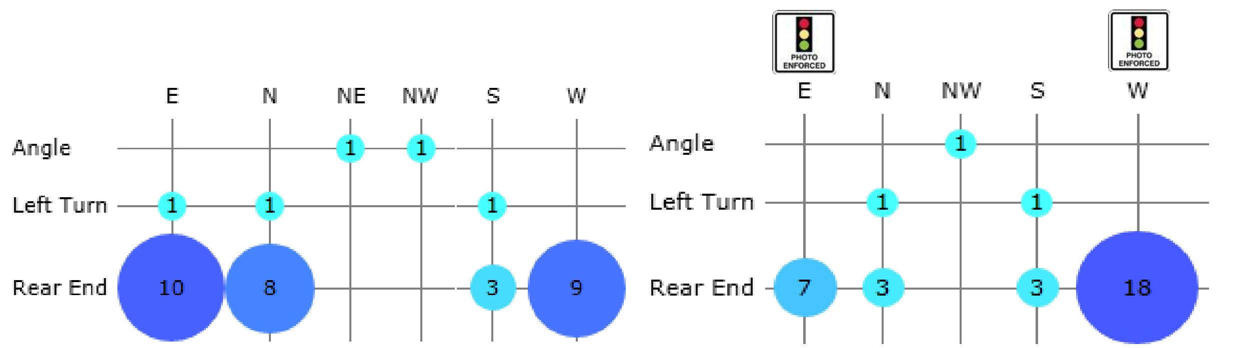
Table 4-25: Summary of Selected RLC and Non-RLC Intersections

Jurisdiction	Number of Intersections				
	RLC-equipped Intersections				Non-RLC-equipped Intersections
	All Approaches	Intersections Equipped with 1, 2, or 3 Approaches			Number of Intersections
		1	2	3	
Unincorporated Orange County	10	10	0	0	20
City of Orlando	9	4	3	2	18
City of Apopka	6	2	3	1	12
Total	25	16	6	3	50

Each intersection was analyzed by type of crash and severity level. Figure 4-9 shows an example of an intersection equipped with 2 RLCs in the eastbound and westbound approaches (three-year before and after periods) by crash type and severity level and traffic direction. It is worth mentioning that the change in frequency and severity of target crashes varied across approaches, and camera-equipped intersections in the before-after periods. However, there was a notable decrease in angle and left-turn crashes and increase in rear-end crashes in terms of frequency and severity.



Target Crashes (Type by Severity)



Target Crashes (Type by Direction)

Before Period (2006-2008) After Period (2009-2011)

Figure 4-9: Before-After Target Crash Type by Severity and Direction (Conroy and Vineland Intersection)

4.3.4 Converting a Minor-Road Stop-Controlled Intersection to a Modern Roundabout

The five-year RCI data (2008~2012) for the whole state were used to identify 225 modern roundabouts in Florida. Roundabouts were located using the RCI road feature “ROTARY”. Roadway ID and mileage point for each leg of roundabouts were collected using Transtat I-view.

AADT in 2012 was used to represent the traffic volume during the 5-year period. The data for only 130 roundabouts were collected. After excluding the roundabouts with missing AADT, there were a total of 63 roundabouts.

Crash records for these 63 roundabouts and 190 minor-road stop-controlled intersections were also collected from the CARS database to evaluate the safety effectiveness of *converting a minor-road stop-controlled intersections to a modern roundabout*. However, since there were some stop-controlled intersections without minor roadway ID, the minor road AADT could not be obtained for these intersections. Thus, only the major road AADT at stop-controlled intersections was compared with the highest AADT among legs for roundabouts. Total numbers of sites and crashes for roundabouts and minor-road stop-controlled intersections are shown in Table 4-26.

Table 4-26: Numbers of Modern Roundabouts and Minor-Road Stop-Controlled Intersections

Modern Roundabout		Minor-Road Stop-Controlled Intersection	
Number of Sites	Total Crashes	Number of Sites	Total Crashes
63	38	190	717
AADT: 258 ~ 60,000 veh/day			

4.3.5 Converting Traditional Mainline Toll Plaza to Hybrid Mainline Toll Plaza

Traditional mainline toll plaza (TMTP) systems require vehicles to rapidly decelerate, navigate through different fare transaction options, and then accelerate and merge with traffic. Unlike

TMTP, electronic toll collection (ETC) technologies allow vehicles to pass through the toll plaza without interruption as tolls are charged electronically. Thus, hybrid mainline toll plaza (HMTP) that retrofits existing tollbooths with express open ETC lanes are widely deployed In Florida. For this reason, the research team considered *converting TMTP to HMTP* as a treatment to improve safety although the HSM does not specify the CMF for this treatment. Figures 4-10 ~ 4-13 show designs and guide signs for mainline toll plazas.

Figure 4-10: Traditional Mainline Toll Plaza (TMTP)
(Source: FHWA, 2013)

Figure4-11: Hybrid Mainline Toll Plaza (HMTP)

(Source: Orlando-Orange County Expressway Authority, 2013)

Figure 4-12: All Electronic Toll Collection (AETC)

(Source: FHWA, 2013)

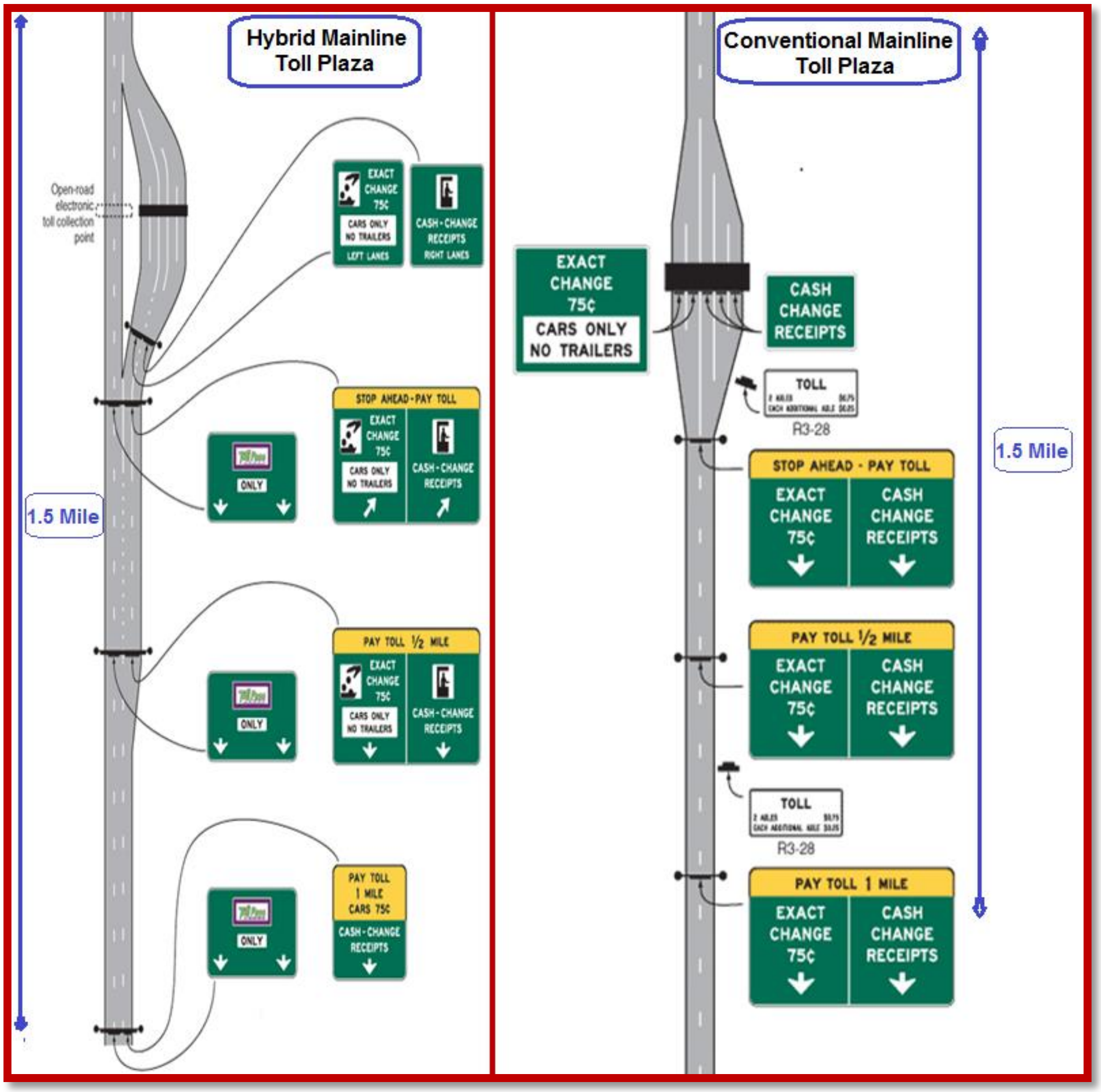


Figure4-13: Advance Signage for Conventional and Hybrid Mainline Toll Plaza

(Source: FHWA, 2013)

Data were collected from 98 Mainline Toll Plazas (two directions) located on approximately 750 miles of toll roads in the State of Florida. Multiple sources of data including RCI, Transtat I-view aerial mapping system, Five Years Work Program, Financial Project Search Database, and Straight Line Diagrams (SLDs) were used. The data were verified using Google Earth and the reports published by Florida turnpike and Orlando-Orange County Expressway Authority (OOCEA). There were thirty sites converted from TMTP to HMTP. Forty-two untreated sites with TMTP design were also identified as reference sites. Reference sites are different from the comparison sites; reference sites are broader than the comparison sites with more variation in AADT, roadway characteristics and crash history. Twenty-six sites with an HMTP for which the design has not been changed since it was built were used to evaluate the quality of the calibrated SPFs, CMFs and crash modification functions (CMFunctions). Numbers of treated and untreated sites and HMTPs without design change are shown in Table 4-27.

Crash data for three years before and three years after the implementation of the treatment in 2002-2012 were used to examine the safety impact of converting TMTP to HMTP. According to the Manual on Uniform Traffic Control Devices (MUTCD), the signposting distances and the influence areas of the mainline toll plaza cover 1 mile before and 0.5 mile after the centerline of the mainline toll plaza. Crashes that occurred within the influence areas of toll plazas were extracted from the CARS database. It should be noted that the crash data in the period six months before and after the conversion of TMTP to HMTP were excluded from the analysis.

Table 4-27: Numbers of Sites for Mainline Toll Plaza

	Sites converted from TMTP to HMTP	Reference (Untreated) sites of TMTP	HMTPs without design change
Number of Sites	30	42	26

CHAPTER 5. ROADWAY SEGMENTS

5.1 Adding a Through Lane

The observational before-after approach discussed in the previous chapter was applied to a*dding a through lane* treatment. The evaluation of safety effectiveness was conducted using naïve before-after, before-after with comparison group, and before-after with empirical Bayes approaches for a*dding a through lane* on urban and rural two-way-two-lane. Moreover, the safety effectiveness of a*dding a through lane* on Urban and Rural two-way-two-lane was estimated for different severity levels; total crashes (all severity), and fatal and injury (F+I) crashes.

5.1.1 Naïve Before-After

The observational before-after naïve approach was applied on the 41 and 43 sites with a*dding a through lane* totaling 8.578 and 53.561 miles for urban and rural two-way-two-lane roadway segments, respectively, that were upgraded to four multilane divided. It should be noted that the evaluation of the safety effectiveness here is estimated for two countermeasures; *adding a through lane* and a*dding a raised median* at the same time. Due to data availability, CMFs were not calibrated for expanding 2 lane roads to four lanes undivided. We might need to resort to a cross sectional analysis to identify the CMF in that situation.

5.1.2 Safety Effectiveness for Total Crashes

For the 41 and 43 treated urban/ rural two-lane sites respectively, crash rates were calculated using the mean ADT and length of segment as discussed in the previous chapter. The crash modification factors were estimated based on crash rates for both individual locations and all locations combined and the Poisson test of significance was performed.

Overall, the total crash rate across all locations for urban roadways was reduced from 24.79 crashes per million vehicle mile (MVM) to 6.96 crashes per MVM after adding a lane and dividing the roadway with a raised median, representing about 71.5% reduction in the total crash rate. The reduction of total crash rate was statistically significant. For rural two-way-two-lane; the crash rate dropped from 26.18 crashes per MVM to 16.66 crashes per MVM, the estimated safety effectiveness was 36.35%.

Same approach was applied to fatal and injury (F+I) crashes only, a*dding a through lane* at each direction of a two-lane roadways *and* separating with *a raised median* reduced F+I crashes by 48.42% and 34.98% for urban and rural 2-lane roadways, respectively.

5.1.3 Before-After with Comparison Group

Using SAS® 9.3, the research team developed a procedure to apply the HSM 16 steps of observational before-after with comparison group illustrated in Figure 5-1. The procedure was applied on the same 41 and 43 sites mentioned in the previous section. The safety effectiveness of a*dding a lane* and a*dding a median* was estimated for both individual locations and all locations combined for roadway segments using crash experience data from 381 and

370comparison locations totaling 67.814 and 230.331 miles for urban and rural two-lane roadways, respectively. Overall, the safety effectiveness for urban two-lane roadways across all locations was significantly improved by 64.49% and with standard error of 9.94% for total crashes (all severity). The statistical significance of the estimated safety effectiveness was calculated as:

$$Abs\left(\frac{\text{Safety } \textit{Effectiveness}}{\text{SE (Safety } \textit{Effectiveness})}\right) = \frac{64.49}{9.94} = 6.49 \qquad (5\text{-}1)$$

Since Abs [safety effectiveness/SE (safety effectiveness)] is ≥ 1.96, it can be concluded that the treatment effect is significant at the 95 percent confidence level. The final results for urban/rural total crashes and F+I crashes are presented in the below Table 5-1 and compared to other CMFs that were estimated using different methods in Table 5-8.

Table 5-1:CMFs for *Adding a Through Lane* using Naïve Before-After Method

Category	Severity	Urban	Rural
		CMF (Safety Effectiveness)	**CMF** (Safety Effectiveness)
2-lane Roads	**Total Crashes**	**0.28** (71.43%)	**0.64** (36.35%)
	F+I	**0.52** (48.42%)	**0.65** (34.97%)

Step 1	Calculate predicted crash frequency at each treatment site, separately for before and after period.	Estimation of Mean Treatment Effectiveness
Step 2	Calculate predicted crash frequency at each comparison site, separately for before and after period.	
Step 3	Calculate adjustment factor for each combination of treatment and comparison site, separately for before and after period.	
Step 4	Calculate adjusted crash frequency for each combination of treatment and comparison site, separately for before and after period.	
Step 5	Calculate total comparison-group adjusted crash frequency for each treatment site in before period.	
Step 6	Calculate total comparison-group adjusted crash frequency for each treatment site in after period.	
Step 7	Calculate the comparison ratio for each treatment site.	
Step 8	Calculate the expected crash frequency for each treatment site in the after period, had no treatment been implemented	
Step 9	Calculate the safety effectiveness expressed as an odds ratio at an individual treatment site.	
Step 10	Calculate the log odds ratio for each treatment site.	
Step 11	Calculate the weight for each treatment site.	
Step 12	Calculate the weighted average log odds ratio across all treatment sites.	
Step 13	Calculate the overall effectiveness of the treatment expressed as an odds ratio.	
Step 14	Calculate the overall effectiveness of the treatment expressed as a percentage change in crash frequency.	

Step 15	Calculate the standard error of the treatment effectiveness	Estimation of Precision of the Treatment Effectiveness
Step 16	Asses the statistical significance of the estimated safety effectiveness	

Figure 5-1: Overview of Before-After Comparison Group Safety Evaluation
(Source: AASHTO, 2010)

5.1.4 Before-After with Empirical Bayes

5.1.4.1 SPFs for Roadway Segments

A total of 1291 and 1301 reference roadway segments were identified with similar roadway characteristics to the treatment sites in the 'before' period for urban and rural 2-lane roadways, respectively. Roadway geometry data were collected from RCI and matched to crash data collected from the CARS database. It is worth mentioning that more reference sites information with their corresponding roadway characteristics and traffic data were collected to calibrate reliable SPF. As discussed in Chapter 3, reference sites are different from the comparison group; the reference sites are broader than the comparison group with more variation in AADT, roadway characteristics, and crash history. Two sets of SPFs were estimated using NB; simple SPF and full SPF. Using PROC GENMOD procedure in SAS, negative binomial models were fitted for the frequency of reference group crashes with the explanatory variables attempted: log(AADT), length of the segment, width of shoulder, width of lane, and speed limit. Simple and full SPFs were fitted for the total number of crashes and for injury and fatal crashes (F+I). It should be noted that the results for the simple SPFs were slightly different than the ones reported in FDOT BDK80 977-07 final report due to using different recent crash years and segmentation method (Gan et al., 2012).

Table 5-2 shows the results for the simple SPF model for total crashes on urban two-way-two-lane roadway segments. In the full SPF, log(ADT), Speed Limit, and length of segment were the most significant variables in the final model as shown in Table 5-3.

Table 5-2: Florida-Specific Simple SPFs for Total Crashes on Urban Two-Way Two-Lane Roadways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	1274	1378.5132	1.0820
Pearson Chi-Square	1274	2040.4558	1.6016
Log Likelihood		31254.6047	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-5.0195	0.5680	-6.1328	-3.9063	78.10	<.0001
LogADT	1	0.7864	0.0596	0.6695	0.9032	174.04	<.0001
Dispersion	1	0.9157	0.0368	0.8463	0.9907		

Table 5-3: Florida-SpecificFull SPFs for Total Crashes on Urban Two-Way Two-Lane Roadways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	1272	1079.6911	0.8488
Pearson Chi-Square	1272	1599.0446	1.2571
Log Likelihood		-154.7239	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-7.9825	0.6692	-9.2940	-6.6709	142.30	<.0001
LogADT	1	1.0048	0.0690	0.8697	1.1400	212.26	<.0001
SpeedLimit	1	-0.0303	0.0037	-0.0375	-0.0231	67.37	<.0001
SegLength	1	0.8677	0.1011	0.6695	1.0659	73.60	<.0001
Dispersion	1	0.4871	0.0371	0.4195	0.5656		

The results for the simple SPF model for fatal and injury (F+I) crashes is presented in Table 5-4. The same set of variables in the full SPF model for total crashes came out to be significant for F+I as shown in Table 5-5.

