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Safety Effectiveness of Conversion of Two-Way-Left-Turn Lanes into Raised Medians

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SAFETY EFFECTIVENESS OF CONVERSION OF TWO-WAY-LEFT-TURN LANES INTO RAISED MEDIANS

by

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ABSTRACT

Two way left turn lanes (TWLTL) and raised medians are common median treatments on roadways. This research focused on evaluating the safety effectiveness of conversion of TWLTLs into raised medians using Before-After and Cross Sectional Studies. In the Before-After Studies, we evaluated the effect of this treatment using the Naïve, Before-After with Comparison Group (CG), and Before-After with Empirical Bayes (EB) Methods. In order to apply these methods, a total of 33 segments of a treated group and 109 segments of a comparison group have been collected. Also, safety performance functions (SPFs) have been developed using the negative binomial model in order to calibrate crash modification factors (CMF) using the Before-After with Empirical Bayes Method. This research also evaluated the safety effectiveness of this treatment on four and six lane roads using Before-After with CG and Before-After with EB. The type of raised medians was further evaluated using Before-After with CG and EB.

In sum, the results from this study show that applying the before-After and Cross Sectional studies have proved that the conversion from a TWLTL to a raised median helped to reduce total, fatal and injury, head on, angle, and left turn crashes. It significantly reduces crashes for head-on and left turn crashes, by restricting turning maneuvers. Also, this study has proved that the treatment is more effective on four rather than six lane roads. Furthermore, two types of raised medians, concrete and lawn curb, were evaluated after the conversion from TWLTLs. It was found that both medians have similar effects due to the conversion, and both median types helped in reducing the number of crashes.

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CHAPTER 1. INTRODUCTION

1.1 Background

A two way left turn lane (TWLTL) and raised median are common types of median treatments. A TWLTL is a continuous lane in the center of a road to allow traffic to make left turn in both directions at any point along the roadway. The regular width of a TWLTL is 14 feet (Priyanka Alluri, 2012). Figure 1-1 is an example of a TWLTL median.

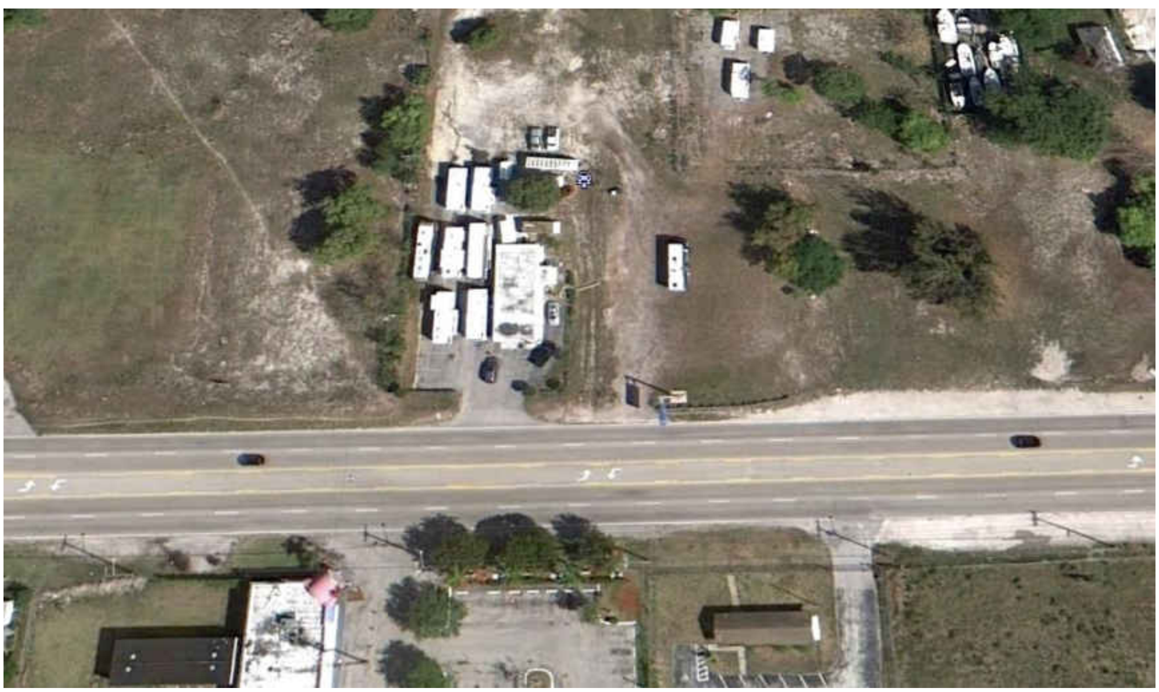

Figure 1-1: An Example of Two Way Left Turn Lane (TWLTL) Median (Source: Google Earth)

On the other hand, a raised median is a raised barrier in the center of a road to separate opposing lanes of traffic. There are many types of raised median such as, median curb, curb with lawn, and curb with landscaping.

Both of these median types have advantages and disadvantages. Table 1-1 shows the main advantages and disadvantages of TWLTLs and raised medians (Priyanka Alluri, 2012).

Table 1-1: Main Advantages and Disadvantages of TWLTLs and Raised Medians

TWLTLS	
Advantages	Disadvantages
- Reduce the delay of left turning vehicles. - Provide direct access to the required property. - Separate the left turning vehicles from the through traffic lane. -Provide operational flexibility for emergency vehicles.	- Encourage random access. - Could be used as a passing lane. - Visibility problems of painting marking - No refuge area for pedestrians. - High possibility of head-on crashes. - More conflict points.
Raised Medians	
Advantages	Disadvantages
- Provide a refuge area for pedestrians. - Reduce number of crashes at midblock area. - Reduce traffic conflict points especially at driveways. - Reduce headlight glare.	- Increase left turning vehicles at opening - Increase the travel time for some turning vehicles. - Limit access points. - Reduce operational flexibility for emergency vehicles.

Business and property owners do not prefer the installation of a raised median due to the negative impact on their businesses. Therefore, they prefer a TWLTL because of the continuous access that allows drivers to enter at any point of the road.

1.2 Research Objectives

The main purpose of this research is to identify the crash modification factor of conversion of medians from TWLTLs to raised medians at urban areas in Florida by using different methods. The specific objectives of this research are the following:

1- Prepare a brief summary of the existing literature review.

2- Identify the crash modification factor (CMF) using simple before and after (Naïve Method), Before-After with Comparison Group (CG), Before-After with Empirical Bays (EB), and Cross Sectional Methods.

3- Identify the safety effectiveness of this treatment for four and six lane roads and compare between them.

4- Explore which type of raised median is more effective after the conversion from TWLTL.

1.3 Research Outline

This research consists of six chapters and an appendices. The rest of the research is organized as follows. Chapter 2 provides a comprehensive literature review of previous studies on the safety impacts of conversion TWLTLs to raised medians. Chapter 3 presents the methodology that was followed to calculate the CMFs. Chapter 4 presents the ways and efforts of the data collection and preparation. Chapter 5 includes the research analyses and results. Chapter 6 provides discussion and conclusion.

CHAPTER 2. LITERATURE REVIEW

Extensive efforts from transportation professionals have done to investigate new methods to accommodate the growing number of vehicles on the roadways. In this section, we provide a comprehensive literature review of the previous studies and some critical factors that affect the median treatment.

2.1 Previous Studies

Papayannoulis et al. (1999) studied 264 segments and found that TWLTLs had a 20 percent reduction in total crashes compared to undivided medians; however, raised medians had a 40 percent reduction compared to undivided medians (Papayannoulis, 1999). Also, Bonneson and McCoy (1997) found that a conversion from a TWLTL to a raised median made a reduction in total crashes by about 33 percent (Bonneson, 1997). Moreover, Maze and Plozak (1997) studied the safety effectiveness of this treatment in Ankeny and Clive in Towa, and they found that the crash rates were reduced by 36.5 percent and 41.7 percent in the cities, respectively (Maze, 1998). Long et al. (1993) identified that urban four lane arterials with raised median had a 16.8 percent lower crash rate compared to those with TWLTLs. Also, Parsonson et al. (1993) observed a 37 percent and 48 percent reduction in total and injury crash rates, respectively. Schultz et al. (2011) found that after installation of a raised median the crash frequency of total and severe injury crashes were reduced by 39 percent and 44 percent, respectively. Finally, Georgia department of transportation found that the crash rate a 6-lane roadway separated by a raised median was 4.4 crashes per million-vehicle mile (MVM) of travel lower than similar facility with a TWLTL.

On the other hand, some studies have reported high increase in crash rates after the installation of raised medians. Schultz et al. (2007) identified that a 43 percent increase in total crash rate after the conversion of raised median on Utah. Also, Phillips (2004) observed a higher percent of fatal crashes at locations with raised medians compared to similar roads with TWLTLs. Squires and Parsonson (1989) found that TWLTLs could be safer than raised median on six lane arterials with low traffic volume and few access points.

As a result, we cannot say that the conversion from TWLTLs to raised medians will help to reduce crashes at any location in the United States. There are some factors that may affect the result of our treatment, and we should study these factors and their effect in the analysis process. These factors are presented in the next section.

2.2 Contributing Factors

There are some factors affect the result of our treatment, and these factors should be taken into our consideration in the analysis process.

2.2.1 Driveway Density

Regardless of the type of median treatment, increasing access density will increase crash rate (Gluck, 1999). Azzeh et al. (1975) found that when the driveway density was high, a raised median was safer than TWLTL. Reducing number of access points will reduce the conflict points; thus, improve safety and traffic flow (Pappayannoulis et al., 1999). The relation between crash rate and access density was steeper on roadways where raised median does not exist (Peng, 2004). Bretherton (1994) considered TWLTLs to be safer on arterials with fewer than 60 commercial driveways per mile, and raised medians were considered to be safer for higher level of development. Glennon et al. (1975a) also found that when driveway density was 60 or more per mile, non-traversable medians were safer. The Center of Transportation Research and Education (CTRE) reports that there are more frequent crashes with greater driveway densities, as cars make more frequent left-turns and right-turns (CTRE 2003d). On the other hand, Parsonson (1990) indicates that driveways per mile were not found to be significant for either raised median or TWLTL. TWLTL should not be used if the access on only one side of the road (Parker 1983). So, we should examine this factor and see if it is a significant factor or not.

2.2.2 Traffic Volume

Traffic volume plays a vital role in this treatment. If the traffic volume is substantial and left turning vehicle is high, a TWLTL median becomes ineffective. Bonneson and McCoy (1997) found that raised median treatments have fewer crashes than TWLTLs for roads that have traffic volume greater than 20,000 vehicles per day. Also, Parsonson et al (1990) recommended raised medians for roadway segments with expected traffic volume between 24,000 and 28,000 vehicles per day (Parsonson et al, 1990). TWLTLs have lower number of crashes per mile when the roadway has traffic volume ranging from 10,000 to 30,000 vehicles per day (Parker 1983). With a heavy traffic volume that is near or at capacity, the left turning vehicles may not be able to find a safe gap, and the raised medians are recommended (Priyanka Alluri, 2012). As a result, traffic volume is a very significant factor that affects safety at TWLTL medians sites.

2.2.3 Speed Limit

Speed limit is a significant factor that affects safety at TWLTLs sites. AASHTO presents recommendations about the use of TWLTLs. They say, "*TWLTL works well when the speed on the arterial is relatively low (25-45 mph) and there are no heavy concentrations of left turning traffic*" (AASHTO, 2004). Also, the stopping sight distance is an important factor. If the stopping sight distance is less than the AASHTO standards, a TWLTL should not be used (Parker 1983). The Florida Department of Transportation (FDOT) requires all multilane roads that have over 40 mph in the design speed to have a restrictive median.

CHAPTER 3. METHODOLOGY

One of the main methodologies to evaluate the safety effectiveness of a treatment is the Observational Studies, which contain two main groups: Before-After Studies and Cross Sectional Studies. In this research, we used both studies to evaluate the effect of this treatment. Commonly, we can conduct Observational Before-After by using the following methods; 1) Naïve Before-After, 2) Before-After with Comparison Group, 3) Before-After with Empirical Bayes Method. The result that we get from applying these methods is the crash modification factor (CMF), which is "*a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site*" (FHWA, 2010). A CMF of 1.00 indicates no effect on safety; a CMF greater than 1.00 represents an expected increase in crashes, and a CMF less than 1.00 indicates an expected reduction in crashes due to the implementation of a given treatment. In this chapter, we will explain in details how to apply each of these methods in order to get the accurate CMF.

3.1 <u>Naïve Before-After</u>

The Naïve method is a simple way to see if the treatment worked positively or not, and it is considered as a good starting point for evaluation of the effect of the treatment. The Naïve method assumes that there was no change from the before to the after period. This method does not account for changes from the before to after period, such as maturation and regression-to-the-mean, so, the result of this method is not enough to see the accurate effect of the treatment. This method usually overestimates the effect of the treatment due to the regression to the mean problem (Hauer, 1997). The best way to estimate the CMF for this method is to calculate crash rate for both before and after the implementation of the treatment by using equation 3-1.

$$\text{Crash Rate (CR)} = \frac{\text{Total Number of Crashes}}{\text{Exposure}} \tag{3\_1}$$

Where the exposure is usually in million vehicles mile (MVM) of travel. Equation 3-2 shows the way we calculated the exposure.

$$\text{Exposure} = \frac{\text{Project section Length} \times \text{ADT} \times \text{number of Years} \times 365}{1{,}000{,}000} \tag{3\_2}$$

After calculating the crash rates for the before and after periods, we should estimate the CMF using equation 3-3

$$\text{CMF} = \frac{\text{Crash Rate for After period}}{\text{Crash Rate for Before period}} \tag{3\_3}$$

After getting the crash rates of before and after periods, we used Poisson test of significant to check the significance of the change in crash rates from before to the after period. Poisson test of significance is explained in the next section.

3.2 Poisson Test of Significant

The Poisson test of significant was used on a 95 percent confidence to check the significance of the change in crash rate in Naïve Before-After method. First, we calculate the R-value as shown in equation 3-4.

$$\text{R} = \frac{2.326 \times \sqrt{\text{b}' - 0.16} - 0.35}{\text{b}'} \times 100 \tag{3\_4}$$

Where b' can be calculated as shown in equation 3-5.

$$b' = Total\ No.of\ crashes\ in\ before\ period\ \times \frac{ADT_A \times Days\ in\ after\ period}{ADT_B \times Days\ in\ Before\ period} \qquad (3\_5)$$

Where;

ADT_A = Average daily traffic in after period.

ADT_B = Average daily traffic in before period.

We consider the change is significant based on 95 percent confidence if the actual (reduction) percent is equal or greater than R-value. Likewise, if the actual percent is less than R-value, the change is not significant.

3.3 Before-After with Comparison Group (CG) Method

To account for variety of causal factors that change with time, we can use Before–After with the Comparison Group method. This method provides more accurate estimation than the Naïve method. This method uses an untreated (comparison) group of locations that are similar to the treated sites in geometric characteristics, traffic volume, and crash history. In this step, we should do our best in the data collection process to make the similarity between the treated and comparison groups high.