Table 5-4: Florida-Specific Simple SPFs for F+I Crashes on Urban Two-Way Two-Lane Roadways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	1274	1318.9264	1.0353
Pearson Chi-Square	1274	1635.7036	1.2839
Log Likelihood		2961.6081	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-5.9485	0.5997	-7.1238	-4.7731	98.39	<.0001
LogADT	1	0.7621	0.0628	0.6390	0.8851	147.41	<.0001
Dispersion	1	0.7133	0.0389	0.6410	0.7938		

Table 5-5: Florida-SpecificFull SPFs for F+I Crashes on Urban Two-Way Two-Lane Roadways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	1272	1409.7128	1.1083
Pearson Chi-Square	1272	1501.6991	1.1806
Log Likelihood		20209.5554	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-6.0358	0.6009	-7.2136	-4.8580	100.88	<.0001
LogADT	1	0.8957	0.0612	0.7758	1.0157	214.23	<.0001
SpeedLimit	1	-0.0160	0.0034	-0.0227	-0.0093	22.03	<.0001
SegLength	1	1.1044	0.1138	0.8813	1.3276	94.13	<.0001
Dispersion	1	0.8150	0.0368	0.7460	0.8903		

Tables 5-6 and 5-7 summarize the results from all calibrated NB models for urban and rural two-lane roadway segments for both total and F+I crashes.

Table 5-6: Florida-Specific Full SPFs for Urban and Rural Two-Way Two-Lane Roadways (Total and F+I Crashes)

Category	Severity	Florida-Specific Full SPFs								
		Intercept		Log(ADT)		Speed Limit		Segment Length		Dispersion (k)
		Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	
Urban										
2-lane Roads	Total	-7.9825	<.0001	1.0048	<.0001	-0.0303	<.0001	0.8677	<.0001	0.4871
	F+I	-6.0358	<.0001	0.8957	<.0001	-0.0160	<.0001	1.1044	<.0001	0.8150
Rural										
2-lane Roads	Total	-11.4845	<.0001	1.0837	<.0001	0.0287	<.0001	0.6140	0.0131	0.6725
	F+I	-11.5280	<.0001	1.0119	<.0001	0.0312	<.0001	0.7921	0.0016	0.3414

Table 5-7: Florida-Specific SimpleSPFs for Urban and Rural Two-Way Two-Lane Roadways (Total and F+I Crashes)

Category	Severity	Florida-Specific Simple SPFs				
		Intercept		Log(ADT)		Dispersion (k)
		Estimate	P-Value	Estimate	P-Value	
Urban						
2-lane Roads	Total	-5.0195	<.0001	0.7864	<.0001	0.9157
	F+I	-5.9485	<.0001	0.7621	<.0001	0.7133
Rural						
2-lane Roads	Total	-8.1513	<.0001	0.9388	<.0001	0.631
	F+I	-8.264	<.0001	0.805	<.0001	0.678

Step 1	Calculate the predicted crash frequency for each site during each year of the before period.
Step 2	Calculate the predicted crash frequency for each site summed over the entire before period.

EB Estimation of the Expected Crash Frequency in the Before Period

Step 3	Calculate the predicted crash frequency for each site during each year of the after period.
Step 4	Calculate an adjustment factor to account for differences between before and after periods.
Step 5	Calculate the expected crash frequency for each site over the entire after period in the absence of the treatment..

EB Estimation of the Expected Crash Frequency in the After Period

Step 6	Calculate an estimate of the safety effectiveness at each site in terms of an odds ratio.
Step 7	Calculate an estimate of the safety effectiveness at each site in as a percentage crash change.
Step 8	Calculate the overall effectiveness of the treatment for all sites combined in terms of an odds ratio.
Step 9	Perform an adjustment to obtain an unbiased estimate of the treatment effectiveness in terms of an odds ratio.
Step 10	Calculate the overall unbiased safety effectiveness as a percentage change in crash frequency across all sites

Estimation of the Treatment Effectiveness

Step 11	Calculate the variance of the unbiased estimated safety effectiveness as an odds ratio.
Step 12	Calculate the standard error of the odds ratio from step 11.
Step 13	Calculate the standard error of the unbiased safety effectiveness calculated in step 10.
Step 14	Assess the statistical significance of the estimated safety effectiveness.

Estimation of Precision of the Treatment Effectiveness

Figure 5-2: Overview of EB Before-After Safety Evaluation
(Source: AASHTO, 2010)

The 14 steps of the observational before-after with EB method illustrated in Figure 5-2 were applied on the same 41 sites mentioned in the previous section. The safety effectiveness of a*dding a lane* and a*dding a median* was estimated using full and simple SPFs and observed crash history on the treatment sites at individual and combined locations levels. For example, the safety effectiveness across all locations for *adding a through lane and a raised median* on urban 2-lane roadways was significantly improved by 64.80% using full SPF while the safety effectiveness was estimated to be 67.70% using the simple SPF. The EB method using full and simple SPFs was applied to urban and rural roadway segments for both total and F+I crashes.

Table 5-8 summarizes the results from the three different approaches, naïve before-after, before-after with CG, and before-after with EB. Among CMFs from different methods, the CMF with the lowest standard error was recommended as the best Florida-specific CMF.

Table 5-8: Comparison of CMFs for *Adding a Through Lane* on Two-Lane Undivided Roadways

Category	Severity	Method						
		Naïve Before-After	Before-After with Comparison Group		EB Before-After			
					Simple SPF		Full SPF	
		CMF (Safety Effectiveness)	**CMF** (Safety Effectiveness)	S.E.	**CMF** (Safety Effectiveness)	S.E.	**CMF** (Safety Effectiveness)	S.E
Urban								
2-lane Roads	**Total Crashes**	0.28 (71.43%)	0.35 (64.49%)	0.10 (9.94%)	0.32 (67.70%)	0.08 (8.04%)	**0.35** (64.80%)	**0.09** (8.76%)
	F+I	0.52 (48.42%)	0.36 (64.37%)	0.10 (9.72%)	**0.33** (67.03%)	**0.09** (8.04%)	0.36 (64.34%)	0.10 (8.76%)
Rural								
2-lane Roads	**Total Crashes**	0.64 (36.35%)	0.73 (27.26%)	0.10 (9.94%)	**0.71** (29.48%)	**0.09** (9.04%)	0.74 (25.87%)	0.09 (9.4%)
	F+I	0.65 (34.97%)	0.54 (46.12%)	0.09 (8.94%)	0.59 (40.24%)	0.09 (8.88%)	**0.51** (49.42%)	**0.07** (7.19%)

Note: The values in bold are recommended CMFs for Florida.

It can be seen that the results from the naïve method overestimated the treatment effects for total crashes on urban 2-lane roads total crashes, possibly due to the regression-to-the-mean bias. The results from before-after with comparison group are almost identical to the multivariate EB. The multivariate EB method required more roadway geometry data for the treatment sites. Compared to the before-after with comparison group and multivariate EB methods, the univariate EB method provided the least standard error of about 8%, therefore, it was favored and the recommended CMF is 0.32 (±0.08) for *adding a lane and adding a raised median* on urban two-way-two lane roadway segments. It is worth mentioning that the naïve before-after analysis underestimated the safety effectiveness for F+I crashes for both urban and rural two-lane roads. Comparison group method returned similar results to the EB method with slightly higher standard error. This particular treatment is not addressed in the HSM, but it is regarded as very common and important.

5.1.5 Median Width Investigation

In the meeting with FDOT, Mr. Joseph Santos requested the research team to investigate the safety effectiveness of various median widths when upgrading the 2-lane to 4-lane divided roads. It should be noted that the safety effectiveness of either a*dding a lane* or a*dding a median* cannot be evaluated separately for upgrading 2-lane to 4-lane divided roadways since both treatments were implemented at the same time. The sole safety effectiveness of a*dding a median* can only be identified from the sites where a raised median was only added. The research team could not find enough sample for estimating CMFs for adding a raised median only at a 4-lane undivided using the before-after method.

The treated sites for urban roadways were selected for this analysis, the roadways segments were split into 3 categories depending on their median width; 12-14 ft, 20-24 ft, and > 30 ft. Table 5-9shows the number of sites, CMFs and their variance for each category using the empirical Bayes method. It can be concluded that roadways with raised medians are safer than two-way two-lane roadways in general and the wider the median the safer the roadway. Figure 5-3 shows the relationship between the observed average crashes per mile per year (CPMPY) for the after period for urban 4-lane roadways and median width. It can be seen that wider medians decrease the risk of total crashes.

Table 5-9: CMFs for *Adding Lanes (Converting Urban 2-lane to 4-lane Divided Roadways)*

Median Width (After)	CMF (Total Crashes)	SE	No. of Sites
12-14 ft	0.47	0.23	12
20-24 ft	0.52	0.15	5
> 30 ft	0.28	0.01	24

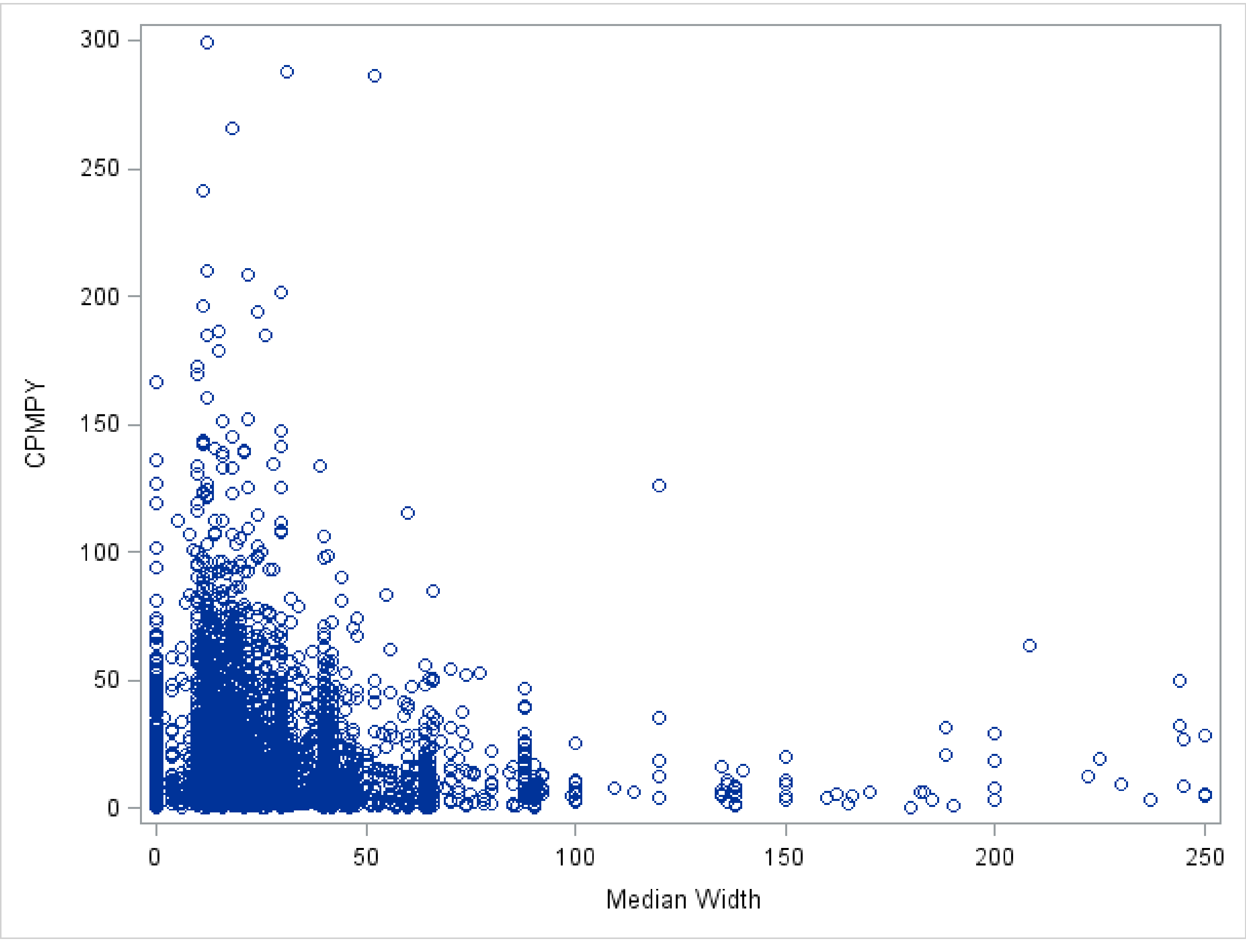


Figure 5-3: Urban Four-Lane Divided Median Width and Observed Crashes per Mile per Year (CPMPY)

5.2 Adding Shoulder Rumble Strips on Two-Lane Undivided Roadways

Naïve before-after, before-after with comparison group methods were performed for evaluating of safety effects of installing s*houlder rumble strips* treatment. Moreover, before-after with empirical Bayes method was used for calculating CMFs of All crash type (all severity) & (fatal + injury) of rural. Since total segment length and crash frequency of urban arterial of case 1 (two-lane undivided roadway and type 1 to 2) are short and small, value of CMF from this case was not significant.

5.2.1 Naïve Before-After

The observational before-after naïve method was used for s*houlder rumble strips* on 56 segments. The CMFs were calculated based on crash rates of each categories and 'Exposure' was estimated in million vehicle miles (MVM) of travel.

5.2.2 Before-After with Comparison Group

The before-after with comparison group method was performed for s*houlder rumble strips* on 'rural+urban' and rural condition of case 1.In this study, the comparison group was collected based on over 3 times the length of the treated group. Two years of crash data, of the before and after periods were considered for the treated and comparison groups.

5.2.3 Before-After with Empirical Bayes

In this study, the before-after with empirical Bayes method was used for 2 categories, which are total and severe crashes on 2-lane rural roadways. Florida specific-SPFs shown in Table 5-10 were used for calculating predicted crash counts.

Table 5-10: Florida-Specific Simple SPFs for Rural Two-lane Roads (Total and F+I Crashes)

Category	Severity	Florida-specific Simple SPFs				
		Intercept		Log(ADT)		Dispersion (k)
		Estimate	P-Value	Estimate	P-Value	
Rural						
2-lane Roads	Total	-6.923	<.0001	0.874	<.0001	0.464
	F+I	-7.660	<.0001	0.894	<.0001	0.444

5.2.4 Result of Analysis

The observational before-after naïve, CG, and EB methods were used for evaluation of safety effectiveness of *shoulder rumble strips* on Two-lane undivided roadway. As shown in Table 5-11, the CMFs for All Crash Types (All severities) and SVROR (All severities) were significant at the 95% level for rural/urban 2-lane roads, whereas most CMF for rural 2-lane roads were significant at a 95% and 90% confidence level except SVROR (fatal+injury).

Table 5-11: Comparison of CMFs for *Adding Shoulder Rumble Strips on Two-lane Undivided Roadways*

Category	Severity	Method				
		Naïve Before-After	Before-After with Comparison Group		EB Before-After Simple SPF	
		CMF (Safety Effectiveness)	**CMF** (Safety Effectiveness)	S.E.	**CMF** (Safety Effectiveness)	S.E
Rural + Urban						
2-lane Roads	**All Crash Type (all severity)**	0.839 (16.10%)	0.712** (28.80%)	0.100	-	-
	All Crash Type (Fatal + Injury)	0.773 (22.70%)	0.808 (19.20%)	0.134	-	-
	SVROR (all severity)	0.469 (53.10%)	0.503** (49.70%)	0.161	-	-
	SVROR (Fatal + Injury)	0.565 (43.50%)	0.670 (33.00%)	0.249	-	-
Rural						
2-lane Roads	**All Crash Type (all severity)**	0.893 (10.70%)	0.701** (29.90%)	0.105	0.768** (23.20%)	0.118
	All Crash Type (Fatal + Injury)	0.816 (18.40%)	0.746* (25.40%)	0.134	0.778* (22.20%)	0.118
	SVROR (all severity)	0.510 (49.00%)	0.564** (43.60%)	0.182	-	-
	SVROR (Fatal + Injury)	0.605 (39.50%)	0.678 (32.20%)	0.253	-	-

**Significant at a 95% confidence level. *Significant at a 90% confidence level.

In the HSM, CMFs for s*houlder rumble strips* are only provided for rural multilane highways and freeways, but not urban/rural two-lane roadways. Thus, Florida-specific CMFs could not be compared with the CMFs in the HSM.

5.3 Shoulder Rumble Strips, Widening Shoulder Width, Shoulder Rumble Strips + Widening Shoulder Width on Rural Multilane Highways

Naïve before-after, before-after with comparison group, and before-after with empirical Bayes methods were performed for evaluating of safety effects of installing s*houlder rumble strips*, w*idening shoulder width*, and s*houlder rumble strips + widening shoulder width* on rural multi-lane highways. A majority of treated sites have the speed limit range of '65~70mph' for the three treatments. Table 5-12 provides the proportions of the treated sites by speed limit range for the three treatments.

Table 5-12: Numbers of Treated Sites by Speed Limit Range for Rural Multi-Lane Highways

	Speed Limit Range (mph)							
	45 ~ 50		55 ~ 60		65 ~ 70		Total (45~70)	
Treatment Types	# of Segments	%	# of Segments	%	# of Segments	%	# of Segments	%
Shoulder Rumble Strips	1	4 %	2	7 %	24	89 %	27	100 %
Widening Shoulder Width	3	10 %	12	40 %	15	50 %	30	100 %
Shoulder Rumble Strips + Widening Shoulder Width	1	3 %	2	7 %	27	90 %	30	100 %

5.3.1 Naïve Before-After

The observational naïve before-after method was applied s*houlder rumble strips*, w*idening shoulder width*, and *shoulder rumble strips + widening shoulder width* on 27, 30, and

30segments, respectively. The CMFs were calculated based on crash rates of each segment and 'Exposure' was estimated in million vehicle miles (MVM) of travel.

5.3.2 Before-After with Comparison Group

The before-after with comparison group method was performed for s*houlder rumble strips*, w*idening shoulder width*, and s*houlder rumble strips + widening shoulder width* on rural multi-lane highways. The total length of the comparison group is over 4 times longer than the treated group.

5.3.3 Before-After with Empirical Bayes

A total of 719 roadway segments were identified as reference sites with similar roadway characteristics to the treated sites in the before period for rural multilane highways. Roadway characteristics and matched crash data were collected from RCI and CARS databases, respectively. The Simple SPF (with AADT only) was fitted for four different conditions of crash type and severity level: 1) all crashes, 2) fatal and injury (F+I) crashes, 3) all single vehicle run-off road crashes (SVROR), and 4) F+I SVROR. The SPFs were developed using the negative binomial (NB) model formulation as follows:

(5-2)

where,

= predicted crash frequency per mile per year,

= annual average daily traffic volume, and

, = coefficients.

Tables 5-13, 5-14, 5-15, and 5-16 provide the results of the calibrated Florida-specific SPFs for the four different conditions of crash type and severity levels for rural multilane highways.

Table 5-13: Florida-Specific Simple SPFs for 'All Crashes (All severities)' on Rural Multi-Lane Highways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	719	746.4588	1.0382
Pearson Chi-Square	719	1067.3260	1.4845
Log Likelihood		17274.8843	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-8.5895	0.4537	-9.4788	-7.7002	358.40	<.0001
LogADT	1	1.0732	0.0445	0.9861	1.1604	582.70	<.0001
Dispersion	1	0.5215	0.0321	0.4623	0.5883		

Table 5-14: Florida-Specific Simple SPFs for 'All Crashes (F+I)' on Rural Multi-Lane Highways

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	719	755.9102	1.0513
Pearson Chi-Square	719	1002.8203	1.3947
Log Likelihood		6108.7601	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-7.9776	0.4976	-8.9530	-7.0022	256.98	<.0001
LogADT	1	0.9584	0.0487	0.8630	1.0538	387.67	<.0001
Dispersion	1	0.5366	0.0374	0.4681	0.6152		

Table 5-15: Florida-Specific Simple SPFs for 'SVROR Crashes (All severities)' on Rural Multi-Lane Highways

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	719	725.3695	1.0089
Pearson Chi-Square	719	1023.4279	1.4234
Log Likelihood		321.2984	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-6.8912	0.7144	-8.2915	-5.4910	93.04	<.0001
LogADT	1	0.7420	0.0699	0.6051	0.8789	112.84	<.0001
Dispersion	1	1.1385	0.0941	0.9682	1.3387		

Table 5-16: Florida-Specific Simple SPFs for ‘SVROR Crashes (F+I)’ on Rural Multi-Lane Highways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	719	675.8714	0.9400
Pearson Chi-Square	719	913.0624	1.2699
Log Likelihood		-389.3672	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-6.0816	0.8133	-7.6756	-4.4876	55.92	<.0001
LogADT	1	0.6128	0.0795	0.4570	0.7687	59.37	<.0001
Dispersion	1	1.2476	0.1276	1.0210	1.5244		

5.3.4 Result of Analysis

The results of observational before-after naïve, CG, and EB methods are summarized in Table 5-17. The CMFs calculated using three methods show that the combinations of shoulder rumble strips and widening shoulder width reduce crashes except for SVROR of the widening shoulder width treatment. This may be due to the insufficient number of SVROR, which is only 10% of the total crash counts for the widening shoulder width treatment, whereas SVROR account for 40% of the total crash counts for the other two treatments.

Between two different speed limit ranges, 45~70 mph and 65~70 mph, for All crashes, it was found that there is a 0.8% difference in the CMFs for shoulder rumble strips, 16.4% difference in the CMFs for widening shoulder width, and 2.1% difference in the CMFs of shoulder rumble strips + widening shoulder width treatment. The results indicate that speed limits significantly affect safety effectiveness of widening shoulder width.

Table 5-17: Florida-Specific CMFs for *Shoulder Rumble Strips, Widening Shoulder Width, and Shoulder Rumble Strips + Widening Shoulder Width on Rural Multi-Lane Highways*

			Speed Limit Range (45 ~70 mph)					Speed Limit Range (65 ~70 mph)			
			Naïve	CG method		EB method (Simple SPF)		CG method		EB method (Simple SPF)	
Treatment Types	Crash Type	Severity	CMF	CMF	S.E	CMF	S.E	CMF	S.E	CMF	S.E
Shoulder Rumble Strips	All types	All severities	0.787	**0.728****	0.067	**0.772****	0.068	**0.725****	0.068	**0.784****	0.070
		F+I	0.636	**0.626****	0.089	**0.638****	0.089	**0.626****	0.091	**0.656****	0.093
	SVROR	All severities	0.764	**0.597****	0.092	**0.789***	0.113	**0.582****	0.091	**0.802***	0.117
		F+I	0.680	**0.641****	0.145	**0.724***	0.161	**0.592****	0.140	0.775	0.175
Widening Shoulder Width	All types	All severities	0.933	**0.815****	0.087	**0.843***	0.178	**0.691****	0.123	**0.659****	0.119
		F+I	0.909	**0.783****	0.110	**0.679****	0.098	**0.609****	0.151	**0.507****	0.130
	SVROR	All severities	0.955	1.358	0.342	0.683	0.190	1.396	0.429	**0.599****	0.203
		F+I	1.018	1.999	0.634	0.774	0.277	1.018	0.455	**0.393****	0.186
Shoulder Rumble Strips + Widening Shoulder Width	All types	All severities	0.637	**0.498****	0.063	**0.599****	0.074	**0.475****	0.064	**0.585****	0.076
		F+I	0.712	**0.660****	0.112	**0.703****	0.118	**0.631****	0.114	**0.684****	0.122
	SVROR	All severities	0.506	**0.395****	0.079	**0.437****	0.087	**0.399****	0.083	**0.461****	0.095
		F+I	0.720	**0.625****	0.149	**0.675****	0.161	**0.575****	0.145	**0.669***	0.167

**significant at a 95% confidence level
*significant at a 90% confidence level

5.3.5 Comparison with CMFs in HSM

The HSM provides CMFs for widening paved shoulders on rural two-lane roadways and they are determined using the equations as shown in Table 5-18. The CMFs were estimated using simple Before/After and Yoke comparison methods. The base condition of the CMFs (i.e., CMF = 1.00) is a 6-ft shoulder width. In general, widening shoulder width reduces specific crash types including SVROR, multi-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe crashes. However, Florida-specific CMFs for widening shoulder width were developed for different range of width, crash types, and roadway types in this study. Due to these differences, Florida-specific CMFs and the CMFs in the HSM for widening shoulder width are not comparable.

Table 5-18: CMFs for Shoulder Width on Rural Two-lane Roadway Segments in the HSM

Shoulder Width	AADT (vehicles / day)		
	< 400	400 to 2,000	> 2,000
0-ft	1.10	$1.10 + 2.5 \quad 10^{-4}$ (AADT - 400)	1.50
2-ft	1.07	$1.07 + 1.43 \quad 10^{-4}$ (AADT - 400)	1.30
4-ft	1.02	$1.02 + 8.125 \quad 10^{-4}$ (AADT - 400)	1.15
6-ft	1.00	1.00	1.00
8-ft or more	0.98	$0.98 + 6.875 \quad 10^{-4}$ (AADT - 400)	0.87

The HSM also contains CMFs for shoulder rumble strips on rural multilane highways as shown in Table 5-19. Between the two Florida-specific CMFs obtained from CG and EB methods, the CMF with smaller standard error was selected as the best Florida-specific CMF because it is a more accurate estimate. This selected Florida-specific CMF was compared with the CMF in the HSM and the recommended CMF for Florida was determined using the following rules:

Case 1: Both Florida-specific CMF and CMF in the HSM are statistically significant at a85% confidence level ($|Z_{crit, \alpha/2=0.075}| = 1.44$), the Florida-specific CMF is only recommended because it reflects the unique characteristics of Florida.

Case 2: If only Florida-specific CMF or the CMF in the HSM is statistically significant at a85% confidence level, only the statistically significant CMF is recommended. This is because safety effectiveness of a given treatment is unknown if a CMF is not significant.

Case 3: If the CMF for a specific treatment is not included in the HSM, only the Florida-specific CMF is recommended. However, if the Florida-specific CMF is not significant, it is not recommended since the safety effectiveness of the treatment is unknown.

Table 5-19: CMF for Shoulder Rumble Strips on Rural Multi-Lane Highways in the HSM

Treatment	Setting (Road type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	S.E.
Install continuous milled-in shoulder rumble strips	Rural (Multi-lane divided)	2,000 to 50,000	All types (All severities)	0.84	0.1
			All types (F+I)	0.83	0.2
			SVROR (All severities)	0.90	0.3
			SVROR (F+I)	0.78	0.3

It was found that Florida-specific CMFs for all crash types and severities except for the SVROR (F+I) for widening shoulder width are statistically significant at a 95% confidence level. Thus, the CMFs from this study are recommended for Florida as shown in Table 5-20.

Table 5-20:**Recommended CMFs for *Shoulder Rumble Strips, Widening Shoulder Width and Shoulder Rumble Strips + Widening Shoulder Width on Rural Multi-Lane Highways in Florida***

Treatment Type	Crash Type (Severities)	Florida-Specific CMFs		CMFs in the HSM
		Speed Limit: 45~70 mph AADT: 2,000 ~ 50,000	Speed Limit: 65~70 mph AADT: 2,000 ~ 50,000	Speed Limit: Unknown AADT: 2,000 ~ 50,000
		CMF (S.E.)	CMF (S.E.)	CMF (S.E.)
Shoulder Rumble Strips	All types (All severities)	**0.73* (0.07)**	**0.73* (0.07)**	0.84* (0.1)
	All types (F+I)	**0.64* (0.09)**	**0.63* (0.09)**	0.83 (0.2)
	SVROR (All severities)	**0.60* (0.09)**	**0.58* (0.09)**	0.90 (0.3)
	SVROR (F+I)	**0.64* (0.15)**	**0.59* (0.14)**	0.78 (0.3)
Widening Shoulder Width	All types (All severities)	**0.83* (0.09)**	**0.66 (0.12) ***	-**
	All types (F+I)	**0.68* (0.10)**	**0.51* (0.13)**	-**
	SVROR (All severities)	**0.68* (0.19)**	**0.60* (0.20)**	-**
	SVROR (F+I)	**-****	**0.39* (0.19)**	-**
Shoulder Rumble Strips + Widening Shoulder Width	All types (All severities)	**0.50* (0.06)**	**0.48* (0.06)**	-**
	All types (F+I)	**0.66* (0.11)**	**0.63* (0.11)**	-**
	SVROR (All severities)	**0.40* (0.08)**	**0.40* (0.08)**	-**
	SVROR (F+I)	**0.63* (0.15)**	**0.58* (0.15)**	-**

Note: The values in bold are recommended CMFs for Florida.
*Significant at a 95% confidence level.
**Not available.

5.4 Converting a Two-Way Left-Turn Lane to a Raised Median

The safety effectiveness of *converting a TWLTL to a raised median* was evaluated using naïve before-after, before-after with CG, and before-after with EB Methods. The safety effectiveness of this treatment was estimated for different severity levels - all severity and fatal and injury crashes, and head-on crashes.

The observational naïve before-after method was applied to 33 treated segments with a total of 9.27 miles. The CMFs were calculated based on crash rates with the exposure measure in million vehicle miles of travel (MVM). On average, the total crash rates for all sites decreased by 46% during the after period. The crash rates for fatal and injury crashes, and head-on crashes also dropped by 35% and 55%, respectively. The result of Poisson test of significance shows that these reductions in total crash rate are statistically significant.

The observational before-after with CG method was performed for 33 treated sites and 109 comparison sites. The treated and comparison sites have similar roadway characteristics and traffic volumes. On average, the total crashes across all locations decreased by 47%. The crashes for fatal and injury crashes, and head-on crashes also dropped by 33% and 73%, respectively.

The before-after with EB method was also applied. A total of 109 roadway segments were identified as reference sites with similar roadway characteristics and traffic volume to the treated sites in the before period. Florida-specific full SPFs were developed using the NB distribution. Tables 5-21 and 5-22 provide the results of Florida-specific full SPFs for total crashes and F+I crashes, respectively.

Table5-21: Florida-Specific Full SPFs for *Converting a TWLTL to a Raised Median* (Total Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-19.7458	2.6529	-24.9454	-14.5462	55.40	< 0.0001
Log(AADT)	1	2.2798	0.2403	1.8089	2.7507	90.03	< 0.0001
Length	1	1.5526	0.6836	0.2128	2.8924	5.16	0.0231
Speed Limit	1	-0.0477	0.0239	-0.0945	-0.0009	4.00	0.0455
Dispersion	1	1.0909	0.1712	0.8020	1.4839		

Table 5-22: Florida-Specific Full SPFs for *Converting a TWLTL to a Raised Median* (F+I Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-19.6039	2.6427	-24.7834	-14.4244	55.03	< 0.0001
Log(AADT)	1	2.2493	0.2421	1.7748	2.7239	86.30	< 0.0001
Length	1	1.7570	0.6638	0.4561	3.0579	7.01	0.0081
Speed Limit	1	-0.0560	0.0234	-0.1019	-0.0102	5.74	0.0166
Dispersion	1	0.9558	0.1657	0.6804	1.3426		

All variables shown in SPFs are significant at a 95% confidence level. Table 5-23summarizes the CMFs using naïve before-after and before-after with comparison group, and before-after with empirical Bayes methods. Since the standard errors of the CMFs are lower for the CG method than the EB method for all crash types, the CMFs estimated using the CG method are recommended as Florida-specific CMFs for converting a TWLTL to a raised median.

In particular, this treatment is the most safety effective for head-on crashes as indicated by the lowest CMF among crash types and severity levels.

Table 5-23: Recommended CMFs for *Converting a TWLTL to a Raised Median* in Florida

Severity/ Crash type	Before-After with CG		Before-After with EB (Full SPF)	
	CMF	SE	CMF	SE
Total Crashes	**0.53**	**0.02**	0.73	0.04
F+I	**0.67**	**0.04**	0.89	0.06
Head-on	**0.27**	**0.07**	0.49	0.15

Note: The values in bold are recommended CMFs for Florida.

5.5 Adding Lighting

5.5.1 Result of Analysis

The observational before-after with CG method was applied to the 45 and 33 treated sites for all road types with all number of lanes and urban 4-lane/6-lane principal and minor arterials, respectively. The safety effectiveness of *adding lighting* was estimated for individual sites and averaged over all sites using the crash data from 45 treated and 33 comparison sites, respectively, with similar roadway characteristics and AADT.

In the before-after with EB method, a total of 230and 164 roadway segments were identified as reference sites for all road types with all number of lanes and urban 3-lane/4-lane principal and minor arterials, respectively. Roadway characteristics and crash data were collected from FDOT databases. Simple and full SPFs with NB distribution were developed using these data. Tables 5-24 and 5-25 present the best full SPFs for different crash types and severity levels: 1) all crashes, 2) non-injury crashes, 3) fatal and injury (F+I), 4) severity levels (3 to 4) crashes, 5)rear end crashes, 6) angle crashes, 7)all Single vehicle run-off road crashes, and 8) All other crashes. CMFs were estimated for different crash types and severity levels using their respective SPFs. All variables shown in SPFs are significant at a 95% confidence level.

Table 5-24: Florida-Specific SPFs for *Adding Lighting* (All Road Types with All Number of Lanes)

		Intercept		Log(AADT)		Speed Limit		Length		Over Dispersion Parameter (K)
Crash Type	Severity levels	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	
All types	All	-4.8170	<.0016	0.3473	<.0214	0.0422	<.0001	0.1565	<.0001	0.7831
	No Injury	-7.866	<.0001	0.5529	<.0005	0.0442	<.0003	0.1400	<.0001	0.8033
	F+I	-6.2509	<.0001	0.4509	<.0034	0.0396	<.0013	0.1551	<.0001	0.8984
	Severity Level 3-5	-3.7382	<.0279	0.3766	<.0277	-	-	0.1824	<.0001	1.0227
Rear-end	All	-10.5845	<.0001	0.8627	<.0001	0.0279	<.0250	0.1254	<.0001	0.6053
Angle	All	-10.9692	<.0001	0.7679	<.0001	0.0465	<.0012	0.1208	<.0001	0.5952
Single	All	-4.3031	<.0001	-	-	0.0642	<.0001	0.1408	<.0001	0.9322
All other	All	-2.0503	<.0003	-	-	0.0402	<.0001	0.1616	<.0001	0.5833

Table5-25: Florida-Specific SPFs for *Adding Lighting* (Urban 4-lane/6-lane Principal and Minor Arterials)

		Intercept		Log(AADT)		Speed Limit		Length		Over Dispersion Parameter (K)
Crash Type	Severity levels	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	Estimate	P-Value	
All types	All	-4.3123	<.0372	0.4262	<.0308	0.0203	<.0488	0.1641	<.0001	0.4579
	No Injury	-2.1816	<.0032	-	-	0.0569	<.0001	-	-	1.3945
	F+I	-5.6659	<.0169	0.4930	<.0278	0.0242	<.0277	0.1617	<.0001	0.4672
	Severity Level 3-5	-1.1384	<.0474	-	-	0.0273	<.0153	0.1558	<.0001	0.4337
Rear-end	All	-8.5910	<.0084	0.7973	<.0110	-	-	0.1688	<.0001	0.6434
Angle	All	-8.4649	<.0041	0.7680	<.0068	-	-	0.1525	<.0001	0.1505
Single	All	-4.6611	<.0002	-	-	0.0597	<.0118	0.1797	<.0003	1.0939
All other	All	-1.4051	<.0266	-	-	0.0496	<.0001	-	-	1.1446

5.5.2 Comparison with CMFs in HSM

For all road types with all number of lanes, *adding lighting* has a positive effect on reduction in crashes for all crash types and severity levels except for the no injury crashes as shown in Table 5-26. Florida-specific CMFs were compared with the CMFs in the HSM for F+I and no injury crashes and they were similar. The CMFs in the HSM were estimated using meta-analysis/expert panel and the EB method. The before-after with EB method provided lower standard errors of

CMFs than the before-after CG method. Therefore, CMFs from the EB method are recommended for the CMFs for the crash types and severity levels that do not exist in the HSM.

Table5-26: Recommended CMFs for *Adding Lighting* in Florida (All Road Types with All Number of Lanes)

		Florida-specific						HSM	
		Before-After with CG		Before-After with EB					
				Simple SPF		Full SPF			
Crash Type	Severity Levels	CMF	SE	CMF	SE	CMF	SE	CMF	SE
All types	F+I	0.60	0.15	0.57	0.13	**0.63**	**0.12**	0.72	0.06
	No- Injury	0.87	0.24	0.82	0.19	**0.84**	**0.18**	0.83	0.07
	Injury Level 3-5	0.93	0.30	**0.89**	**0.17**	0.91	0.19	N/A	N/A
	All Severity	0.72	0.12	0.63	0.11	**0.68**	**0.09**	N/A	N/A
Rear End	All	0.65	0.21	0.61	0.15	**0.67**	**0.14**	N/A	N/A
Angle	All	0.68	0.24	**0.64**	**0.18**	0.67	0.19	N/A	N/A
Single	All	0.75	0.27	**0.72**	**0.18**	0.77	0.21	N/A	N/A
All other	All	0.67	0.16	0.70	0.10	**0.72**	**0.08**	N/A	N/A

Note: The values in bold are recommended CMFs for Florida.