The comparison group is used to get the CMF. We use it to calculate the ratio of observed crashes in the after period to the before period. Then, we multiply this ratio by the observed crashes in the before period for the treated group in order to get the expected crashes in the after period for the treated group as shown in equation 3-6.

$$N_{expected\ T,A} = N_{observed\ T,B} \times \frac{N_{observed\ C,A}}{N_{observed\ C,B}} \qquad (3\_6)$$

Then, we calculate the variance of $N_{expected\ T,A}$ by using equation 3-7.

$$Var(N_{expected,T,A}) = N_{expected\ T,A}{}^2 \left(\frac{1}{N_{observed\ T,B}} + \frac{1}{N_{observed\ C,B}} + \frac{1}{N_{observed\ C,A}} \right) \quad (3\_7)$$

And the CMF and its variance can be estimated from equations 3-8 and 3-9

$$\mathrm{CMF} = \frac{(\frac{\mathrm{N_{observed\ T,A}}}{\mathrm{N_{expected\ T,A}}})}{(1 + \left(\frac{\mathrm{Var\ (N_{expected,T,A})}}{\mathrm{N_{expected,T,A}}{}^2}\right))} \quad (3\_8)$$

$$\mathrm{Var\ (CMF)} = \frac{\mathrm{CMF}^2((1/\mathrm{N_{observed,T,A}}) + (\mathrm{Var}(\mathrm{N_{expected,T,A}})/\mathrm{N_{expected,T,A}}{}^2))}{(1 + \frac{\mathrm{Var}(\mathrm{N_{expected,T,A}})}{\mathrm{N_{expected,T,A}}{}^2})^2} \quad (3\_9)$$

Where;

$\mathrm{N_{observed\ T,B}}$= The observed number of crashes in the before period for the treated group.

$\mathrm{N_{observed\ T,A}}$= The observed number of crashes in the after period for the treated group.

$\mathrm{N_{observed\ C,B}}$= The observed number of crashes in the before period for the comparison group.

$\mathrm{N_{observed\ C,A}}$= The observed number of crashes in the after period for the comparison group.

3.4 Before-After with Empirical Bayes Method

The objective of this method is to more accurately estimate the CMF. It is generally accepted among researchers and practitioners in calculating the CMF because it accounts for the regression to the mean by providing estimation for the mean crash frequency of similar reference sites using Safety performance functions (SPFs). These SPFs account for traffic volume changes which results in a true safety effect of the treatment because the SPFs use average daily traffic and sometimes other characteristics of the site such as, number of lane, posted speed, and driveway density.

The method is based on three fundamental assumptions (Hauer, 1997):

1. The number of crashes at any site follows a Poisson distribution.
2. The mean 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., 2000).

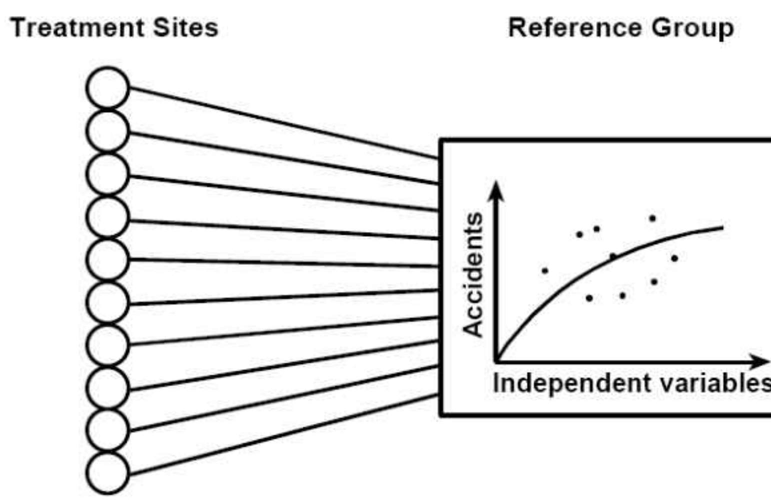

Figure 3-1: Conceptual Approach of the Empirical Bayesian Method
(Source: Harwood et al., 2000)

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 'evidence' from the reference sites is obtained as an output from the SPF. SPF is a regression model which provides an estimate of crash occurrence 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 the negative binomial form is used to fit the before period crash data of the reference sites with their geometric and traffic parameters. In the simplest way, in order to apply this method, the first step is to develop the SPF as explained in the next section. After developing the SPF using negative binomial model, we will get the $N_{\text{Predicted T, B}}$ and $N_{\text{Predicted T, A}}$ as a result of this model. After getting these values, we can calculate the weight factor estimated from the over-dispersion parameter of the negative binomial regression relationship and the predicted 'before' period crash frequency for the treatment site as shown in equation 3-10.

$$\text{Weight} = \frac{1}{1+\frac{\mu\times n}{\varphi}} \qquad (3\_10)$$

Where;

n = Number of years in the before period,

φ = Over-dispersion parameter.

μ = The number of accidents/(km-year) for expected on similar segments.

As you see from the previous equation that the weight is reduced if many years of crash data are used. Now, we can calculate the $N_{\text{expected T,B}}$ as shown in equation 3-11.

$$N_{\text{expected,T,B}} = \text{weight}*(N_{\text{predicted,T,B}}) + (1-\text{weight})*(N_{\text{observed,T,B}}) \qquad (3\_11)$$

After getting the $N_{expected,T,B}$, we can calculate the $N_{expected,T,A}$ as shown in equation 3-12.

$$N_{expected,T,A}=N_{expected,T,B}\ (N_{predicted,T,A}/\ N_{predicted,T,B}) \tag{3_12}$$

Where,

$N_{expected,T,B}$ = The unadjusted empirical Bayes estimate.

$N_{predicted,T,B}$ = The predictednumber of crashes estimated by the SPF in the before period.

$N_{predicted,T,A}$ = The predictednumber of crashes estimated by the SPF in the after period.

The variance of $N_{expected,T,A}$ is estimated from $N_{expected,T,A}$, the before and after SPF estimates and the SPF weight, from Equation 3-13.

$$Var(N_{expected,T,A}) = N_{expected,T,A}\ (\ N_{predicted,T,A}\ /\ N_{predicted,T,B})(1 - weight) \tag{3_13}$$

And the CMF and its variance can be estimated from equations 3-14 and 3-15

$$\mathrm{CMF} = \frac{\left(\frac{N_{\mathrm{observed\ T,A}}}{N_{\mathrm{expected\ T,A}}}\right)}{\left(1 + \left(\frac{\mathrm{Var}\ (N_{\mathrm{expected,T,A}})}{{N_{\mathrm{expected,T,A}}}^{2}}\right)\right)} \tag{3_14}$$

$$\mathrm{Var}\ (\mathrm{CMF}) = \frac{\mathrm{CMF}^2\left(\left(1/N_{\mathrm{observed,T,A}}\right) + \left(\mathrm{Var}(N_{\mathrm{expected,T,A}})/{N_{\mathrm{expected,T,A}}}^{2}\right)\right)}{\left(1 + \frac{\mathrm{Var}\left(N_{\mathrm{expected,T,A}}\right)}{{N_{\mathrm{expected,T,A}}}^{2}}\right)^2} \tag{3_15}$$

3.5 Safety Performance Function (SPF)

Data from the reference group are used to 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 the traffic volume and the roadway characteristics such as, number of lanes, width of lanes, and posted speed. There are two main types of SPFs: 1) 'Full' SPF and 2) 'Simple' SPF. 'Full' SPF is a mathematical relationship that relates crash frequency to both traffic and geometric parameters, whereas 'Simple' SPF includes Annual Average Daily Traffic (AADT) as the sole variable in predicting crash frequency on the roadways. The Highway Safety Manual (HMS) uses the simple SPF to calibrate the CMF. In this study, we used the full SPF, which produces more accurate results than the simple SPF.

After calibrating the model, we should check the goodness of fit of the calibrated model. In our study, we used Pearson's chi-square to see if the model is a good fit for the data. Also, we calculate the Akaike Information Criterion (AIC). Calculating AIC will help us if we found several significant models of the same type of crashes, and we want to see which model has the best fit. The model with the smallest value of AIC is considered the best. In the general form, the AIC is shown in equation 3-16.

$$\text{AIC} = -2k + 2 \ln (L) \qquad (3\_16)$$

Where,

k = Number of parameters.

L= Maximum value of likelihood for the estimated model.