For urban 4-lane/6-lane principal and minor arterials, *adding lighting* also has a positive effect on reduction in crashes for all crash types and severity levels as shown in Table 5-27. The HSM does not specify CMFs for this particular road type. Similar to all road types with all number of lanes, the before-after with EB method (using full SPFs) provided lower standard errors than the before-after with CG method. Therefore, it is recommended to use CMFs from the EB method.

Table 5-27: Florida-Specific CMFs for *Adding Lighting* (Urban 4-lane/6-lane Principal and Minor Arterials)

		Florida-specific				HSM	
		Before-After with CG		Before-After with EB (Full SPF)			
Crash Type	**Severity Levels**	**CMF**	**SE**	**CMF**	**SE**	**CMF**	**SE**
All types	**F+I**	0.70	0.11	**0.68**	**0.05**	N/A	N/A
	No-Injury	0.74	0.09	**0.76**	**0.08**	N/A	N/A
	Injury Level 3-5	0.75	0.15	**0.77**	**0.09**	N/A	N/A
	All Severity	0.72	0.11	**0.74**	**0.10**	N/A	N/A
Rear-end	**All**	0.73	0.18	**0.62**	**0.12**	N/A	N/A
Angle	**All**	0.77	0.14	**0.82**	**0.10**	N/A	N/A
Single	**All**	0.60	0.13	**0.63**	**0.09**	N/A	N/A
All other	**All**	0.71	0.12	**0.82**	**0.12**	N/A	N/A

Note: The values in bold are recommended CMFs for Florida.

5.6 Adding a Raised Median

5.6.1 Result of Analysis

The research team evaluated safety effectiveness of *adding a raised median* using cross-sectional analysis. A set of Florida-specific SPFs using NB distribution were developed to estimate CMFs for each treatment at a specific road type and setting. SPFs describe crash frequency in a function of explanatory variables including the presence of a raised median, AADT and length of roadway segments as follows:

$$F_i = \exp(\alpha + \beta_1 * RMED_i + \beta_2 * Length_i) * AADT_i^{\beta_3} \quad (5\text{-}3)$$

where,

F_i = crash frequency on a road segment i;

$RMED_i$ = presence of a raised median on a road segment i (= 1 if the median of a segment i is raised, = 0 if the median of a segment i is not raised);

$Length_i$= length of a road segment i (mi);

$AADT_i$ = average annual daily traffic on a road segment i (veh/day);

α = constant;

β = coefficients for variables.

Then CMFs were calculated using the following equation:

$$CMF = \exp(\beta_1 * (1-0)) = \exp(\beta_1) \quad (5\text{-}4)$$

CMFs for urban two-lane roads could not be estimated since the coefficient β_1 was not statistically significant at a 90% confidence level. This is potentially because medians are not raised on most segments of two-lane roads as shown in Table 4-18. The results of SPFs for urban and rural multi-lane roads by severity (injury/non-injury) and crash type (head-on) are shown in Tables 5-28 and5-29.The SPF for all crashes (all severities) was not developed since the CMF for this crash type and severity level is not provided in the HSM. All the factors are statistically significant at a 90% confidence level.

Table5-28: Florida-Specific SPFs for *Adding a Raised Median* on Urban Multi-Lane Roads

(a) Injury crashes (KABC)

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	829	888.8753	1.0722
Pearson Chi-Square	829	953.9374	1.1507
Log Likelihood		4411.3118	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-14.5572	0.8324	-16.1886	-12.9257	305.84	<.0001
RMED	1	**-0.3011**	0.1161	-0.5286	-0.0736	6.73	0.0095
Log(AADT)	1	1.4698	0.0821	1.3089	1.6307	320.52	<.0001
Length	1	0.8253	0.0779	0.6725	0.9781	112.10	<.0001
Dispersion	1	1.1087	0.0906	0.9446	1.3014		

(b) Non-injury crashes (O)

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	829	866.8724	1.0457
Pearson Chi-Square	829	953.9374	1.1507
Log Likelihood		3621.7713	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-13.9038	0.8106	-15.4926	-12.3150	294.18	<.0001
RMED	1	**-0.2123**	0.1131	-0.4339	0.0092	3.53	0.0604
Log(AADT)	1	1.3998	0.0800	1.2430	1.5565	306.31	<.0001
Length	1	0.7672	0.0701	0.6298	0.9045	119.85	<.0001
Dispersion	1	0.9786	0.0841	0.8270	1.1581		

(c) Head-on crashes (KABCO)

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	829	210.7986	0.2543
Pearson Chi-Square	829	848.0456	1.0230
Log Likelihood		-172.7704	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-19.3184	3.0238	-25.2448	-13.3919	40.82	<.0001
RMED	1	**-1.1117**	0.3781	-1.8528	-0.3706	8.64	0.0033
Log(AADT)	1	1.6339	0.2954	1.0549	2.2129	30.59	<.0001
Length	1	0.3924	0.1692	0.0607	0.7240	5.38	0.0204
Dispersion	1	1.5643	0.9695	0.4643	5.2709		

Table5-29: Florida-Specific SPFs for *Adding a Raised Median* on Rural Multi-Lane Roads

(a) Injury crashes (KABC)

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	414	445.9688	1.0772
Pearson Chi-Square	414	465.8810	1.1253
Log Likelihood		1459.5887	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-14.0892	1.1658	-16.3741	-11.8043	146.06	<.0001
RMED	1	**-0.2743**	0.1395	-0.5478	-0.0008	3.86	0.0493
Log(AADT)	1	1.4440	0.1148	1.2190	1.6690	158.23	<.0001
Length	1	0.5315	0.0759	0.3827	0.6804	48.99	<.0001
Dispersion	1	0.9439	0.1143	0.7445	1.1968		

(b) Non-injury crashes (O)

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	414	435.3235	1.0515
Pearson Chi-Square	414	476.4638	1.1509
Log Likelihood		1850.6638	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-15.5619	1.2401	-17.9924	-13.1314	157.48	<.0001
RMED	1	**-0.2834**	0.1509	-0.5792	0.0125	3.52	0.0605
Log(AADT)	1	1.5990	0.1227	1.3585	1.8395	169.85	<.0001
Length	1	0.4171	0.0746	0.2710	0.5633	31.29	<.0001
Dispersion	1	1.1466	0.1309	0.9168	1.4340		

(c) Head-on crashes (KABCO)

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	414	64.8923	0.1567
Pearson Chi-Square	414	302.3123	0.7302
Log Likelihood		-69.3515	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-24.8252	7.0977	-38.7365	-10.9140	12.23	0.0005
RMED	1	**-1.2442**	0.6412	-2.5008	0.0125	3.77	0.0523
Log(AADT)	1	2.1401	0.6896	0.7885	3.4916	9.63	0.0019
Length	1	0.4893	0.2712	-0.0422	1.0209	3.26	0.0712
Dispersion	1	5.9525	3.3379	1.9832	17.8658		

5.6.2 Comparison with CMFs in HSM

Table 5-30 compares Florida-specific CMFs with CMFs in the HSM. The CMF in the HSM was estimated using the meta analysis. In general, Florida-specific CMFs are comparable with CMFs in the HSM for all road types and severity. In particular, Florida-specific CMFs indicate that safety effectiveness of a raised median is much higher for head-on crashes (68~71% reduction). Thus, a raised median is effective in reducing head-on crashes which are generally more severe than the other crash types.

Table 5-30: Recommended CMFs for *Adding a Raised Median* in Florida

	Florida-specific			HSM		
Setting (Road type)	Traffic Volume	Crash Type (Severity)	CMF (SE)	Traffic Volume	Crash Type (Severity)	CMF (SE)
Urban (Two-lane)[a]	500~54,500	All types (Injury)	**-***	Unspecified	All types (Injury)	**0.61** (0.1)
Urban (Multi-lane)[b]	1000~158,000	All types (Injury)	**0.81 (0.09)**	Unspecified	All types (Injury)	0.78 (0.02)
		All types (Non-injury)	**0.74 (0.09)**		All types (Non-injury)	1.09 (0.02)
		Head-on (All severity)	**0.32 (0.13)**		Head-on (All severity)	-
Rural (Multi-lane)[b]	1,547~139,000	All types (Injury)	**0.76 (0.12)**	Unspecified	All types (Injury)	0.88 (0.03)
		All types (Non-injury)	**0.75 (0.11)**		All types (Non-injury)	0.82 (0.03)
		Head-on (All severity)	**0.29 (0.20)**		Head-on (All severity)	-

*Not statistically significant at a 90% confidence level.
[a]Crashes not at intersection and driveway access only (SITELOC = 1 or 4)
[b]Crashes not at intersection only (SITELOC = 1 only)
Note: The values in bold are recommended CMFs for Florida.

5.7 Increasing Median Width

5.7.1 Result of Analysis

Florida-specific SPFs were developed to identify the effect of *increasing median width* on crash frequency as follows:

$$F_i = \exp(\alpha + \beta_1 * (MEDWD_i - 10) + \beta_2 * Length_i) * AADT_i^{\beta_3} \qquad (5\text{-}5)$$

where,

$MEDWD_i$= the median width of a road segment *i* (ft).

Ten feet was subtracted from each specific median width in order to identify marginal effects of increasing median width from 10 feet, which is the baseline condition of median width in the HSM. Then Florida-specific CMFs were calculated using the following equation:

$$CMF = \exp(\beta_1 * (MEDWD - 10)) \qquad (5\text{-}6)$$

It was found that the length of roadway segments is not significant for rural 4-lane with full access control at a 95% confidence level. Also, the effect of increasing median width on crash frequency was counter-intuitive for rural 4-lane with partial and non-access control - unrealistically very high increase in crash frequency with an increase in median width for non-raised medians. Thus, CMFs were developed for urban roads only.

In the HSM, CMFs are provided for cross-median crashes only on “traversable” medians. However, since there are raised medians on most urban 4-lane and 5 or more lane roadway segments as shown in Table 4-15, cross-median crashes rarely occurred in Florida. Thus, CMFs for total crashes on all median types (mostly raised medians) were estimated in this study. The results of SPFs for urban multi-lane roads are shown in Tables5-31 ~ 5-33.All the factors are statistically significant at a 90% confidence level.

Table 5-31: Florida-Specific SPF for *Increasing Median Width* on Urban 4 Lanes with Full Access Control

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	106	79.4988	0.7500
Pearson Chi-Square	106	80.5226	0.7596
Log Likelihood		711.0245	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-25.5109	6.5665	-38.3810	-12.6408	15.09	0.0001
MEDWD-10	1	**-0.0156**	0.0042	-0.0238	-0.0074	13.93	0.0002
LogAADT	1	2.6218	0.6296	1.3878	3.8557	17.34	<.0001
Length	1	-0.6511	0.2894	-1.2184	-0.0838	5.06	0.0245
Dispersion	1	4.6668	1.0016	3.0643	7.1075		

Table 5-32: Florida-Specific SPF for *Increasing Median Width* on Urban 5 or More Lanes with Full Access Control

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	143	170.1928	1.1902
Pearson Chi-Square	143	125.4124	0.8770
Log Likelihood		9114.5270	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-13.5019	1.6691	-16.7732	-10.2305	65.44	<.0001
MEDWD-10	1	**-0.0016**	0.0006	-0.0027	-0.0004	7.28	0.0070
Log(AADT)	1	1.4194	0.1509	1.1237	1.7151	88.51	<.0001
Length	1	0.6398	0.0744	0.4940	0.7857	73.89	<.0001
Dispersion	1	0.4318	0.0629	0.3245	0.5746		

Table 5-33: Florida-Specific SPF for *Increasing Median Width* on Urban 4 Lanes with Partial or No Access Control

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	1007	628.3734	0.6240
Pearson Chi-Square	1007	1037.9429	1.0307
Log Likelihood		2061.2973	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-7.1363	1.1517	-9.3936	-4.8790	38.39	<.0001
MEDWD-10	1	**-0.0060**	0.0034	-0.0126	0.0007	3.11	0.0779
Log(AADT)	1	0.7435	0.1164	0.5152	0.9717	40.77	<.0001
Length	1	0.5976	0.1456	0.3122	0.8829	16.85	<.0001
Dispersion	1	7.0200	0.5501	6.0205	8.1854		

5.7.2 Comparison with CMFs in HSM

Florida-specific CMFs for *increasing median width* calculated using Eq. 5-6were compared with CMFs in the HSM as shown in Table 5-34. The CMFs in the HSM were also estimated using the cross-sectional method (Harkey et al., 2008).Negative coefficients of (*MEDWD*-10) indicate that CMFs decrease as median width increases from 10 feet, similar to CMFs in the HSM. This is potentially because there are larger recovery and emergency parking areas for run-off-the-road vehicles at wider medians (Haleem et al., 2013). However, it should be noted that Florida-specific CMFs are not directly comparable with the HSM CMFs since they are for different crash type and median type.

It was found that *increasing median width* has the highest safety effectiveness on urban 4-lane roads with full access control followed by urban 4-lane roads with partial or no access control and urban 5 or more lane roads with full access control. This result indicates that *increasing median width* is more effective in reducing total crashes on roadway segments with lower number of lanes and full access control.

Table 5-34: Recommended CMFs for *Increasing Median Width* in Florida

(a) Urban 4lanes with Full Access Control

	Florida-specific (All medians)			HSM (Traversable medians only)		
Median Width	Traffic Volume	Crash Type (Severity)	CMF (SE)	Traffic Volume	Crash Type (Severity)	CMF (SE)
10-ft to 20-ft conversion	7,800~123,500	All types (All severity)	**0.86 (0.04)**	4,400~131,000	Cross-median (Unspecified)	0.89 (0.04)
10-ft to 30-ft conversion			**0.73 (0.06)**			0.80 (0.07)
10-ft to 40-ft conversion			**0.63 (0.08)**			0.71 (0.09)
10-ft to 50-ft conversion			**0.54 (0.09)**			0.64 (0.1)
10-ft to 60-ft conversion			**0.46 (0.1)**			0.57 (0.1)
10-ft to 70-ft conversion			**0.39 (0.1)**			0.51 (0.1)
10-ft to 80-ft conversion			**0.34 (0.1)**			0.46 (0.1)
10-ft to 90-ft conversion			**0.29 (0.1)**			0.41 (0.1)
10-ft to 100-ft conversion			**0.25 (0.1)**			0.36 (0.1)

Note: The values in bold are recommended CMFs for Florida.

Table 5-34: Recommended CMFs for *Increasing Median Width* in Florida (Continued)

(b) Urban5 or more lanes with Full Access Control

	Florida-specific (All medians)			HSM (Traversable medians only)		
Median Width	Traffic Volume	Crash Type (Severity)	CMF (SE)	Traffic Volume	Crash Type (Severity)	CMF (SE)
10-ft to 20-ft conversion	18,900~158,000	All types (All severity)	**0.98 (0.01)**	2,600~282,000	Cross-median (Unspecified)	0.89 (0.04)
10-ft to 30-ft conversion			**0.97 (0.01)**			0.80 (0.07)
10-ft to 40-ft conversion			**0.95 (0.02)**			0.71 (0.09)
10-ft to 50-ft conversion			**0.94 (0.02)**			0.64 (0.1)
10-ft to 60-ft conversion			**0.92 (0.03)**			0.57 (0.1)
10-ft to 70-ft conversion			**0.91 (0.03)**			0.51 (0.1)
10-ft to 80-ft conversion			**0.89 (0.04)**			0.46 (0.1)
10-ft to 90-ft conversion			**0.88 (0.04)**			0.41 (0.1)
10-ft to 100-ft conversion			**0.87 (0.05)**			0.36 (0.1)

(c) Urban4 lanes with Partial or No Access Control

	Florida-specific (All medians)			HSM (Traversable medians only)		
Median Width	Traffic Volume	Crash Type (Severity)	CMF (SE)	Traffic Volume	Crash Type (Severity)	CMF (SE)
10-ft to 20-ft conversion	100~97,000	All types (All severity)	**0.94 (0.03)**	1,900~150,000	Cross-median (Unspecified)	0.87 (0.04)
10-ft to 30-ft conversion			**0.89 (0.06)**			0.76 (0.06)
10-ft to 40-ft conversion			**0.84 (0.09)**			0.67 (0.08)
10-ft to 50-ft conversion			**0.79 (0.11)**			0.59 (0.1)
10-ft to 60-ft conversion			**0.74 (0.13)**			0.51 (0.1)
10-ft to 70-ft conversion			**0.70 (0.14)**			0.45 (0.1)
10-ft to 80-ft conversion			**0.66 (0.16)**			0.39 (0.1)
10-ft to 90-ft conversion			**0.62 (0.17)**			0.34 (0.1)
10-ft to 100-ft conversion			**0.58 (0.18)**			0.30 (0.1)

Note: The values in bold are recommended CMFs for Florida.

5.8 Narrowing Lane Width

5.8.1 Result of Analysis

Florida-specific SPFs were developed to identify the effect of *narrowing lane width* on crash frequency as follows:

i) Rural two-lane roadway segments:

$$F_i = \exp(\alpha + \beta_1 * (LANEWD_i - 12) + \beta_2 * MAXSP_i + \beta_3 * DIV_i + \beta_4 * Length_i) * AADT_i^{\beta_3} \quad (5\text{-}7)$$

ii) Rural multi-lane undivided or divided roadway segments:

$$F_i = \exp(\alpha + \beta_1 * (LANEWD_i - 12) + \beta_2 * MAXSP_i + \beta_3 * Length_i) * AADT_i^{\beta_3} \quad (5\text{-}8)$$

where,

$LANEWD_i$= the lane width of a road segment *i* (ft);

$MAXSP_i$= the speed limit on a road segment *i* (mph);

DIV_i=1 if a roadway segment *i* is divided, = 0 a roadway segment *i* is undivided.

Shoulder width was initially included in the above models but it was not statistically significant at a 90% confidence level. Twelve feet was subtracted from each specific lane width in order to identify marginal effects of *narrowing lane width* from 12 feet. Twelve feet is designated as the baseline condition of lane width in the HSM. Florida-specific CMFs were calculated using the following equation:

$$CMF = \exp(\beta_1 * (LANEWD - 12)) \quad (5\text{-}9)$$

The results of SPFs for rural two-lane and divided multi-lane roads are shown in Tables 5-35 and 5-36.All the factors are statistically significant at a 90% confidence level. Lane width was not significant in the SPF for rural undivided multi-lane roads. As shown in the tables, lane width has a negative effect on crash frequency. This indicates that crash frequency is lower for narrower lane width. The tables also show that crash frequency is higher on the road segments with higher speed limit. In particular, crash frequency is lower on the divided rural two-lane roads than the undivided rural two-lane roads.

Table 5-35: Florida-Specific SPFs for *Narrowing Lane Width* on Rural Two-lane Roadways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	964	466.7806	0.4842
Pearson Chi-Square	964	2041.5260	2.1178
Log Likelihood		-358.3532	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-10.0802	1.1432	-12.3207	-7.8396	77.75	<.0001
LANEWD-12	1	**0.1593**	0.0860	-0.0091	0.3278	3.44	0.0638
MAXSP	1	0.0815	0.0107	0.0606	0.1024	58.45	<.0001
DIV	1	-0.5903	0.2689	-1.1173	-0.0634	4.82	0.0281
LENGTH	1	0.3780	0.0522	0.2756	0.4804	52.35	<.0001
Log(AADT)	1	0.4882	0.1071	0.2783	0.6981	20.78	<.0001
Dispersion	1	1.3244	0.3384	0.8026	2.1854		

Table 5-36: Florida-Specific SPFs for *Narrowing Lane Width* on Rural Divided Multi-Lane Roadways

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	410	384.7612	0.9384
Pearson Chi-Square	410	484.4806	1.1817
Log Likelihood		510.8340	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-13.8442	1.2894	-16.3713	-11.3170	115.28	<.0001
LANEWD-12	1	**0.2717**	0.1442	-0.0108	0.5542	3.55	0.0595
MAXSP	1	0.0446	0.0065	0.0318	0.0574	46.68	<.0001
LENGTH	1	1.0897	0.1282	0.8386	1.3409	72.30	<.0001
Log(AADT)	1	0.5179	0.0719	0.3771	0.6587	51.95	<.0001
Dispersion	1	0.6713	0.1494	0.4340	1.0385		

5.8.2 Comparison with CMFs in HSM

Florida-specific CMFs for *narrowing lane width* calculated using Eq. 3-7 were compared with CMFs in the HSM as shown in Table 3-10. The table shows that the effects of narrowing lane width are inconsistent between Florida and the HSM. In the HSM, CMFs increase as the lane width decreases – i.e., wider lane width is safer.

The CMF in the HSM was estimated using the cross-sectional method and the expert panel’s judgment. The HSM recommends that CMFs are determined using the crash modification functions (CMFunctions) which describe CMF in a function of AADT. In case of rural two-lane roads, the CMFunctions were developed based on Zegeer et al. (1988) and Griffin and Mak (1987) for AADT > 2000 veh/day and AADT < 400 veh/day, respectively, and the expert panel’s judgment for AADT between 400 and 2000 veh/day (Harwood et al., 2000).

Table 5-37: Recommended CMFs for *Narrowing Lane Width* in Florida

		Florida-specific			HSM	
Setting (Road type)	Lane Width	AADT	CMF	SE	AADT	CMF
Rural (Two-lane)	9-ft or less 10-ft 11-ft 12-ft or more	103~56,000	**0.62** **0.73** **0.85** **1.00**	**0.20** **0.17** **0.11** **-**	All	1.05~1.50 1.02~1.30 1.01~1.05 1.00
Rural (Undivided Multi-lane)	9-ft or less 10-ft 11-ft 12-ft or more		-*		All	1.04~1.38 1.02~1.23 1.01~1.04 1.00
Rural (Divided Multi-lane)	9-ft or less 10-ft 11-ft 12-ft or more	1,600~139,000	**0.44** **0.58** **0.76** **1.00**	**0.16** **0.13** **0.07** **-**	All	1.03~1.25 1.01~1.15 1.01~1.03 1.00

Note: The values in bold are recommended CMFs for Florida.
*Not statistically significant at a 90% confidence level.

However, unlike the HSM, some studies found that narrowing lane width reduces crash frequency similar to this study. For instance, Mehta and Lu (2013) found that crash frequency increases with lane width on rural two-lane roads and rural four-lane divided roads in Alabama. The study accounted for the effects of speed limits and shoulder width in SPFs. Gross et al. (2009) also reported that effects of lane width on crash frequency were neither consistently positive nor negative due to variation in shoulder width. Thus, they suggested that CMFs be determined considering interaction between lane width and shoulder width. Potts et al. (2007) also recommended that *narrowing lane width* be used as a treatment based on local conditions since the effect of lane width varies by location. In this sense, the above Florida-specific CMFs are reasonable as they were estimated using the local data. Higher CMFs for wider lane width are mainly because speed limits are generally higher on the road segments with wider lane width as shown in Tables 4-18 and 4-19.

5.9 Converting 4 to 3 Lanes

5.9.1 Result of Analysis

Florida-specific SPFs with NB distribution were developed to identify the effect of *converting 4 to 3 lanes* on urban arterials as follows:

$$F_i = \exp(\alpha + \beta_1 * Road\_Type_i + \beta_2 * Length_i) * AADT_i^{\beta_3} \qquad (5\text{-}10)$$

where,

$Road\_Type_i$ = roadway type of a road segment *i* (= 1 if the segment *i* is a 3-lane road, = 0 if the segment *i* is a 4-lane road).

Then CMFs were calculated using the following equation:

$$CMF = \exp(\beta_1) \qquad (5\text{-}11)$$

The results of SPFs for KABCO and KABC are shown in Table 5-38. All the factors are statistically significant at a 90% confidence level.

Table 5-38: Florida-Specific SPFs for *Converting 4 to 3 Lanes* on Urban Arterials

(a) KABCO

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	337	235.2878	0.6982
Pearson Chi-Square	337	227.6905	0.6756
Log Likelihood		555.7689	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-18.7535	2.9058	-24.4488	-13.0583	41.65	<.0001
Road_type	1	**-0.5767**	0.2661	-1.0982	-0.0552	4.70	0.0302
Length	1	0.7595	0.4377	-0.0985	1.6175	3.01	0.0827
Log(AADT)	1	2.0429	0.3124	1.4306	2.6552	42.76	<.0001
Dispersion	1	4.4055	0.5899	3.3887	5.7275		

(b) KABC

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	337	220.7746	0.6551
Pearson Chi-Square	337	286.0248	0.8487
Log Likelihood		-12.7586	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-17.1244	2.8261	-22.6633	-11.5854	36.72	<.0001
Road_type	1	**-0.4574**	0.2605	-0.9679	0.0532	3.08	0.0791
Length	1	0.9034	0.4085	0.1028	1.7040	4.89	0.0270
Log(AADT)	1	1.7887	0.3011	1.1985	2.3789	35.29	<.0001
Dispersion	1	3.5658	0.5745	2.6002	4.8900		

5.9.2 Comparison with CMFs in HSM

Florida-specific CMFs were calculated and compared with CMFs in the HSM for KABCO as shown in Table 5-39. The CMF for KABC is not provided in the HSM. The CMF in the HSM was estimated using the EB method.

The table shows that the Florida-specific CMF is lower than the CMF in the HSM for KABCO. Since standard error of Florida-specific CMF is higher than standard error of CMF in the HSM, it can be concluded that the CMF for KABCO in the HSM is more reliable. However, traffic volume is only specified for Florida-specific CMFs, but not CMFs in the HSM.

Table 5-39: Recommended CMFs for *Converting 4 to 3 Lanes* in Florida

	Florida-specific			HSM		
Road type	Traffic Volume	Crash Type (Severity)	CMF (SE)	Traffic Volume	Crash Type (Severity)	CMF (SE)
Urban Undivided Arterials	2,000~28,500	All types (KABCO)	**0.56 (0.15)**	Unspecified	All types (KABCO)	0.71 (0.02)
		All types (KABC)	**0.63 (0.17)**		All types (KABC)	-

Note: The values in bold are recommended CMFs for Florida.

5.10 Narrowing Paved Right Shoulder Width

5.10.1 Result of Analysis

SPFs were developed to identify the safety effects of *narrowing paved right shoulder width* on crash frequency as follows:

$$F_i = \exp(\alpha + \beta_1 * (Shld\_Width_i - 8) + \beta_2 * Length_i) * AADT_i^{\beta_3} \quad (5\text{-}12)$$

where,

$Shld\_Width_i$= the paved right shoulder width of a road segment *i* (ft).

Eight feet was subtracted from each specific shoulder width in order to identify marginal effects of narrowing shoulder width from 8 feet. Eight feet is designated as the baseline condition of lane width in the HSM. Florida-specific CMFs were calculated using the following equation:

$$CMF = \exp(\beta_1 * (Shld\_Width) - 8) \quad (5\text{-}13)$$

SPFs for KABCO and KABC are shown in Table 5-40. All the factors are statistically significant at a 90% confidence level.

Table 5-40: Florida-Specific SPFs for *Narrowing Paved Right Shoulder Width* on Rural Multi-Lane Roadways

(a) KABCO

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	313	343.0863	1.0961
Pearson Chi-Square	313	521.0393	1.6647
Log Likelihood		623.3225	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-9.9555	1.3421	-12.5859	-7.3251	55.03	<.0001
Shld_Width-8	1	**-0.0749**	0.0444	-0.1620	0.0122	2.84	0.0919
Length	1	0.8038	0.1504	0.5090	1.0985	28.56	<.0001
Log(AADT)	1	1.0596	0.1344	0.7961	1.3230	62.15	<.0001
Dispersion	1	0.9172	0.1115	0.7228	1.1639		

(b) KABC

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	313	325.8380	1.0410
Pearson Chi-Square	313	398.8423	1.2743
Log Likelihood		-120.8057	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-10.8371	1.5322	-13.8401	-7.8341	50.03	<.0001
Shld_Width-8	1	**-0.0789**	0.0479	-0.1727	0.0149	2.72	0.0993
Length	1	0.8685	0.1482	0.5780	1.1591	34.32	<.0001
Log(AADT)	1	1.0649	0.1527	0.7656	1.3641	48.64	<.0001
Dispersion	1	0.7401	0.1372	0.5149	1.0644		

5.10.2 Comparison with CMFs in HSM

Florida-specific CMFs were calculated and compared with CMFs in the HSM as shown in Table 5-41. The CMFs in the HSM were estimated using analysis-driven expert panels. The research team could not compare Florida-specific CMFs for KABC with the HSM since the CMF for KABC was not provided in the HSM.

In general, Florida-specific CMFs for KABCO has higher safety effects than CMF in the HSM. However, Florida-specific CMFs are not directly comparable with the HSM CMFs since they did not specify traffic volume and standard error. It can be concluded that Florida-specific CMFs for KABCO and KABC are more reliable results.

Table 5-41: Recommended CMFs for *Narrowing Paved Right Shoulder Width* in Florida

Treatment	Road Type	Florida-specific			HSM		
		AADT	CMF	SE	AADT	CMF	SE
Crash type: All Types / Severity: KABCO							
8 to 6-ft Conversion	Rural Multilane Highways	5,000 ~ 35,000	**1.16**	**0.05**	Unspecified	1.04	N/A
8 to 4-ft Conversion			**1.35**	**0.06**		1.09	N/A
8 to 2-ft Conversion			**1.57**	**0.07**		1.13	N/A
8 to 0-ft Conversion			**1.82**	**0.08**		1.18	N/A
Crash type: All Types / Severity: KABC							
8 to 6-ft Conversion	Rural Multilane Highways	5,000 ~ 35,000	**1.17**	**0.06**	-	-	
8 to 4-ft Conversion			**1.37**	**0.07**		-	
8 to 2-ft Conversion			**1.61**	**0.08**		-	
8 to 0-ft Conversion			**1.88**	**0.09**		-	

Note: The values in bold are recommended CMFs for Florida.

5.11 Adding a Bike Lane

5.11.1 Result of Analysis

Florida-specific SPFs were developed to predict crash frequency in a function of the presence of a bike lane, surface width, AADT and length of roadway segments as follows:

$$F_i = \exp(\alpha + \beta_1 * Bike\_Ln_i + \beta_2 * Surf\_Width_i + \beta_3 * Length_i) * AADT_i^{\beta_4} \quad (5\text{-}14)$$

where,

Bike_Ln$_i$ = presence of a bike lane *i* (= 1 if a bike lane exists on a segment *i*, = 0 if a bike lane does not exist on a segment *i*);

Surf_Width$_i$= surface width of a road segment i (ft).

Then CMFs were calculated using the following equation:

$$CMF = \exp(\beta_1) \quad (5\text{-}15)$$

The results of SPFs of All crash types and Bike-related crashes for KABCO and KABC are shown in Tables 5-42. All the factors are statistically significant at a 90% confidence level.

Table5-42: Florid-Specific SPFs for *Adding a Bike Lane* on Urban Multi-Lane Roadways

(a) All crash types and KABCO

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	587.4475	1.1474
Pearson Chi-Square	512	572.9884	1.1191
Log Likelihood		12724.8226	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-5.6584	1.7001	-8.9906	-2.3263	11.08	0.0009
Bike_Ln	1	**-0.3861**	0.1213	-0.6238	-0.1484	10.13	0.0015
Surf_Width	1	0.0139	0.0046	0.0049	0.0230	9.06	0.0026
Length	1	3.0304	0.4016	2.2433	3.8175	56.95	<.0001
Log(AADT)	1	0.6567	0.1803	0.3033	1.0102	13.26	0.0003
Dispersion	1	1.6478	0.1139	1.4391	1.8868		

(b) All crash types and KABCO

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	567.6695	1.1087
Pearson Chi-Square	512	528.9901	1.0332
Log Likelihood		4765.1393	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-6.5465	1.7139	-9.9057	-3.1873	14.59	0.0001
Bike_Ln	1	**-0.3196**	0.1216	-0.5579	-0.0812	6.91	0.0086
Surf_Width	1	0.0107	0.0046	0.0017	0.0197	5.46	0.0194
Length	1	3.1861	0.4035	2.3953	3.9768	62.36	<.0001
Log(AADT)	1	0.6972	0.1813	0.3418	1.0527	14.78	0.0001
Dispersion	1	1.5603	0.1210	1.3402	1.8164		

Table5-42: Florid-Specific SPFs for *Adding a Bike Lane* on Urban Multilane Roadways (Continued)

(c) Bike-related crashes and KABCO

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	293.8709	0.5740
Pearson Chi-Square	512	488.9287	0.9549
Log Likelihood		-267.7702	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-13.6638	3.3544	-20.2383	-7.0893	16.59	<.0001
Bike_Ln	1	**-0.8623**	0.2247	-1.3028	-0.4218	14.72	0.0001
Surf_Width	1	0.0138	0.0078	-0.0016	0.0292	3.10	0.0785
Length	1	2.5895	0.5058	1.5981	3.5810	26.21	<.0001
Log(AADT)	1	1.1077	0.3474	0.4267	1.7886	10.17	0.0014
Dispersion	1	1.6979	0.4085	1.0595	2.7209		

(d) Bike-related crashes and KABC

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	284.2315	0.5551
Pearson Chi-Square	512	495.4334	0.9676
Log Likelihood		-263.8280	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-13.2241	3.4032	-19.8942	-6.5540	15.10	0.0001
Bike_Ln	1	**-0.9205**	0.2325	-1.3761	-0.4648	15.67	<.0001
Surf_Width	1	0.0155	0.0080	-0.0002	0.0312	3.75	0.0529
Length	1	2.5632	0.5261	1.5320	3.5944	23.73	<.0001
Log(AADT)	1	1.0530	0.3525	0.3621	1.7438	8.92	0.0028
Dispersion	1	1.7699	0.4308	1.0985	2.8518		

Florida-specific CMFs were calculated as shown in Table 5-43. In general, Florida-specific CMFs show positive effects on road safety. In particular, the CMFs for bike-related crashes are lower than the CMFs for all crash types. The results indicate that a bike lane is more effective in reducing bike-related crashes than all crash types. For all crash types, safety effectiveness of adding a bike lane for KABCO is higher than KABC. On the other hand, for bike-related crashes, safety effectiveness of adding a bike lane for KABCO is lower than KABC.

Table 5-43:Recommended CMFs for *Adding a Bike Lane* in Florida

Crash Type	Traffic Volume	Severity	CMF	SE
All types	2,900~59,500	KABCO	**0.68**	**0.08**
		KABC	**0.73**	**0.09**
Bike-related Crashes		KABCO	**0.42**	**0.10**
		KABC	**0.40**	**0.09**

5.11.2 Comparison with CMFs in CMF Clearinghouse

Since the CMF for *adding a bike lane* is not available in the HSM, Florida-specific CMFs could not be compared with CMFs in the HSM. Instead, Florida-specific CMFs were compared with some CMFs in the CMF Clearinghouse as shown in Table 5-44. According to Jensen (2008), adding a bike lane increases frequencies of all crash types (KABCO), all crash types (KABC), and bike-related crashes (KABCO) for roadways in Copenhagen, Denmark. On the other hand, Rodegerdts et al. (2004) suggested adding a bike lane reduces bike-related crashes (KABCO). The CMFs in Jensen (2008) were estimated by before-after with CG method. However, Rodegerdts et al. (2004) did not specify the method used to estimate the CMF. The inconsistency in some results between Florida-specific and CMF Clearinghouse CMFs is mainly due to differences in roadway types, area types and driver/bicyclist behavior between the U.S. and Denmark.

Table 5-44: Comparison of CMFs for *Adding a Bike Lane* with CMF Clearinghouse

	Florida-Specific		CMF Clearinghouse			
			Jensen (2008)		Rodegerdts et al. (2004)	
Crash Type	Severity Levels	CMF	Severity Levels	CMF	Severity Levels	CMF
All types	KABCO	**0.68**	KABCO	1.30	KABCO	-
	KABC	**0.73**	KABC	1.27	KABC	-
Bike-related Crashes	KABCO	**0.42**	KABCO	1.27	KABCO	0.65
	KABC	**0.40**	KABC	-	KABC	-

Note: The values in bold are recommended CMFs for Florida.

CHAPTER 6. INTERSECTIONS AND SPECIAL FACILITIES

6.1 Signalization of Stop-Controlled Intersections

The safety effectiveness of adding a new traffic signal at stop-controlled intersections was evaluated using naïve before-after, before-after with comparison group methods and EB method. In order to validate the CMFs in the HSM, the treated sites were categorized according to the HSM; one CMF is estimated for all rural intersections and another two CMFs for urban 3-leg and 4-leg intersections, respectively.