3.6 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 it's 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).

$y_i|\lambda_i \sim$ Poisson (λ_i)

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

Then, P(y_i) ~ Negbin (λ_i, k)

$$= \frac{\Gamma(1/k + y_i)}{y_i!\Gamma(1/k)}\left(\frac{k\lambda_i}{1+k\lambda_i}\right)^{y_i}\left(\frac{1}{1+k\lambda_i}\right)^{1/k} \qquad (3\_17)$$

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 3-18.

$$\lambda = \exp(\beta^T X + \varepsilon) \qquad (3\_18)$$

Where,

β = A vector of regression of parameter estimates;

X= A vector of explanatory variables;

$\exp(\varepsilon)$ = 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 3-19.

$$\operatorname{var}(y) = \lambda + k\lambda^2 \qquad (3\_19)$$

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 as given in Equation 3-20.

$$l(\beta, k) = \prod_i \frac{\Gamma(1/k + y_i)}{y_i!\Gamma(1/k)} \left(\frac{k\lambda_i}{1+k\lambda_i}\right)^{y_i} \left(\frac{1}{1+k\lambda_i}\right)^{1/k} \qquad (3\_20)$$

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

3.7 Cross Sectional Studies

It should be noted that the CMF for certain treatments could only be estimated using the Cross-sectional 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). However, in our study, we applied both Before-After Studies and Cross Sectional Studies.

The Cross-sectional method requires the development of crash prediction models (i.e. SPFs) to calculate the CMFs. The models are developed using the crash data for both sites with and without the treatment of interest for the same time period (2-5 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 (Carter et al., 2012). Sufficient sample size is particularly important when many variables are included in the SPF. Having more treated and untreated sites will ensure large variations in crash frequency and variables, and helps better understanding of the relationships. The treated and untreated sites must have comparable geometric characteristics and traffic volume (AASHTO, 2010).

We 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 for over-dispersion. The model describes crash frequency in a function of explanatory variables including geometric characteristics, AADT and length of roadway segments as follows:

$$F_i = \exp(\alpha + \beta_1 * \ln AADT_i + \beta_2 * RMED_i + \beta_3 * Length_i + \beta_k * x_{ki}) \quad (3\_21)$$

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 TWLTL);

$Length_i$ = 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;

β_1, β_2, …,β_k = Coefficient for the variable k.

In the above equation, length and AADT are independent variables to identify the isolated effect of the treatment 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):

$$CMF = \exp(\beta_k * (x_{kt} - x_{kb})) \tag{3\_22}$$

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 predict the total crash frequency or the frequency of specific crash type or crash severity. The standard error (SE) of the CMF is calculated as follows (Bahar, 2010):

$$SE = \frac{\exp(\beta_k * (x_{kt} - x_{kb}) + SE_{\beta_k}) - \exp(\beta_k * (x_{kt} - x_{kb}) - SE_{\beta_k})}{2} \tag{3\_23}$$

Where,

SE = Standard error of the CMF.

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

CHAPTER 4. DATA COLLECTION AND PREPARATION

The purpose of this chapter is to describe the data collection and preparation process and effort in this research. Florida Department of Transportation (FDOT) provided many data sources, which were used to identify the needed locations and to get the crash data for these locations. The sources are Roadway Characteristics Inventory (RCI), TRANSTAT-IVIEW Aerial Mapping System, and Crash Analysis Reporting (CAR). Furthermore, Google Earth was used to validate some of the locations and construction's dates for the treated group.

4.1 FDOT's Sources

4.1.1 Roadway Characteristics Inventory (RCI)

The RCI data is mainly used to identify the geometric characteristics of roadway segments or intersections, traffic volume, and many other important variables. The RCI data are available from 2004 to this recent year, so roadway characteristics prior 2004 are not available at RCI data. RCI data contains about 49 main variables such as, surface width, number of lanes, median width and its type, type of road, shoulder width and its type, and posted speed.

4.1.2 TRANSTAT-IVIEW Aerial Mapping System

This source is useful to verify information and check location with a roadway ID number and beginning and end milepost. Mostly, this source was used to locate the sites that we want to study; then, Google Earth was used to verify some of the data and check treatment's dates and type.

4.1.3 Crash Analysis Reporting (CAR)

CAR is a large crash database from 2003 to the recent year. It is a tool that can be used for crash analysis. By using CAR, if we want to study specific sites, we can get all crash types and severity levels for these sites.

4.2 Data Collection for Before-After Studies

In this section, we explain the data collection and preparation effort in order to apply the before and after studies. The data in this section were used to calculate the CMF using Naïve Method, Before-After with Comparison Group Method, and Before-After with Empirical Bayes Method.

4.2.1 Data Collection for the Treated Group

The two-year RCI data (2004 and 2012) for the whole state was used as a way to find the treated and comparison groups for this treatment. By matching the milepost of the two years, the sites where the median type was converted from TWLTL to raised median were identified as the treated group. The influence areas of the intersection, which is 250 feet from the center of the intersection, were excluded using TRANSTAT-IVIEW, and Google Earth was used to validate the RCI data. Also, the beginning and end of the construction period of the treated segments were identified using RCI and Google Earth. As a result, a total of 33 treated segments were identified with a minimum 0.104-mile segment's length. The driveway density of the treated segments was identified using Google Earth. Table 4-1 presents the segments' information of the treated group.

Table 4-1: Segments' Information of the Treated Group

District No.	County	Roadway ID	Construction Beginning Date	Construction End Date	Length
1	Sarasota	17040000	1/30/2006	12/28/2006	0.317
1	Sarasota	17040000	1/30/2006	12/28/2006	0.252
1	Sarasota	17040000	1/30/2006	12/28/2006	0.368
1	Sarasota	17040000	1/30/2006	12/28/2006	0.18
1	Sarasota	17040000	1/30/2006	12/28/2006	0.24
1	Sarasota	17040000	1/30/2006	12/28/2006	0.739
3	Leon	55080000	3/30/2006	11/12/2007	0.522
3	Leon	55080000	3/30/2006	11/12/2007	0.119
3	Leon	55080000	3/30/2006	11/12/2007	0.457
7	Hillsborough	10030000	11/29/2007	1/8/2008	0.245
7	Hillsborough	10030000	11/29/2007	1/8/2008	0.349
7	Hillsborough	10030000	11/29/2007	1/8/2008	0.358
7	Hillsborough	10030000	11/29/2007	1/8/2008	0.198
7	Hillsborough	10030000	11/29/2007	1/8/2008	0.438
7	Hillsborough	10030000	11/29/2007	1/8/2008	0.104
1	Lee	12020000	1/31/2006	6/8/2008	0.336
1	Lee	12020000	1/31/2006	6/8/2008	0.735
1	Lee	12020000	1/31/2006	6/8/2008	0.12
1	Lee	12020000	1/31/2006	6/8/2008	0.118

District No.	County	Roadway ID	Construction Beginning Date	Construction End Date	Length
1	Lee	12020000	1/31/2006	6/8/2008	0.401
4	St Lucie	94010000	11/12/2007	3/30/2009	0.14
4	St Lucie	94010000	11/12/2007	3/30/2009	0.42
7	Citrus	2030000	3/14/2007	11/12/2007	0.252
1	Lee	12004000	6/8/2008	4/1/2010	0.164
3	Leon	55002000	3/30/2006	11/12/2007	0.191
4	Palm Beach	93130000	2/27/2006	2/13/2008	0.121
5	Marion	36004000	1/30/2008	4/18/2009	0.17
5	Marion	36004000	1/30/2008	4/18/2009	0.144
5	Orange	75003000	11/12/2007	12/20/2008	0.287
5	Volusia	79030000	5/19/2005	12/30/2005	0.306
5	Volusia	79030000	5/19/2005	12/30/2005	0.142
5	Volusia	79030000	5/19/2005	12/30/2005	0.137
5	Volusia	79030000	5/19/2005	12/30/2005	0.2

4.2.2 Data Collection for the Comparison Group

After getting the treated group, we started collecting the comparison group for each site in order to use them in our analysis. The segments where median type (TWLTL) remains unchanged in the after period were identified as the comparison group if they have the similar traffic volume and geometric characteristics as the treated segments in the before period. The RCI data for the comparison group was collected in the same way as the treated group. Also, the driveway density of the comparison segments was identified using Google Earth. Table 4-2 presents the overall summary of the data collection for converting TWLTLs to raised median.