6.1.1 Naïve Before-After

A total of 32 treated *signalized* intersections in rural area (8 intersections including three-leg and four-leg) and urban area (15 three-leg and 9 four-leg intersections) were used in naïve before-after analysis. As shown in Table 3-6, the signalization reduced total crashes in rural area by -3.9%, and total crashes at urban 3-leg and 4-leg intersections by 17.6% and 31.3%, respectively. It should be noted that the standard errors for the estimated CMFs are relatively high due to the limited number of treated sites. To avoid this problem, CMFs will also be estimated using cross-sectional analysis.

6.1.2 Before-After with Comparison Group

The observational before-after with comparison group was performed on the 32 treated sites mentioned as explained in the data collection section. The safety effectiveness of *signalization* was estimated for individual sites and averaged over all sites using crash experience data from 202 comparison sites with similar roadway characteristics and AADT. Table 6-1 shows the coefficients and goodness-of-fit of each SPF. The calibrated CMFs for total crashes in rural and urban 4-leg intersections showed a reduction in total crashes by 2.2% and 30.4%, respectively, but an increase in total crashes by 1.3% at urban 3-leg intersections as shown in Table6-2.

6.1.3 Before-After with Empirical Bayes

SPFs were developed using the NB Model formulation as follows:

(6-1)

where,

= predicted crash frequency;

= annual average daily traffic volume;

= 1 for 3-leg intersections or = 0 for 4-leg intersections;

= 1 if there exist two through lanes on major approach or = 0 otherwise; and

, , , = coefficients.

SPFs were developed for three intersection types (rural 3-leg and 4-leg intersections, urban 3-leg intersections, and urban 4-leg intersections) and four different crash types (total, right-angle, left-turn and rear-end crashes).In rural areas, SPFs were developed for 3-leg and 4-leg intersections together due to limited samples. In urban areas, SPFs were developed for 3-leg and 4-leg intersections separately. However, the SPF for left-turn crashes at urban 4-leg intersections was not significant. Thus, there are 11 SPFs as shown in Table 6-1. CMFs were estimated for different intersection and crash types using their respective SPFs. The AADT in the year 2007 was used to represent the AADT for years between 2005 and 2009.

Table 6-1: Florida-Specific SPFs for *Signalization of Stop-Controlled Intersections*

	No. of obser-vations	Log Likeli-hood	Full Log-Likelihood	AIC	Intercept	Log_ AADT	Leg*	Lane**	Dis-persion
Rural 3+4 Leg Total Crashes	45	25.11	-84.74	177.47	-6.09	0.78	-0.61	ns	0.44
Rural 3+4 Leg Right Angle Crashes	45	-33.69	-47.32	102.64	-6.08	0.65	-0.90	ns	0.91
Rural 3+4 Leg Left- Turn Crashes	45	-12.49	-14.98	35.95	-39.81	3.89	ns	ns	4.01
Rural 3+4 Leg Rear End Crashes	45	-30.48	-45.20	100.41	-11.63	1.19	-1.19	1.30	0.44
Urban 3-Leg Total Crashes	90	260.60	-206.71	419.41	-11.47	1.26	-	ns	1.39
Urban 3 Leg Right Angle Crashes	90	-65.99	-104.03	214.06	-10.32	0.99	-	ns	1.88
Urban 3 Leg Rear End Crashes	90	-26.74	-112.34	230.68	-26.85	2.63	-	ns	1.14
Urban 3 Leg Left-Turn Crashes	90	-56.29	-71.89	149.78	-14.40	1.33	-	ns	2.70
Urban 4-Leg Total Crashes	55	403.83	-126.07	258.13	-16.85	1.84	-	ns	1.01
Urban 4 Leg Right Angle Crashes	55	-4.31	-70.73	147.45	-19.22	1.94	-	ns	0.88
Urban 4 Leg Rear End Crashes	55	-13.43	-59.29	124.58	-23.70	2.35	-	ns	0.17
Urban 4 Leg Left-Turn Crashes	-	-	-	-	-	-	-	-	-

ns: Not significant at a 90% confidence level.
*Leg: = 1 for 3-leg intersections or= 0 for 4-leg intersections.
**Lane: = 1 if there exist two through lanes on major approach or = 0 otherwise.

All variables shown in SPFs are significant at a 90% confidence level. The result shows that3-leg intersections have lower number of crashes compared to 4-leg intersections. This result is reasonable since 3-leg intersections have less conflict points than 4-leg intersections.

The result also shows that intersection signalization has a positive effect on reduction in total crashes, angle crashes, and left-turn crashes for all types of intersections although some of these effects are not significant at a 95% confidence level. According to the result of EB analysis, angle crashes are significantly reduced at urban 3-leg and 4-leg intersections by 33.3% and 53.8%, respectively, as shown in Table 6-2.

Left-turn crashes were also reduced after the signalization. At rural 3-leg and 4-leg intersections, CMF was 0.5 which represents 50% reduction in left-turn crashes after signalization of stop-controlled intersections. At urban 3-leg intersections, left-turn crashes were reduced by 55%. Thus, signalization is a good treatment to reduce left-turn crashes at these two types of intersections. CMF for urban 4-leg intersections could not be determined because the SPF for urban 4-leg intersections was not significant. However, CMFs for left-turn crashes generally have positive effects for all types of intersections and before-after methods.

On the other hand, the results of EB method shows that CMFs for rear-end crashes are greater than one. This suggests that rear-end crashes are increased after signalization. This increasing trend is statistically significant at a 95% confidence level at urban 3-leg intersections. The result also shows that the increase in rear-end crashes is the highest at urban 3-leg intersections.

Table 6-2: Recommended CMFs for *Signalization of Stop-Controlled Intersections* in Florida

CMF Method	Florida-Specific CMF		
	Naïve	CG Method	EB Method
Rural 3-Leg & 4-Leg Intersections			
Total Crashes (S.E.)	1.04	0.98 (0.13)	0.99 (0.13)
Angle crashes (S.E.)	0.67	0.74* (0.18)	**0.70*** **(0.17)**
Rear-End Crashes (S.E.)	1.92	1.40 (0.37)	**1.95*** **(0.51)**
Left-Turn Crashes (S.E.)	0.53	1.35 (0.47)	**0.50*** **(0.20)**
Total Crashes (S.E.)	0.82	1.01 (0.09)	0.92 (0.08)
Angle Crashes (S.E.)	0.50	0.64* (0.11)	**0.67*** **(0.11)**
Rear-End Crashes (S.E.)	2.34	**2.26*** **(0.48)**	3.98* (0.74)
Left-Turn Crashes (S.E.)	0.33	0.68* (0.18)	**0.45*** **(0.13)**
Total Crashes (S.E.)	0.69	0.70* (0.07)	**0.61*** **(0.06)**
Angle crashes (S.E.)	0.50	0.54* (0.09)	**0.46*** **(0.08)**
Rear-End Crashes (S.E.)	0.97	**0.71*** **(0.13)**	1.17 (0.18)
Left-Turn Crashes (S.E.)	0.31	**0.66*** **(0.18)**	-** -**

Note: The values in bold are recommended CMFs for Florida.
*Significant at a85% confidence level.
**Not available.

6.1.4 Comparison with CMFs in HSM

As described earlier, the CMF with smaller standard error was selected as the best Florida-specific CMF between the two CMFs obtained from CG and EB methods. This selected Florida-specific CMF was compared with the CMF in the HSM and the recommended CMF for Florida was determined as shown in Table 6-3.The CMFs in the HSM were estimated using the EB method.

For rural 3-leg and 4-leg intersections, the CMF for total crashes in the HSM is statistically significant at an 85% confidence level but the Florida-specific CMF is not. Therefore, the CMF in the HSM is recommended for total crashes. For angle crashes, the Florida-specific CMF is recommended since it is statistically significant at an 85% confidence level. For rear-end crashes, the Florida-specific CMF is found to be similar to the CMF in the HSM. However, since the Florida-specific CMF is not statistically significant at an 85% confidence level, the CMF in the HSM is recommended. For left-turn crashes, the Florida-specific CMF is recommended since it is statistically significant at an 85% confidence level.

For urban 3-leg intersections, both Florida-specific CMF and CMF in the HSM for total crashes are not statistically significant. This indicates that the safety effectiveness of signalization is unknown for total crashes. Therefore, there is no recommended CMF for total crashes. For angle and rear-end crashes, the Florida-specific CMF is recommended since it is statistically significant at an 85% confidence level. For all other crash and intersection types, Florida-specific CMFs are recommended since CMFs are not included in the HSM.

Table6-3: Recommended CMFs for *Signalization of Stop-Controlled Intersections* in Florida

Crash Type	Florida-Specific CMF	CMF in HSM
Rural 3-Leg & 4-Leg Intersections		
Total Crashes (S.E.)	0.98 (0.13)	**0.56*** **(0.03)**
Angle crashes (S.E.)	**0.70*** **(0.17)**	0.23* (0.02)
Rear-End Crashes (S.E.)	**1.95*** **(0.51)**	1.58* (0.20)
Left-Turn Crashes (S.E.)	**0.50*** **(0.20)**	0.40* (0.06)
Urban 3-Leg Intersections		
Total Crashes (S.E.)	0.92 (0.08)	0.95 (0.09)
Angle Crashes (S.E.)	**0.67*** **(0.11)**	0.33* (0.06)
Rear-End Crashes (S.E.)	**2.26*** **(0.48)**	2.43* (0.40)
Left-Turn Crashes (S.E.)	**0.45*** **(0.13)**	-** -**
Urban 4-Leg Intersections		
Total Crashes (S.E.)	**0.61*** **(0.06)**	-** -**
Angle crashes (S.E.)	**0.46*** **(0.08)**	-** -**
Rear-End Crashes (S.E.)	**0.71*** **(0.13)**	-** -**
Left-Turn Crashes (S.E.)	**0.66*** **(0.18)**	-** -**

Note: The values in bold are recommended CMFs for Florida.
*Significant at a85% confidence level.
**Not available.

6.2 Adding Left-Turn Lanes

As discussed earlier in the data collection section, the research team categorized the sites with a*dding left-turn lanes* according to the HSM. Due to limitation of data, only 18 rural stop-controlled 3-leg and 9rural 4-leg intersections were considered. Naïve before-After, before-after with CG, and before-after with EB methods were applied to calibrate the CMFs for a*dding left-turn lanes*. The targeted intersections in our treatment samples are minor stop-controlled intersections with an additional left-turn lane on a major approach.

6.2.1 Naïve Before-After

Table 6-8 shows the estimated CMFs using naïve before-after method for total and F+I crashes. It can be seen that there is almost no difference in total crashes at rural 3-leg intersections. However, CMFs for F+I crashes show a significant improvement in safety after a*dding left-turn lanes* at both rural 3-leg and 4-leg intersections.

6.2.2 Before-After with Comparison Group

The research team has identified 90 comparison sites to perform before-after with comparison group analysis. As shown in Table 3-11, the safety effectiveness of a*dding left-turn lanes* was -32% and 32%for total crashes (all severities) on rural 3-leg and 4-leg intersections, respectively. The reduction in F+I crashes were -11% and 32% after a*dding left-turn lanes* at rural 3-leg and 4-leg intersections, respectively. However, the standard errors for the estimated CMFs are relatively high due to the limited number of the treated sites.

6.2.3 Before-After with Empirical Bayes

Simple SPFs were developed using the NB Model formulation as follows:

(6-2)

where,

= predicted crash frequency;

= annual average daily traffic volume;

, = coefficients.

Four SPFs were developed for different intersection types (rural 3-leg and 4-leg) and crash types (total and F+I). AADT in the year 2009 was used to represent AADT for the years between 2007 and 2011. A total of 89 and 41 intersections were used to develop SPF for rural 3-leg and 4-leg intersections, respectively. The four SPFs are shown in Tables 6-4 ~ 6-7. All sets of AADT shown in SPFs are significant at a 95% confidence level.

Table 6-4: Florida-Specific SPFs for *Adding Left-Turn Lanes* at Rural 3-Leg Intersections (Total Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-6.1779	2.3429	-10.7699	-1.5859	6.95	0.0084
Log Major AADT	1	0.7790	0.2667	0.2562	1.3018	8.53	0.0035
Dispersion	1	1.2962	0.3274	0.7901	2.1266		
Numbers of Observations: 89 Log Likelihood:-0.7089 Full Log Likelihood:-160.1522 AIC: 326.3043							

Table 6-5: Florida-Specific SPFs for *Adding Left-Turn Lanes* at Rural 3-Leg Intersections (F+I Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-7.2909	2.7075	-12.5975	-1.9842	7.25	0.0071
Log Major AADT	1	0.8514	0.3065	0.2506	1.4523	7.71	0.0055
Dispersion	1	1.1693	0.3672	0.6318	2.1639		
Numbers of Observations: 89 Log Likelihood:-55.574 Full Log Likelihood: -129.4673 AIC: 264.9346							

Table 6-6: Florida-Specific SPFs for *Adding Left-Turn Lanes* at Rural 4-Leg Intersections (Total Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-9.5280	4.7198	-18.7787	-0.2773	4.08	0.0435
Log Major AADT	1	1.2204	0.5461	0.1501	2.2907	4.99	0.0254
Dispersion	1	3.6735	1.2251	1.9108	7.0624		
Numbers of Observations: 41 Log Likelihood:113.8591 Full Log Likelihood:-75.6757 AIC: 157.3513							

Table 6-7: Florida-Specific SPFs for *Adding Left-Turn Lanes* at Rural 4-Leg Intersections (F+I Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-9.8563	4.7100	-19.0876	-0.6249	4.38	0.0364
Log Major AADT	1	1.2047	0.5419	0.1427	2.2667	4.94	0.0262
Dispersion	1	3.0507	1.1328	1.4734	6.3164		
Numbers of Observations: 41 Log Likelihood:25.2531 Full Log Likelihood: -65.3217 AIC: 136.6435							

The result of the EB method shows that *adding left-turn lanes* reduces F+I crashes at rural 3-leg intersections but increases F+I crashes at rural 4-leg intersections as shown in Table

6-8. However, due to the limited sample size, CMFs for total crashes are not significant in the EB method at an 85% confidence level. On the other hand, the result of CG method shows the opposite effects - *adding left-turn lanes* increases F+I crashes at rural 3-leg intersections but reduces F+I crashes at rural 4-leg intersections. Due to this inconsistency in the results between EB and CG methods, the CMF with lower standard error was considered as a valid CMF. Thus, the best Florida-specific CMFs for F+I crashes are 0.73 (from EB method) and 0.64 (from CG method) for rural 3-leg and 4-leg intersections, respectively.

However, for rural 4-leg intersections, it should be noted that SPFs for total crashes and F+I crashes in CG method were developed using the crash data for only 41 intersections due to limited samples. Thus, in spite of statistical significance, care must be taken for the use of the CMFs for *adding left-turn lanes* obtained from CG method.

Table 6-8: Florida-Specific CMFs for *Adding Left-Turn Lanes* at Rural 3-Leg and 4-Leg Intersections

CMF Method	Florida-Specific CMF		
	Naïve	CG	EB
Rural 3-Leg Intersections			
Total Crashes (S.E.)	1.110	1.32 (0.24)	1.07 (0.19)
F+I crashes (S.E.)	0.751	1.11 (0.25)	0.73* (0.17)
Rural 4-Leg Intersections			
Total Crashes (S.E.)	0.816	0.69* (0.11)	1.12 (0.19)
F+I Crashes (S.E.)	0.821	0.64* (0.14)	1.33 (0.28)

*Significant at a85% confidence level.

6.2.4 Comparison with CMFs in HSM

The recommended CMFs for *adding left-turn lanes* were determined based on the comparison between the best Florida-specific CMF and the CMF in the HSM as shown in Table 6-9. The CMFs in the HSM were estimated using the EB, CG, and Yoked comparison methods.

For rural 3-leg intersections, the CMF for total crashes in the HSM is statistically significant at an 85% confidence level, but the Florida-specific CMF is not. Thus, the CMF in the HSM is recommended for total crashes. For F+I crashes, since the Florida-specific CMF is statistically significant at an 85% confidence level, it is recommended. Similarly, for rural 4-leg intersections, Florida-specific CMFs for total and F+I crashes are recommended as they are statistically significant at an 85% confidence level.

Table 6-9: Recommended CMFs for *Adding Left-Turn Lanes* at Rural 3-Leg and 4-Leg Intersections in Florida

Crash type	Florida-Specific CMF	CMF in HSM
Rural 3-Leg Intersections		
Total Crashes (S.E.)	1.07 (0.19)	**0.56*** **(0.07)**
F+I crashes (S.E.)	**0.73*** **(0.17)**	0.45* (0.10)
Rural 4-Leg Intersections		
Total Crashes (S.E.)	**0.69*** **(0.11)**	0.52* (0.04)
F+I Crashes (S.E.)	**0.64*** **(0.14)**	0.42* (0.04)

Note: The values in bold are recommended CMFs for Florida.
*Significant at a85% confidence level.

6.3 Adding Red-Light Cameras

6.3.1 Result of Analysis

The observational before-after EB method was applied to crashes at the 25 Red-Light-Camera (RLC)-equipped intersections. The aggregate safety effectiveness for all RLC-equipped intersections was estimated and the Poisson test of significance was performed on all target approaches and all approaches combined. As shown in Table 6-10, there was a reduction in angle and left-turn crashes but the reduction is more significant on target approaches than all approaches for the treated sites. Angle and left-turn crashes decreased by 24% and 26% for target approaches for all severity and fatal and injury (F+I) levels, respectively. However, rear-end crashes for target approaches increased by 32% and 41% for all severity and F+I, respectively. The magnitude and the direction of reduction or increase in each crash type and severity level on all approaches, to a lesser degree, were similar to those on target approaches. This indicates spillover benefits that the presence of RLCs affected driver behavior on all approaches. The EB method was also applied to the 50 untreated intersections close to the RLC-equipped intersections to examine the spill-over effects on adjacent non-RLC-equipped intersections. The before-after periods for these intersections were demarcated by the first RLC installation date in Orange County. The results from this analysis indicated that there was a statistically significant spill-over effect on adjacent intersections for angle and left-turn crashes (all severity only) and insignificant spill-over effect on rear-end crashes at all and F+I severity levels.