Table 4-2: The main Results of The Treated and Comparison Groups.

Group	Segments Length (miles)	No. Of roadways	No. Of segments
Treated	9.27	12	33
Comparison	30	28	109

4.2.3 Matching Crash Data

The final step in the data collection process was matching the crash data for the treated and comparison segments. The information of crash severity and type was obtained for each segment in the treated and comparison groups from the CAR system. All of the treated segments had at least two years before and after their median conversion. For each segment in the treated site, we picked the same years before and after period of the comparison sites. Table 4-3 presents the crash information of All, Fatal and Injury (F+I), head-on, angle, and left turn crashes in the before and after period of the treated and comparison groups. Regarding the Fatal and Injury Crashes, we analyzed two types of F+I crashes. The first type which is KABC contains four levels of crashes, which are possible injury, non-incapacitating injury, incapacitating injury, and fatal. And, the second type of F+I crashes is KAB, which contains three levels of crashes. They are non-incapacitating injury, incapacitating injury, and fatal crashes.

Table 4-3: Crash Data for the Treated and Comparison Group

Crash Type	Treated Group		Comparison Group	
	Before Crashes	After Crashes	Before Crashes	After Crashes
All	1127	681	1967	2087
F+I (KABC)	559	406	1215	1117
F+I (KAB)	290	216	683	604
Head-on	43	13	63	71
Angle	259	138	437	572
Left Turn	146	38	311	163

4.3 Data Collection for Cross Sectional Studies

In this section, we discuss the data collection and preparation process in order to apply the Cross Sectional method. The needed data in order to apply this method are several years of segments with TWLTLs and another set of segments with raised medians. We used the years 2010, 2011, and 2012 for this method. We collected 100 segments with TWLTLs, and these segments remain unchanged during 2010, 2011, and 2012. Also, we collected another 100 segments with raised medians, and these segments remain without change during 2010, 2011, and 2012. Also, we collected the traffic volume and geometric characteristics for each segment. Table 4-4 shows overall summary of the data collection for this method.

Table 4-4: Data Collection Results for the Cross Sectional Method

Group	Segments Length (miles)	No. Of roadways	No. Of segments
Raised Median	50	45	100
TWLTL	26	34	100

The final step in the data collection and preparation process was matching the crash data for the segments of TWLTLs and raised medians. The information of crash severity and type was obtained for each segment of both raised medians and TWLTLs from the CAR system. Table 4-5 presents the crash information of all, two types of Fatal and Injury (F+I), head-on, angle, and left turn crashes at segments of TWLTLs and raised medians.

Table 4-5: Crash Data at TWLTLs and Raised Medians for Cross Sectional Studies

Crash Type	TWLTLs	Raised Medians
All	1583	1104
F+I (KABC)	808	593
F+I (KAB)	399	296
Head-on	58	13
Angle	455	251
Left Turn	103	31

CHAPTER 5. ANALYSIS AND RESULT

In this research, Before-After studies, which are naïve method, Before-After with Comparison Group, and Before-After with Empirical Bayes methods, and Cross Sectional studies were used to evaluate the safety effectiveness of conversion a TWLTL Median to a Raised Median. The safety effectiveness of this treatment was estimated for different levels, which are all, fatal and injury, head-on, angle, and left turn crashes. Also, the safety effectiveness was estimated for four lane roadways versus six lane roadways and different types of medians.

5.1 Naïve Before-After

The observational Naïve Before-After method was applied, as mentioned in the data collection and preparation chapter, on 33 treated segments with a total of 9.27 miles. The CMFs were calculated based on crash rates and the exposure measure was estimated in million vehicle miles (MVM) of travel. The Poisson test of significant was performed to check if the percent of reduction in crash rates is significant or not. Table 5-1 presents the crash rates of all, two types of F+I, head on, angle, and left turn crashes in before and after period. Also, the table shows the percent of reduction of each type.

Table 5-1: Crash Rates of Different crash Types

Crash Type	Crash Rate (Crashes/MVM)		Percent of Reduction (%)
	Before	After	
Total	2.613	1.425	45.472
F+I (KABC)	0.651	0.423	35.023
F+I (KAB)	0.716	0.466	34.94
Head-on	0.0747	0.0329	55.957

Crash Type	Crash Rate (Crashes/MVM)		Percent of Reduction (%)
	Before	After	
Angle	0.537	0.292	45.62
Left Turn	0.415	0.091	78.20

Overall, the total crash rate across all locations was decreased by 45.47% from before to the after period. We applied the Poisson test of significant, and the reduction of total crash rate was statistically significant based on the 95- percent confidence. The same approach was applied to fatal and injury, head-on, angle, and left turn crashes, and the crash rate for F+I (KABC) and (KAB) decreased by approximately the same percentage, which is 35.00%. The reduction of head on, angle, and left turn crashes were 55.95%, 45.62%, and 78.20%, respectively. The reductions of the whole types of crashes were also statistically significant based on the 95-percent confidence. The CMFs were calculated for total, two types of F+I, head on, angle, and left turn crashes, and the results of CMFs are shown in Table 5-2.

Table 5-2: CMFs' Results Using Naïve Before-After Method

Type of Crashes	Total	F+I (KABC)	F+I (KAB)	Head on	Angle	Left Turn
CMF (Safety Effectiveness)	0.545 (45.47%)	0.650 (35.02%)	0.651 (34.94%)	0.440 (55.95%)	0.544 (45.6%)	0.219 (78.20%)

As shown in Table 5-2, the treatment has a positive effect after the conversion from TWLTL to raised median. Also, it significantly reduces the crashes especially head on and left turn crashes, which is two of the most dangerous types of crashes. So, we can conclude from this method that the treatment highly helped to decrease the percent of crashes for total, F+I, head-on, angle, left turn crashes; however, in this method as we mentioned in the methodology chapter, we don't account for some important factors such as the regression to the mean.

5.2 Before-After with Comparison Group (CG)

The observational Before-After with Comparison Group was performed on 33 treated sites and 109 comparison sites. The Treated and comparison sites had similar roadway characteristics and traffic volumes as shown in APPENDIX A. Table 5-3 shows the CMFs results by using Before-After with Comparison Group.

Table 5-3: CMFs Results Using Before-After with CG Method

Crash Type	CMF (Safety Effectiveness)	S.E.	Confidence Interval
Total	0.530 (47.00%)	0.0182	0.498-0.562
F+1 (KABC)	0.674 (32.60%)	0.0409	0.619-0.728
F+I (KAB)	0.836 (16.40%)	0.0077	0.821-0.851
Head-on	0.271 (72.9%)	0.0653	0.127-0.371
Angle	0.403 (59.70)	0.0024	0.0.398-0.408
Left Turn	0.489 (51.10%)	0.0098	0.470-0.508

As shown in Table 5-3 for Before-After with CG, the treatment helped to reduce all types of crashes, and it significantly helped to reduce Head on, angle, and left turn crashes. Also, we can see that the confidence intervals which are based on 95 percent confidence in all cases did not cross 1, and all of them are less than 1; as a result, there is an expected reduction in crashes due to the implementation of this treatment for all, F+I, head-on, angle, and left turn crashes, and the treatment has a positive effect that helped to reduce the crashes at urban areas by the shown percentages.

5.3 Before-After with Empirical Bayes (EB)

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. The SPFs were developed using the Negative Binomial (NB) Model. Tables 5-4 to 5-9 provide the results of calibrated Florida specific SPFs for total crashes, F+I, head on, angle, and left turn crashes. We calibrated the full SPFs for total, F+I, angle, and left turn crashes, and we calibrated simple SPF for head on crashes.

Table 5-4: Florida-Specific SPF for Conversion 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	-14.0153	2.5914	-26.0944	-15.9361	65.76	<0.0001
Log AADT	1	2.1108	0.2476	1.6256	2.5960	72.70	<0.0001
Length	1	1.1562	0.5575	0.0634	2.2490	4.30	0.0381
Dispersion	1	0.7136	0.1449	0.4793	1.0623		

Table 5-5: Florida-Specific SPF for Conversion a TWLTL to a Raised Median (F+I (KABC) Crashes))

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-18.6272	2.6345	-24.1413	-14.8143	57.50	< 0.0001
Log AADT	1	2.1262	0.2430	1.6500	2.6025	76.56	< 0.0001
Length	1	1.5908	0.5575	0.4981	2.6834	8.14	0.0043
Posted Speed	1	-0.0426	0.0229	-0.0875	0.0024	3.44	0.0436
Dispersion	1	0.4709	0.1263	0.2784	0.7966		

Table 5-6: Florida-Specific SPF for Conversion a TWLTL to a Raised Median (F+I (KAB) Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-18.2127	2.8253	-26.5018	-15.4269	55.06	< 0.0001
Log AADT	1	2.0032	0.2667	1.4805	2.5260	56.41	< 0.0001
Length	1	1.4427	0.5233	0.4170	2.4683	7.60	0.0058
Dispersion	1	0.3906	0.1361	0.1974	0.7731		

Table 5-7: Florida-Specific SPF for Conversion a TWLTL to a Raised Median (Head on Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-32.0804	8.4276	-54.5982	-21.5626	20.42	< 0.0001
Log AADT	1	3.3993	0.7742	1.8820	4.9166	19.28	< 0.0001
Dispersion	1	0.00001	0.0040	0.5254	2.1416		

Table 5-8: Florida-Specific SPF for Conversion a TWLTL to a Raised Median (Angle Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-20.3660	3.3370	-28.9065	-15.8255	44.92	< 0.0001
Log AADT	1	2.0922	0.3171	1.4708	2.7136	43.55	< 0.0001
Driveway Density	1	0.0334	0.0150	0.0040	0.0628	4.97	0.0258
Dispersion	1	0.03480	0.1592	0.1419	0.8531		

Table 5-9: Florida-Specific SPF for Conversion a TWLTL to a Raised Median (Left Turn Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-24.9126	3.3162	-33.4122	-10.4131	65.85	< 0.0001
Log AADT	1	2.5226	0.3081	1.9188	3.1263	67.06	< 0.0001
Dispersion	1	0.0378	0.1194	0.0001	18.4112		

All variables that are shown in the previous six tables are significant based on 95% confidence level, and these models are the best in term of maximum numbers of significant variables. After calibrating the SPF models, we should check the goodness of fit of these models. In order to do that, we checked Pearson's chi-square value and from it we calculate the P-value. Table 5-10 shows Pearson's Chi-square value and the P-value.

Table 5-10: Pearson's Chi-Square and P-Value

Type of Crash	Pearson's chi-square Value	P-Value
Total	111.3116	0.343
F+I (KABC)	101.3983	0.608
F+I (KAB)	104.2458	0.530
Head-on	86.1450	0.921
Angle	110.7057	0.352
Left Turn	88.8668	0.885

For these models, the non-significant p-value suggests that the negative binomial model is a good fit for the data. As we can see that, all of our models are a good fit of the data. Also, I calculated the AIC value, which is based on maximum likelihood and number of parameter in the model. Table 5.11 shows the AIC values of the SPF models. I also included in the table the intercept value and the coefficient of the significant variables.

Table 5-11: AIC Values of SPF Models

Model	Total	F+I (KABC)	F+I (KAB)	Head on	Angle	Left Turn
Intercept	-14.0153	-18.6272	-18.2127	-32.0804	-20.3660	-24.9126
ADT	2.1108	2.1262	2.0032	3.3993	2.0032	2.5226
Length	1.1562	1.5908	1.4427	______	1.4427	_____
Posted Speed	_______	-0.0426	______	_______	______	______
Driveway Density	______	______	______	______	_______	______
AIC	527.33	439.30	350.43	71.50	275.60	214.60

Now, we can apply the equations as explained in the methodology chapter. Table 5-12 shows the CMFs' results of these types of crashes using Before-After with EB.

Table 5-12: CMFs Results Using Before-After with EB Method

Crash Type	CMF (Safety Effectiveness)	S.E.	Confidence Interval
Total	0.621 (37.90%)	0.0594	0.504-0.737
F+1 (KABC)	0.760 (24.00%)	0.093	0.577-0.942
F+1 (KAB)	0.837 (16.30%)	0.130	0.623-1.051*
Head-on	0.525 (47.50%)	0.193	0.146-0.903
Angle	0.671 (32.90%)	0.133	0.410-0.931
Left Turn	0.296 (70.40)	0.105	0.090-0.502

* These confidence intervals are based on 90%.

As shown in Table 5-12 for Before-After with EB, the treatment helped to reduce the total, F+I (KABC), head on, angle, and left turn crashes by 37.90%, 24.00%, 47.50%, 32.90%, and 70.40%, respectively, and the confidence intervals, which is based on 95 percent, for them did not cross unity, and they are less than 1; as a result, there is an expected reduction in crashes due to the implementation of this treatment for total, F+I (KABC), head on, angle, and left turn crashes. However, for F+I (KAB) crashes, the treatment helped to reduce this type of crashes by 16.30%, and we can see that the confidence interval, which is based on 90 percent confidence crossed 1, which means that we are not sure if the treatment had any effect on this type of crashes based on 90 percent confidence interval.

We can conclude that based on Before-After studies the conversion from TWLTLs to raised medians at urban areas reduces crashes at least by 37.90% for total crashes, 24% for F+I (KABC) crashes, 16.30% for F+I (KAB) crashes, and 32.90% for angle crashes. Also, it significantly reduces crashes by at least 47.50% for head-on crashes, and 51.10% for left turn crashes, by restricting turning maneuvers.

5.4 Cross Sectional Studies

Data from a total of 100 raised median segments and another 100 TWLTL segments were collected in order to apply the cross-sectional method. Both sets of segments have similar roadway characteristics and traffic volumes as shown in APPENDIX A. Sets of Florida-specific SPFs using NB distribution were developed to estimate CMFs for total, F+I, head on, angel, and left turn crashes. SPFs describe crash frequency as a function of explanatory variables including the raised median, AADT, and segments' length as explained in methodology chapter. Table 5-13 to 5-18 show the results of SPFs.

Table 5-13: Florida-Specific SPF for Adding 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	-14.3028	5.4524	-24.9893	-3.6162	6.88	0.0087
Log AADT	1	1.561	0.5316	0.5191	2.6029	8.62	0.0033
Median	1	-0.4158	0.2245	-0.8559	0.0243	3.43	0.0461
Length	1	1.9028	0.4088	1.1015	2.7041	21.66	<0.0001
Dispersion	1	1.162	0.1746	0.8656	1.5600		

Table 5-14: Florida-Specific SPF for Adding a Raised Median (F+I (KABC) Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-7.3580	5.1616	-17.4746	2.7586	2.03	0.0100
Log AADT	1	0.7581	0.5043	-0.2303	1.7466	2.26	0.0960
Median	1	-0.4731	0.2112	-0.8870	-0.0593	5.02	0.0250
Length	1	2.0666	0.3567	1.3676	2.7656	33.58	<0.0001
Dispersion	1	0.7259	0.1615	0.4693	1.1227		