Table 6-10: Florida-Specific CMFs for *Adding Red-Light Cameras* at Urban Intersections

Approach	Severity	Angle and Left-Turn Crash		Rear-End Crash	
		CMF (Safety Effectiveness)	S.E.	CMF (Safety Effectiveness)	S.E
Red-Light Cameras Equipped Intersections					
Target Approaches	All Severity	0.76* (24.15%)	0.05 (5.34%)	1.32* (-32.47%)	0.08 (7.92%)
	F+I	0.74** (25.81%)	0.08 (7.71%)	1.41** (-40.88%)	0.1 (9.75%)
All Approaches	All Severity	0.84* (15.73%)	0.04 (4.02%)	1.17** (-17.36%)	0.07 (7.11%)
	F+I	0.87** (13.38%)	0.09 (9.15%)	1.23 (-23.44%)	0.09 (8.92%)
Adjacent Non-Red-Light Cameras Equipped Intersections					
All Approaches	All Severity	0.89** (11.25%)	0.08 (8.04%)	0.99 (1.01%)	0.12 (11.61%)
	F+I	0.92*** (7.87%)	0.09 (8.96%)	1.08 (-8.23%)	0.1 (9.67%)

*, **, and *** correspond with statistical significance at95%, 90%, and 80%confidence level, respectively.

6.3.2 Comparison with CMFs in HSM

Florida-specific CMFs were calculated and compared with CMFs in the HSM as shown in Table 6-11. The CMFs in the HSM were estimated using the before-after with CG and EB methods. Since Florida-specific CMFs are statistically significant at an 85% confidence level, they are recommended.

Table 6-11: Recommended CMFs for *Adding Red-Light Cameras* at Urban 3-Leg and 4-Leg Signalized Intersections in Florida

Crash type	Severity	Florida-Specific CMF	CMF in HSM
Angle	Total (S.E.)	**0.84*** **(0.04)**	0.74* (0.03)
	F+I (S.E.)	**0.87*** **(0.09)**	0.84* (0.07)
Rear-End	Total (S.E.)	**1.17*** **(0.07)**	1.18* (0.03)
	F+I (S.E.)	**1.23*** **(0.09)**	1.24* (0.10)

Note: The values in bold are recommended CMFs for Florida.
*Significant at a85% confidence level.

For the adjacent non-RLC-equipped intersections, Florida-specific CMFs were compared with the CMFs in Persaud et al. (2005) as shown in Table 6-12. The CMFs for non-RLC-equipped intersections are not provided in the HSM. The result shows that only the CMF for total angle crashes in Persaud et al. (2005) is statistically significant at an 85% confidence level. However, all Florida-specific CMFs are not significant. Thus, there are no recommended CMFs for injury angle crashes and total and injury rear-end crashes at adjacent intersections.

Table 6-12: Recommended CMFs for *Adding Red-Light Cameras* at Adjacent Non-RLC-Equipped Intersections in Florida

Crash type	Severity	Florida-Specific CMF	CMF in Persaud et al. (2005) (Referenced in HSM)
Angle	Total (S.E.)	0.89 (0.08)	**0.91*** **(0.02)**
	F+I (S.E.)	0.92 (0.09)	**-****
Rear-End	Total (S.E.)	0.99 (0.12)	0.98 (0.02)
	F+I (S.E.)	1.08 (0.10)	**-****

Note: The values in bold are recommended CMFs for Florida.
*Significant at a85% confidence level.
**Not available.

6.3.3 Macroscopic GIS Analysis for Safety Impacts on Jurisdictional Level

Crash migration is another safety countermeasure accompanying phenomena; crashes might migrate from the treated sites to the untreated sites because of possible shift in travel patterns to avoid RLC locations. This section examines crash spillover and migration phenomena at the county level using before-after cluster analysis and Kernel Density Estimation (KDE) method.

Mapping of the locations of RLC-equipped intersections in Orange County in Florida (cities of Orlando and Apopka, and Alafaya and Oak Ridge Census-Designated Places) shows that these cameras are located close to each other and form clusters on mostly state, county, and US roadways as shown in Figure 4-8.

Only target crashes (angle, left-turn, and rear-end crashes) in three-year before period (2006-2008) and three-year after period (2010-2012) were considered in this analysis. The selection of these years was based on the assumption that the RLC program had started in 2007 and first installation was in late 2008. Crash data were extracted for only intersection or intersection-related, no alcohol/ drugs involvement, and for crashes that occurred only on county, state roadways, and US roadways.

The first step of investigating the target crashes was to examine the spatial distribution and as such the crash hotspots could be identified and focused on for further visual safety evaluation and comparison. The countywide map with frequent target crash clusters (angle and left-turn combined and rear-end crashes) was also presented for better visualization and understanding of the spatial distribution of target crashes.

The Kernel Density Estimation (KDE) (Chainey and Ratcliffe, 2005) was used to serve the purpose of clustering the crashes, and identifying the hotspots and shifts in target crash patterns in before-after periods. The KDE defines the spread of risk as an area around a defined cluster in which there is an increased likelihood of a crash to occur based on spatial dependency. It places a symmetrical surface over each point and then evaluates the distance from the point to a reference location based on a mathematical function and then sums the value for all the surfaces for that reference location. This procedure is repeated for successive points, which allows us to place a kernel over each observation, and sums these individual kernels gives us the density estimate for the distribution of crash points (Chainey and Ratcliffe, 2005).

$$\text{—}\sum \qquad (\;) \qquad\qquad (6\text{-}3)$$

where,

$f(x, y)$ = the density estimate at the location (x, y);

n= the number of observations;

h= the bandwidth or kernel size;

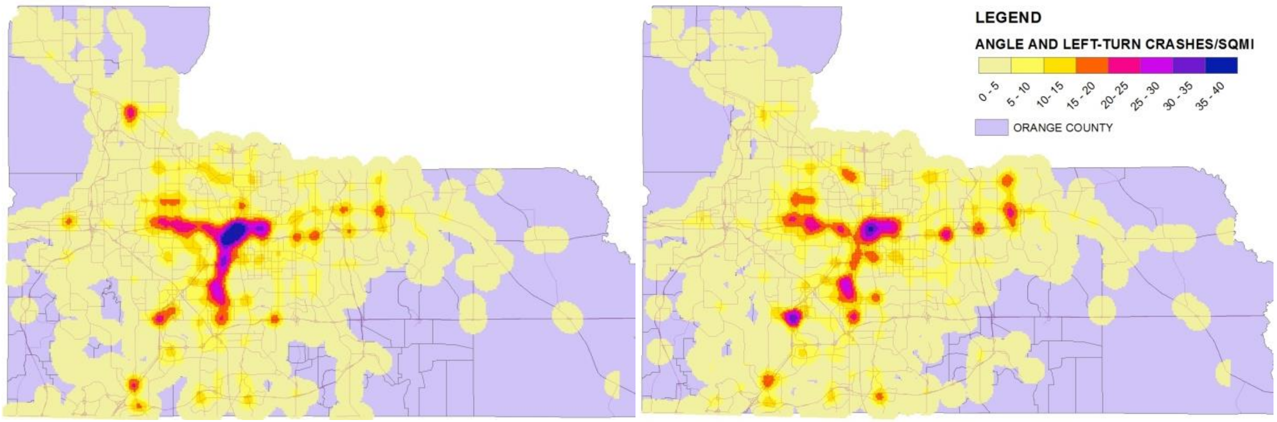
K= the kernel function;

d_i= the distance between the location (x, y) and the location of the i^{th} observation.

The main objective of placing these kernels over the crash points is to create a smooth and continuous surface. Around each point at which the indicator is observed, a circular area (the kernel) of defined bandwidth is created. This takes the value of the particular indicator at that particular point spreads into it according to some appropriate function. Then it sums up all of these values at all places, including those at which no incidences of the indicator variable were recorded, and gives a surface of density estimates.

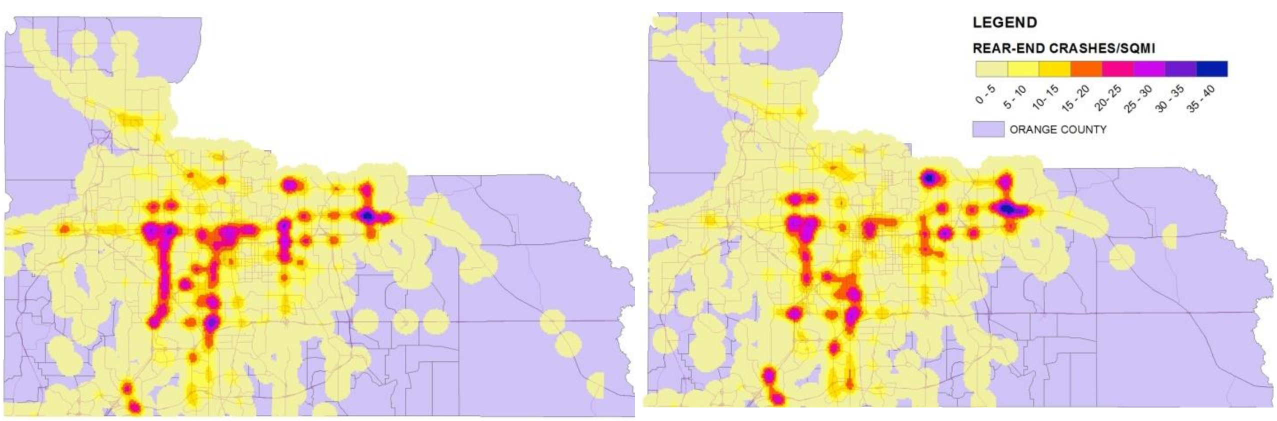
The ArcGIS spatial analyst tool provides the features needed to perform the cluster analysis using density estimation methods. The KDE process requires that the data-points be spatially jointed. To join the points spatially, fishnet of square size cells was created using the "create fishnet" tool. The cell size (cell width and height) was selected in such a way that the area under consideration is divided into a finite number of cells that can be calculated.

Figures 6-1 and 6-2 show the Orange countywide map with clustering output from the GIS analysis for angle and left-turn crashes and rear-end crashes, respectively. The KDE technique presents the change in pattern of target crashes in the before and after periods, the colors represent the density of crashes in number of crashers per square mile. The Geographic Information System (GIS) analysis showed that there is a considerable reduction in angle and left-turn crashes. As shown in Figure 6-1, the angle and left-turn crash intensities decreased throughout the RLC intersection clusters from 35-40 crashes per square mile to 15-20 crashes per square mile. Moreover, the areas of the affected clusters were decreased significantly.



Before Period (2006-2008) After Period (2010-2012)

Figure 6-1: Cluster Before-After Analysis of Angle and Left-Turn Crashes in Orange County



Before Period (2006-2008) After Period (2010-2012)

Figure 6-2: Cluster Before-After Analysis of Rear-End Crashes in Orange County

There were a slight migration for angle and left-turn crashes, and a notable migration for rear-end crashes to the boundary of the county indicating that the spill-over effects may fade away as we get farther from the RLC intersection clusters. As shown in Figure 6-2, the rear-end crash clusters in red-purple-blue colors (20-40 crashes per square mile) moved from the center of the county to the east-north and south-west boundaries with greater affected area indicated by large blue spots. It is worth mentioning that the expected increase in rear-end crashes cannot be concluded from the generated KDE maps due to a modest spill-over effect. This can be explained by the assumption that drivers might be more cautious not to violate the red light intentionally at non-RLC-equipped intersections. They may run the red in the first 1-second of red if they are caught in the dilemma zone to avoid a rear-end crash (violating red light in the first second of the red is less likely to result in a right-angle crash). While the RLC program in Florida generally has positively effect on reducing drivers red-light violations in Orange County, a prospective study should be considered to account for several other factors affecting target crashes spill-over and migration at signalized intersections.

6.4 Converting a Minor-Road Stop-Controlled Intersection to a Modern Roundabout

6.4.1 Result of Analysis

The safety effect of *converting a minor-road stop-controlled intersection to a modern roundabout* was evaluated using the cross-sectional method due to insufficient samples for applying the before-after methods. Florida-specific SPFs for two severity levels (KABCO, KABC) were developed to predict crash frequency in a function of the presence of roundabout and AADT as follows:

$$F_i = \exp(\alpha + \beta_1 * Roundabout) * AADT_i^{\beta_2} \qquad (6\text{-}4)$$

where,

F_i= crash frequency at an intersection i;

Roundabout= intersection type (= 1 if the intersection i is a modern roundabout, = 0 the intersection i is a minor-road stop-controlled intersection);

$AADT_i$= AADT at an intersection i.

Then CMFs were calculated using the following equation:

$$CMF = \exp(\beta_1) \qquad (6\text{-}5)$$

Florida-specific SPFs for all crashes (KABCO) and F+I crashes (KABC) are shown in Table6-13. All the factors are statistically significant at a 99% confidence level.

Table6-13: Florida-Specific SPFs for *Converting a Minor-Road Stop Control Intersection to a Modern Roundabout*

(a) All Severity Crashes KABCO

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	250	242.4890	0.9700
Pearson Chi-Square	250	389.2920	1.5572
Log Likelihood		606.9344	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-9.9947	1.5263	-12.9862	-7.0032	42.88	<.0001
Log(AADT)	1	1.1459	0.1557	0.8407	1.4511	54.16	<.0001
Roundabout	1	**-0.9783**	0.2924	-1.5515	-0.4052	11.19	0.0008
Dispersion	1	1.7459	0.2556	1.3105	2.3261		

(b) Fatal and Injury Crashes KABC

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	250	229.4154	0.9177
Pearson Chi-Square	250	342.3471	1.3694
Log Likelihood		-2.4440	

Analysis Of Maximum Likelihood Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Wald Chi-Square**	**Pr > ChiSq**
Intercept	1	-9.4807	1.5996	-12.6158	-6.3456	35.13	<.0001
Log(AADT)	1	1.0304	0.1624	0.7120	1.3487	40.24	<.0001
Roundabout	1	**-1.2465**	0.3369	-1.9069	-0.5862	13.69	0.0002
Dispersion	1	1.3629	0.2591	0.9390	1.9782		

6.4.2 Comparison with CMFs in HSM

Florida-specific CMFs were calculated and compared with the CMFs with the HSM as shown in Table 6-14. The CMFs in the HSM were estimated using the EB method. For all severity levels, *converting a minor-road stop-controlled intersection to a modern roundabout* in Florida has a positive effect on reducing crashes similar to the HSM. However, modern roundabouts have higher safety effect for all crashes (KABCO) but lower safety effect for injury crashes (KABC) in Florida compared to the HSM. Based on this result, it is concluded that a modern roundabout is safer than a minor-road stop-controlled intersection. However, further investigation is needed to check validity of these Florida-specific CMFs. Thus, these CMFs are not recommended for Florida.

Table6-14: CMFs for *Converting a Minor-Road Stop-Controlled Intersection to a Modern Roundabout* in Florida

	Florida-specific			HSM		
Crash Type	Traffic Volume	Severity	CMF (SE)	Traffic Volume	Severity	CMF (SE)
All types	258~60,000	KABCO	0.38 (0.11)	Unspecified	KABCO	0.56 (0.05)
		KABC	0.29 (0.10)		KABC	0.18 (0.04)

6.5 Converting Traditional Mainline Toll Plaza to Hybrid Mainline Toll Plaza

Naïve before-after study was conducted for 30 sites of TMTP that were converted to HMTP. CMFs were estimated based on crash rates for both individual and all sites, and the Poisson test of significance was performed. The total crash rate for all sites was reduced from 29.59 crashes per million vehicle miles (MVM) in the 'before' period, to 13.91 crashes per MVM after the conversion to HMTP, representing about 53% reduction in the crash rate. This reduction was statistically significant. The same approach was applied to PDO and F+I crashes, and the results showed that the conversion to HMTP significantly reduced crashes for these severity levels by

57.2% and 54.3%, respectively. The treatment also significantly reduced rear-end and lane-change-related crashes (i.e., sideswipe, lost control, overturned, and angle crashes) by 69% and 59%, respectively.

In the before-after with CG method, the data from 16 treated sites (TMTPs converted to HMTP) and 16 comparison sites (TMTPs without design change) were used. These treated and comparison sites have similar characteristics. CMFs were estimated for both individual and all sites using the crash data for the period three years before and after the treatment. The safety effectiveness for all sites was significantly improved by reducing the total crashes (all severity) by 48% with standard error of 9.42%. The statistical significance of the estimated safety effectiveness was calculated as:

$$\text{Abs}\left(\frac{\text{Safety Effectiveness}}{\text{SE of Safety Effectiveness}}\right) = \frac{48}{9.42} = 5.1$$

Since an absolute value of Safety Effectiveness/SE of Safety Effectiveness is greater than or equal to 1.96, it can be concluded that the treatment effect is significant at a 95% confidence level. The same method was applied to PDO and F+I crashes. The safety effectiveness in reducing PDO and F+I crashes for all sites was significantly improved by 55% and 45.2%, respectively, with a standard error of 8.43% and 9.43%, respectively. The absolute values of Safety Effectiveness/ SE of Safety Effectiveness were4.79 and 6.52 for PDO and F+I crashes, respectively – i.e., the safety effectiveness was statistically significant for both severity levels at a 95% confidence level. The treatment also reduced rear-end and lane-change-related crashes by65.3% and 57.4%, respectively. The absolute values were statistically significant at a 95% confidence level for both types of crashes.

In the before-after with EB method, the data from 42 reference sites (TMTPs) which design has not been changed from 2002 to 2012 were used to develop SPFs for mainline toll plazas. Full SPFs with NB distribution were developed for different severity levels and crash types as shown in Table 6-15.

Table 6-15: Florida-Specific Full SPFs for *Converting TMTP to HMTP* on Roadway Segments

Severity Levels						
	Total Crashes			F+I Crashes		
Parameter	**Estimate**	**Std.Err**	**P > ChiSq**	**Estimate**	**Std.Err**	**P > ChiSq**
Intercept	-9.2609	1.0614	<.0001	-9.0152	1.1002	<.0001
Log(AADT)	1.3271	0.1950	<.0001	1.1128	0.1844	<.0001
Speed limit	-0.0240	0.0104	0.0210	0.0048	0.0105	0.0474
Dispersion	0.4695	0.1034		0.2807	0.0872	
AIC	308.6199			303.2229		
	PDO Crashes					
Parameter	**Estimate**	**Std.Err**	**P > ChiSq**			
Intercept	-10.4611	2.5545	<.0001			
Log(AADT)	1.4220	0.2738	<.0001			
Speed limit	-0.0387	0.0131	0.0032			
Dispersion	0.5756	0.1471				
AIC	312.6152					
Crash Types						
	Rear-end Crashes			Lane-change-related Crashes		
Parameter	**Estimate**	**Std.Err**	**P > ChiSq**	**Estimate**	**Std.Err**	**P > ChiSq**
Intercept	-9.7686	2.2221	<.0001	-11.0950	2.9216	0.0001
Log(AADT)	1.1572	0.2208	<.0001	1.2329	0.2907	<.0001
Downstream of Mainline Toll Plaza	-0.4605	0.2119	0.0298	-0.5511	0.2726	0.0432
Dispersion	0.2684	0.1072		0.3242	0.1730	
AIC	277.6112			267.2759		

Table 6-16comparesCMFs resulted from the CG and EB methods for all sites. It can be seen that standard errors of the CMFs are lower for the EB method than the CG method for all severity and crash types. Thus, the CMFs from the EB method are recommended.