Table 5-15: Florida-Specific SPF for Adding a Raised Median (F+I (KAB) Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-10.5058	4.4025	-29.1344	-11.8771	21.70	<0.0001
Log AADT	1	1.9312	0.4207	1.1066	2.7559	21.07	<0.0001
Median	1	-0.4820	0.2009	-2.8114	-1.3560	31.49	<0.0001
Length	1	1.9620	0.5040	0.9742	2.9498	15.15	<0.0001
Dispersion	1	1.7287	0.4738	1.0102	2.9582		

Table 5-16: Florida-Specific SPF for Adding a Raised Median (Head on Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-27.8401	7.7316	-42.9937	-12.6865	12.97	0.0003
Log AADT	1	2.5665	0.7383	1.1194	4.0135	12.08	0.0005
Median	1	-1.2794	0.5761	-3.3085	-1.0502	14.31	0.0002
Length	1	1.8890	0.7527	0.4138	3.3643	6.30	0.0121
Dispersion	1	5.1099	1.7571	2.6045	10.0254		

Table 5-17: Florida-Specific SPF for Adding a Raised Median (Angle Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-15.4597	2.8642	-21.0734	-9.8459	29.13	<0.0001
Log AADT	1	1.6331	0.2779	1.0884	2.1777	34.53	<0.0001
Median	1	-0.6317	0.2094	-1.0421	-0.2213	9.10	0.0026
Dispersion	1	1.6644	0.2357	1.2610	2.1968		

Table 5-18: Florida-Specific SPF for Adding a Raised Median (Left Turn Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-15.9587	4.4276	-27.6367	-10.2807	18.33	<0.0001
Log AADT	1	1.8309	0.4251	0.9977	2.6641	18.55	<0.0001
Median	1	-1.2860	0.3174	-1.9082	-0.6639	16.42	<0.0001
Dispersion	1	1.2887	0.6015	1.3673	3.8308		

The values shown in Table 5-13, 5-15, 5-16, 5-17, and 5-18 are significant based on 95 percent confidence. However, the values in Table 5-14 are significant based on the 90 percent confidence. After calibrating the SPF, we can apply the equation as explained in the methodology chapter. Table 5-19 shows the CMFs' results using the cross sectional method.

Table 5-19: CMFs' Results Using Cross Sectional Method

Crash Type	CMF (Safety Effectiveness)	S.E.	Confidence Interval
Total	0.660 (34.00%)	0.149	0.368 - 0.952
F+1 (KABC)	0.623 (37.70%)	0.132	0.364 - 0.882
F+1 (KAB)	0.617 (38.30%)	0.123	0.376 - 0.858
Head-on	0.280 (72.00%)	0.169	0 – 0.611
Angle	0.532 (46.80%)	0.112	0.312 – 0.751
Left Turn	0.276 (72.36%)	0.089	0.10 – 0.450

As shown in Table 5-19, the treatment helped to reduce the total, F+I, and angle crashes by approximately 34.00%, 37.00%, and 47.00%, respectively, and it significantly helped to reduce head on and left turn crashes by approximately 72.00%. Also we can see that the confidence intervals which are based on 95 percent confidence for the whole listed types of crashes, did not cross 1, and they are less than 1; as a result, there is an expected reduction in crashes due to the implementation of this treatment for these types of crashes.

5.5 Four Lane Roads versus Six Lane Roads

In this study, we have 33 segments, and all of them are four or six lane roads. We have 18 segments four lane roads and 15 segments six lane roads. Also, regarding the Cross Sectional sample, we have 100 segments, and all of them are four or six lanes. In this part, we intend to explore the safety effectiveness of this treatment on these roads separately. Does the treatment more effective on four lane rather than six lane roads? In order to answer this question, we have to apply the above methodology. In this part, we applied Before-After with CG, Before-After with EB, and Cross Sectional Studies. As we know from the previous sections, in order to calibrate CMFs using Before-After with EB and Cross Sectional Methods, we have to develop SPF model. Tables 5-20 to 5-23 provide the results of calibrated Florida SPFs for four and six lane roads.

Table 5-20: Florida-Specific SPF for Conversion a TWLTL to a Raised Median on Four Lane Roads

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-12.0194	6.5128	-24.7844	0.7455	3.41	0.0650
Log AADT	1	1.5141	0.6313	0.2769	2.7513	5.75	0.0165
Length	1	2.0468	0.9931	0.1003	3.99333	4.25	0.0393
Posted Speed	1	-0.0548	0.0319	-0.1174	0.0077	2.95	0.0858
Dispersion	1	1.3655	0.3002	0.8874	2.1010		

Table 5-21: Florida-Specific SPF for Conversion a TWLTL to a Raised Median on six Lane Roads

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standar d Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-19.8025	8.3653	-36.1981	-3.4068	5.60	0.0179
Log AADT	1	2.4404	0.6621	1.1426	3.7381	13.58	0.0002
Length	1	1.8695	1.0032	-0.0967	3.8356	3.47	0.0624
Posted Speed	1	-0.0856	0.0454	-0.1747	0.0034	3.55	0.0594
Dispersion	1	0.6681	0.1494	0.4310	1.0356		

Table 5-22: Florida-Specific SPF for Adding a Raised Median on Four Lane Roads

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-20.0944	5.1087	-30.1071	-10.0816	15.47	<0.0001
Log AADT	1	2.1600	0.5082	1.1640	3.1560	18.70	<0.0001
Median	1	-0.7502	0.3341	-1.1277	0.1820	2.00	0.0970
Length	1	1.1654	0.4740	0.2364	2.0945	6.05	0.0139
Dispersion	1	1.6753	0.3015	1.1774	2.3839		

Table 5-23: Florida-Specific SPF for Adding a Raised Median on Six Lane Roads

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-12.6474	6.4596	-25.3081	0.0132	3.83	0.0502
Log AADT	1	1.4561	0.6071	0.2663	2.6459	5.75	0.0165
Median	1	-0.7202	0.2709	-1.8793	-0.8175	24.78	<0.0001
Length	1	2.1794	0.5597	1.0823	3.2765	15.16	<0.0001
Dispersion	1	1.3673	0.2200	0.9974	1.8743		

The models shown in Table 5-20, Table 5-21, and Table 5-22 are significant based on the 90 percent confidence. However, the model in Table 5-23 is significant based on the 95 percent confidence. From these models, we are able to calculate the CMFs using EB and Cross Sectional Methods. Table 5-24 shows the CMFs' results using Before-After with CG, Before-After with EB, and Cross Sectional Studies.

Table 5-24: CMFs' Results for Four and Six Lanes Roads Using Before-After with CG Before-After with EB, and Cross Sectional Methods

Road's Number of Lane	Four Lane Roads			Six Lane Roads		
	CMF (Safety Effectiveness)	SE	Confidence Interval	CMF (Safety Effectiveness)	SE	Confidence Interval
Before-After with CG	0.367 (63.30%)	0.027	0.314-0.420	0.612 (38.80%)	0.035	0.544- 0.680
Before-After with EB	0.609 (39.10%)	0.047	0.517- 0.702	0.832 (16.80%)	0.052	0.731- 0.934
Cross Sectional	0.472 (52.77%)	0.160	0.156- 0.785	0.486 (51.33%)	0.133	0.225- 0.747

As shown in Table 5-24 in the three methods, the treatment is more effective on four lane roads rather than six lane roads. Also, we see that the confidence intervals, which are based on the 95 percent confidence for both types of roads did not cross 1, and they are less than 1; as a result, there is an expected reduction in crashes due to the implementation of this treatment for these types of roads. The treatment helped to reduce crashes in four lane roads by 63.30% using Before-After with CG, by 39.10% using Before-After with EB, and by 52.77% using Cross Sectional Method. As a result, the treatment helped to reduce the crashes in four lane roads at least by 39.10%. On the other hand, the treatment helped to reduce crashes in six lane roads by 38.80% using Before–After with CG, by 16.80% using Before-After with EB, and by 51.33% using Cross Sectional Method. As a result, the treatment helped to reduce the crashes in six lane roads at least by 16.80%. Thus, we can conclude that this treatment has a positive effect on both roads, and it is more effective on four lane roads rather than six lane roads.