Table6-16: Recommended CMFs for *Converting TMTP to HMTP* in Florida

Crash Category	Florida-specific			
	Before-After with CG		Before-After with EB (Full SPF)	
	CMF	SE	CMF	SE
Total Crashes	0.52	0.09	**0.53**	**0.05**
F+I	0.55	0.09	**0.54**	**0.07**
PDO	0.45	0.08	**0.46**	**0.06**
Rear-end	0.35	0.10	**0.34**	**0.06**
Lane-change-related*	0.43	0.11	**0.45**	**0.09**

Note: The values in bold are recommended CMFs for Florida.
*Lane-change-related crashes include sideswipe, lost control, overturned and angle crashes.

To evaluate the quality of the SPFs and CMFs, the research team applied the crash data for the three-year after period from the 26 HMTPs which design has not been changed since it was built. The procedure of evaluation is as follows:

1. Calculate the expected number of crashes at each location using the SPFs assuming that the treatment had not been implemented.
2. Multiply the expected crash frequencies by the CMFs presented in Table 6-16 for individual and all sites.
3. Compare the results with the observed crashes at these sites.

The results showed that the best CMFs for all crash categories were produced from the before-after with EB method. Therefore, the EB method is recommended to estimate CMFs.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

This study develops crash modification factors (CMFs) for various treatments in Florida for validating the CMFs provided in the Highway Safety Manual (HSM). The study also develops CMFs for the other treatments not included in the HSM. A total of 16 treatments for roadway segments, intersections and special facilities were considered in this study. For this task, data were extensively collected from multiple data sources maintained by FDOT including multi-year road geometry inventory and crash database. CMFs were calculated using observational before-after and cross-sectional studies for different crash types and injury levels. For any given treatment, only the CMF with lowest standard error was selected as the Florida-specific CMF among various CMFs estimated using different methods.

These Florida-specific CMFs were compared with the CMFs in the HSM. In general, Florida-specific CMFs reflect similar safety effectiveness as the CMFs in the HSM for most treatments. Florida-specific CMFs are also generally statistically significant at an 85% confidence level. These CMFs are recommended for application to Florida as they better reflect local conditions in Florida compared to the HSM. However, for the treatments with unknown safety effectiveness in Florida as indicated by statistically insignificant Florida-specific CMFs, the CMFs in the HSM (if they are statistically significant) are recommended. Florida-specific CMFs for the treatments not included in the HSM are also statistically significant at a 85% confidence level. The recommended CMFs in Florida for all the treatments are summarized in Chapter 8.

Although this study evaluates the validity of the CMFs for the most treatments included in the HSM, there are still some treatments that have not been analyzed. Based on the availability of the data and CMFs in the HSM, as an example it is recommended that Florida-specific CMFs are estimated for the following treatments (but are not limited to) in future Phase II study as follows:

Roadway Segments:

1. Adding a shoulder rumble strip on freeways;
2. Adding a curb on shoulder;
3. Adding school zone;
4. Modifying lane width for *urban* 2-lane/multi-lane arterials and freeways;
5. Changing the type of median barrier (e.g., cable, concrete, steel);
6. Increasing the distance to roadside feature on rural two-lane roads and freeways.

Intersections:

1. Converting a signalized intersection to a modern roundabout;
2. Converting a minor-road stop-controlled intersection to a modern roundabout for different settings (rural, urban, suburban) and number of lanes;
3. Adding right or left turn lane at urban signalized intersections
4. Increasing intersection median width at signalized and non-signalized intersections;
5. Converting traditional and hybrid mainline toll plazas to all electronic toll collection. (Completely Open Toll Collection);

It is also recommended that CMFs for multiple treatments are estimated using cross-sectional methods to evaluate their combined safety effectiveness.

CHAPTER 8. RECOMMENDED FLORIDA-SPECIFIC CRASH MODIFICATION FACTORS

Table 8-1: CMFs for *Adding a Through Lane*

Setting (Road Type)	Crash Type (Severity)	CMF	Std. Error
Urban (Two-lane undivided roadways)	All types (All severities)	**0.35**	**0.09**
	All types (Injury)	**0.33**	**0.09**
Rural (Two-lane undivided roadways)	All types (All severities)	**0.71**	**0.09**
	All types (Injury)	**0.51**	**0.07**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
The CMF for this treatment is not included in the HSM.

Table 8-2: CMFs for *Adding Lanes (Converting Urban 2-lane to 4-lane Divided Roadways)*

Setting (Road Type)	Median Width (ft)	Crash Type (Severity)	CMF	Std. Error
Urban (Two-lane undivided roadways)	12-14 ft	All types (All severities)	**0.47**	**0.23**
	20-24 ft	All types (All severities)	**0.52**	**0.15**
	30 ft or more	All types (All severities)	**0.28**	**0.01**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
The CMF for this treatment is not included in the HSM.

Table 8-3: CMFs for *Adding Shoulder Rumble Strips*

Setting (Road Type)	Crash Type (Severity)	CMF	Std. Error
Rural/Urban (Two-lane undivided roadways)	All types (All severities)	**0.71**	**0.10**
	All types (Injury)	0.81	0.13
	SVROR (All severities)	**0.50**	**0.16**
	SVROR (Injury)	0.67	0.25
Rural (Two-lane undivided roadways)	All types (All severities)	**0.70**	**0.11**
	All types (Injury)	**0.78**	**0.12**
	SVROR (All severities)	**0.56**	**0.18**
	SVROR (Injury)	0.68	0.25

Note: The CMFs in bold are statistically significant at a 90% confidence level.
The CMF for this treatment is not included in the HSM.

Table 8-4:**CMFs for *Adding Shoulder Rumble Strips, Widening Shoulder Width and Adding Shoulder Rumble Strips + Widening Shoulder Width***

Treatment	Setting (Road Type)	Crash Type (Severity)	Traffic Volume AADT	Speed Limit (mph)	CMF	Std. Error
Adding Shoulder Rumble Strips	Rural (Multilane highways)	All types (All severities)	2,000~50,000	45~70	**0.73**	**0.07**
				65~70	**0.73**	**0.07**
		All types (Injury)		45~70	**0.64**	**0.09**
				65~70	**0.63**	**0.09**
		SVROR (All severities)		45~70	**0.60**	**0.09**
				65~70	**0.58**	**0.09**
		SVROR (Injury)		45~70	**0.64**	**0.15**
				65~70	**0.59**	**0.14**
Widening Shoulder Width*	Rural (Multilane highways)	All types (All severities)	2,000~50,000	45~70	**0.83**	**0.09**
				65~70	**0.66**	**0.12**
		All types (Injury)		45~70	**0.68**	**0.10**
				65~70	**0.51**	**0.13**
		SVROR (All severities)		45~70	**0.68**	**0.19**
				65~70	**0.60**	**0.20**
		SVROR (Injury)		45~70	**N/A**	**N/A**
				65~70	**0.39**	**0.19**
Adding Shoulder Rumble Strips + Widening Shoulder Width*	Rural (Multilane highways)	All types (All severities)	2,000~50,000	45~70	**0.50**	**0.06**
				65~70	**0.48**	**0.06**
		All types (Injury)		45~70	**0.66**	**0.11**
				65~70	**0.63**	**0.11**
		SVROR (All severities)		45~70	**0.40**	**0.08**
				65~70	**0.40**	**0.08**
		SVROR (Injury)		45~70	**0.63**	**0.15**
				65~70	**0.58**	**0.15**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
*The CMF for the treatment is not provided in the HSM.

Table 8-5: CMFs for *Converting a TWLTL to a Raised Median*

Setting (Road Type)	Crash Type (Severity)	CMF	Std. Error
Rural/Urban (Undivided roadways)	All types (All severities)	**0.53**	**0.02**
	All types (Injury)	**0.67**	**0.04**
	All types (Injury)	**0.27**	**0.07**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
The CMF for this treatment is not included in the HSM.

Table8-6: CMFs for *Adding Lighting*

Setting (Road Type)	Crash Type (Severity)	CMF	Std. Error
Rural/Urban (All roadways)	All types (Injury)	**0.63**	**0.12**
	All types (Non-injury)	0.84	0.18
	All types (Injury levels 3~5)*	0.89	0.17
	All types (All severities)*	**0.68**	**0.09**
	Rear-end (All severities)*	**0.67**	**0.14**
	Angle (All severities)*	**0.64**	**0.18**
	Single (All severities)*	**0.72**	**0.18**
	Other crash types (All severities)*	**0.72**	**0.08**
Urban (4-lane/6-lane Principal and Minor Arterials)**	All types (Injury)	**0.68**	**0.05**
	All types (Non-injury)	**0.76**	**0.08**
	All types (Injury levels 3~5)	**0.77**	**0.09**
	All types (All severities)	**0.74**	**0.10**
	Rear-end (All severities)	**0.62**	**0.12**
	Angle (All severities)	**0.82**	**0.10**
	Single (All severities)	**0.63**	**0.09**
	Other crash types (All severities)	**0.82**	**0.12**

Note: The CMFs in bold are statistically significant at a85% confidence level.
*The CMF for the crash type and severity level is not included in the HSM.
**The CMF for the setting and road type is not included in the HSM.

Table 8-7: CMFs for *Adding a Raised Median*

Setting (Road Type)	**Traffic Volume (AADT)**	**Crash Type (Severity)**	**CMF**	**Std. Error**
Urban (Two-lane roadways)	Unspecified	All types (Injury)	**0.61***	**0.10***
Urban (Multilane highways)	1000~158,000	All types (Injury)	**0.81**	**0.09**
		All types (Non-injury)	**0.74**	**0.09**
		Head-on (All severities)*	**0.32**	**0.13**
Rural (Multilane highways)	1,547~139,000	All types (Injury)	**0.76**	**0.12**
		All types (Non-injury)	**0.75**	**0.11**
		Head-on (All severities)*	**0.29**	**0.20**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
*The CMF is from the HSM.
The CMF for the crash type is not included in the HSM.

Table 8-8: CMFs for *Increasing Median Width*

Median Width	Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	Std. Error
10-ft to 20-ft conversion	Urban (4 lanes with Full Access Control)	7,800~123,500	All types (All severities)	**0.86**	**0.04**
10-ft to 30-ft conversion				**0.73**	**0.06**
10-ft to 40-ft conversion				**0.63**	**0.08**
10-ft to 50-ft conversion				**0.54**	**0.09**
10-ft to 60-ft conversion				**0.46**	**0.10**
10-ft to 70-ft conversion				**0.39**	**0.10**
10-ft to 80-ft conversion				**0.34**	**0.10**
10-ft to 90-ft conversion				**0.29**	**0.10**
10-ft to 100-ft conversion				**0.25**	**0.10**
10-ft to 20-ft conversion	Urban (5 or more lanes with Full Access Control)	18,900~158,000	All types (All severities)	**0.98**	**0.01**
10-ft to 30-ft conversion				**0.97**	**0.01**
10-ft to 40-ft conversion				**0.95**	**0.02**
10-ft to 50-ft conversion				**0.94**	**0.02**
10-ft to 60-ft conversion				**0.92**	**0.03**
10-ft to 70-ft conversion				**0.91**	**0.03**
10-ft to 80-ft conversion				**0.89**	**0.04**
10-ft to 90-ft conversion				**0.88**	**0.04**
10-ft to 100-ft conversion				**0.87**	**0.05**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
These CMFs for crashes in all median types (not only traversable medians) and all crash types (not only cross-median crashes).

Table 8-8: CMFs for *Increasing Median Width* (Continued)

Median Width	Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	Std. Error
10-ft to 20-ft conversion	Urban (4 lanes with Partial or No Access Control)	100~97,000	All types (All severities)	**0.94**	**0.03**
10-ft to 30-ft conversion				**0.89**	**0.06**
10-ft to 40-ft conversion				**0.84**	**0.09**
10-ft to 50-ft conversion				**0.79**	**0.11**
10-ft to 60-ft conversion				**0.74**	**0.13**
10-ft to 70-ft conversion				**0.70**	**0.14**
10-ft to 80-ft conversion				**0.66**	**0.16**
10-ft to 90-ft conversion				**0.62**	**0.17**
10-ft to 100-ft conversion				**0.58**	**0.18**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
These CMFs for crashes in all median types (not only traversable medians) and all crash types (not only cross-median crashes).

Table 8-9: CMFs for *Narrowing Lane Width*

Lane Width	Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	Std. Error
9-ft or less	Rural (Two-lane)	103~56,000	All types (All severities)	**0.62**	**0.20**
10-ft				**0.73**	**0.17**
11-ft				0.85	0.11
12-ft or more				**1.00**	**-**
9-ft or less	Rural (Divided Multilane)	1,600~139,000	All types (All severities)	**0.44**	**0.16**
10-ft				**0.58**	**0.13**
11-ft				**0.76**	**0.07**
12-ft or more				**1.00**	**-**

Note: The CMFs in bold are statistically significant at a85% confidence level.

Table 8-10: CMFs for *Converting 4 to 3 Lanes*

Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	Std. Error
Urban (Undivided arterials)	2,000~28,500	All types (All severities)	**0.56**	**0.15**
		All types (Injury)	**0.63**	**0.17**

Note: The CMFs in bold are statistically significant at a 95% confidence level.

Table 8-11: CMFs for *Narrowing Paved Right Shoulder Width*

Shoulder Width	Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	Std. Error
8 to 6-ft Conversion	Rural (Multilane)	5,000 ~ 35,000	All types (All severities)	**1.16**	**0.05**
8 to 4-ft Conversion				**1.35**	**0.06**
8 to 2-ft Conversion				**1.57**	**0.07**
8 to 0-ft Conversion				**1.82**	**0.08**
8 to 6-ft Conversion	Rural (Multilane)	5,000 ~ 35,000	All types (Injury)	**1.17**	**0.06**
8 to 4-ft Conversion				**1.37**	**0.07**
8 to 2-ft Conversion				**1.61**	**0.08**
8 to 0-ft Conversion				**1.88**	**0.09**

Note: The CMFs in bold are statistically significant at a 95% confidence level.

Table 8-12: CMFs for *Adding a Bike Lane*

Setting (Road Type)	Traffic Volume (AADT)	Crash Type (Severity)	CMF	Std. Error
Urban (Undivided arterials)	2,900~59,500	All types (All severities)	**0.68**	**0.08**
		All types (Injury)	**0.73**	**0.09**
		Bike-related (All severities)	**0.42**	**0.10**
		Bike-related (Injury)	**0.40**	**0.09**

Note: The CMFs in bold are statistically significant at a 95% confidence level.

Table 8-13: CMFs for *Signalization of Stop-Controlled Intersections*

Setting (Intersection Type)	Crash Type (Severity)	CMF	Std. Error
Rural (3-leg, 4-leg)	All types (All severities)	**0.56***	**0.03**
	Angle (All severities)	**0.70**	**0.17**
	Rear-end (All severities)	**1.95**	**0.51**
	Left-turn (All severities)	**0.50**	**0.20**
Urban (3-leg)	All types (All severities)	0.92	0.08
	Angle (All severities)	**0.67**	**0.11**
	Rear-end (All severities)	**2.26**	**0.48**
	Left-turn (All severities)	**0.45**	**0.13**
Urban (4-leg)	All types (All severities)	**0.61**	**0.06**
	Angle (All severities)	**0.46**	**0.08**
	Rear-end (All severities)	**0.71**	**0.13**
	Left-turn (All severities)	**0.66**	**0.18**

Note: The CMFs in bold are statistically significant at a 90% confidence level.
*The CMF is from the HSM.

Table 8-14: CMFs for *Adding Left-Turn Lanes*

Setting (Intersection Type)	Crash Type (Severity)	CMF	Std. Error
Rural (3-leg)	All types (All severities)	**0.56***	**0.07***
	All types (Injury)	**0.73**	**0.17**
Rural (4-leg)	All types (All severities)	**0.69**	**0.11**
	All types (Injury)	**0.64**	**0.14**

Note: The CMFs in bold are statistically significant at a85% confidence level.
*The CMF is from the HSM.

Table 8-15: CMFs for *Adding Red-Light Cameras at Red-Light-Camera-Equipped Intersections*

Setting (Intersection Type)	Crash Type (Severity)	CMF	Std. Error
Urban (3-leg and 4-leg Signal)	All types (All severities)	**0.84**	**0.04**
	All types (Injury)	**0.87**	**0.09**
	All types (All severities)	**1.17**	**0.07**
	All types (Injury)	**1.23**	**0.09**

Note: The CMFs in bold are statistically significant at a 85% confidence level.

Table 8-16: CMFs for *Adding Red-Light Cameras at Adjacent Non-Red-Light-Camera-Equipped Intersections*

Setting (Intersection Type)	Crash Type (Severity)	CMF	Std. Error
Urban (Signal)	Angle (All severities)	**0.91***	**0.02***
	Angle (Injury)	0.92	0.09
	Rear-end (All severities)	0.99	0.12
	Rear-end (Injury)	1.08	0.10

Note: The CMFs in bold are statistically significant at a 85% confidence level.
*The CMF is from the HSM.

Table8-17: CMFs for *Converting Traditional Mainline Toll Plaza to Hybrid Mainline Toll Plaza*

Setting (Road Type)	Crash Type (Severity)	CMF	Std. Error
Urban (Freeways)	All types (All severities)	**0.53**	**0.05**
	All types (Injury)	**0.54**	**0.07**
	All types (Non injury)	**0.46**	**0.06**
	Rear-end (All severities)	**0.34**	**0.06**
	Lane-change-related* (All severities)	**0.45**	**0.09**

Note: The CMFs in bold are statistically significant at a 95% confidence level.
*Lane-change-related crashes include sideswipe, lost control, overturned and angle crashes.
The CMF for this treatment is not provided in the HSM.

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