5.6 Concrete Curbs versus Lawn Curbs

There are different types of raised medians such as concrete curb, curb with lawn, barrier, and curb with landscaping. In this study, for the after period in the treated group, we have 15 concrete curb segments, 16 lawn curb segments, and 2 landscaping curb segments. As a result of this distribution, we are able to see the safety effectiveness of conversion a TWLTL to a concrete curb median or lawn curb median. Figure 5-1 and 5-2 are examples of curb with concrete median and concrete with lawn median, respectively.

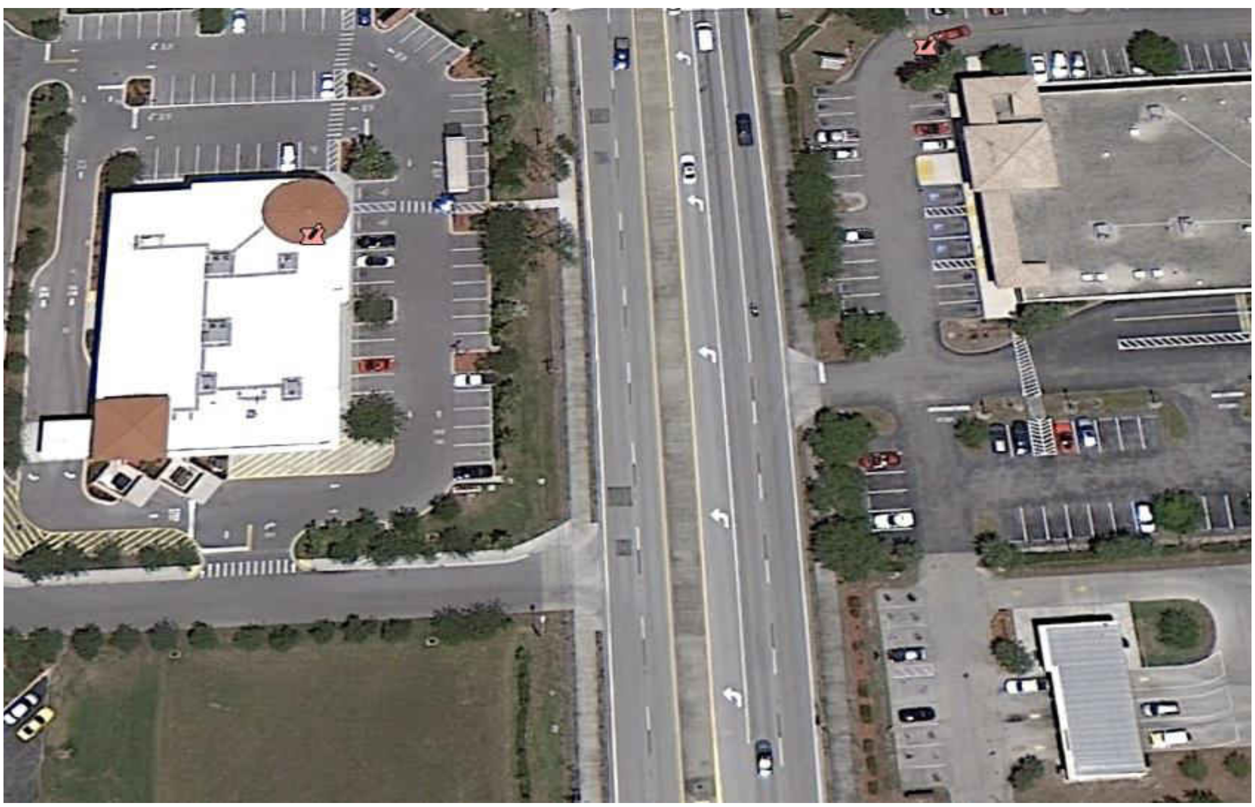

Figure 5-1: An Example of Concrete Curb Median (Source: Google Earth)

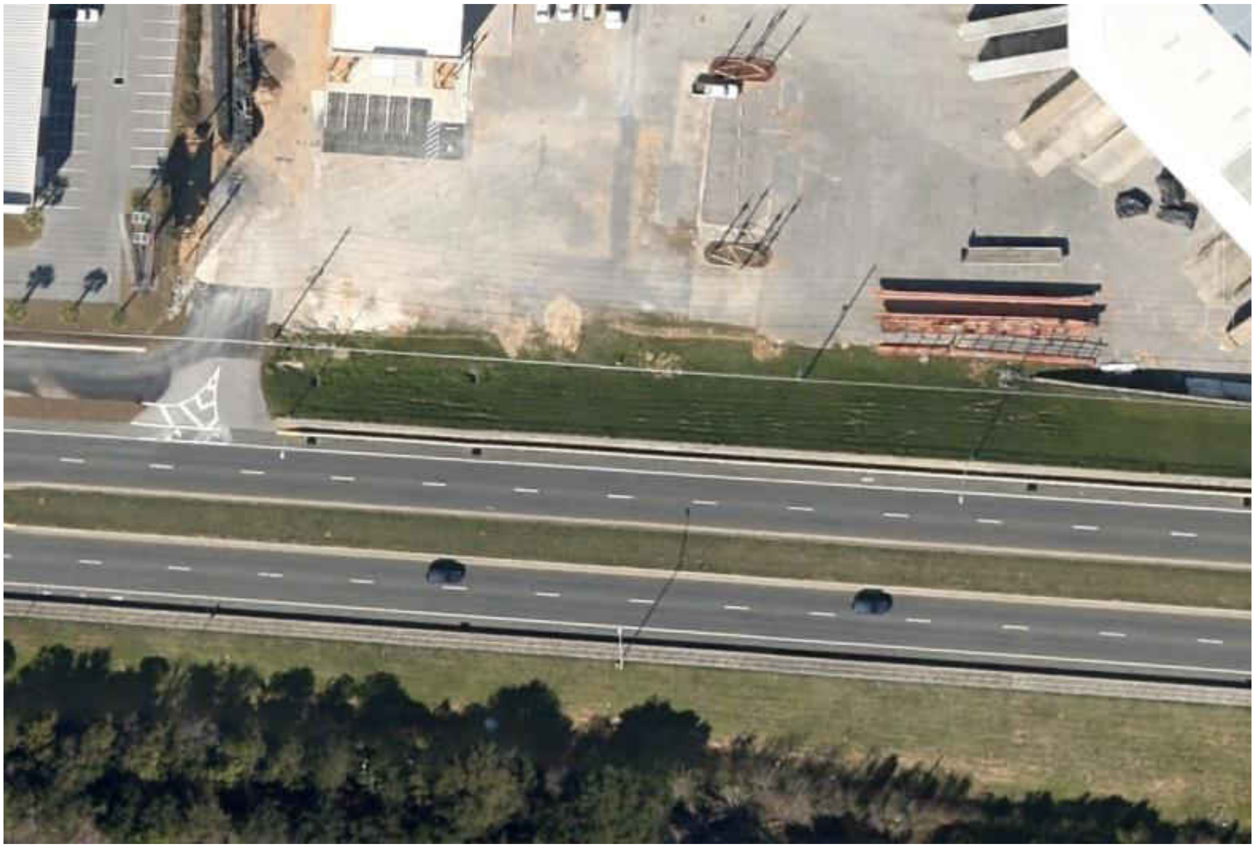

Figure 5-2: An Example of Curb with Lawn Median (Source: Google Earth)

We will compare between these two types and see if there is a difference between them from a safety point of view or not. If so, what is the recommended type? In order to answer this question, we have to apply the Before-After studies. We applied Before-After with CG and Before-After with EB. As we know from the previous sections, in order to calibrate CMFs using Before-After with EB, we have to develop SPF model. Table 5-25 and 5-26 provide the results of calibrated Florida specific SPFs for the conversion from TWLTL median to concrete curb and lawn curb, respectively.

Table 5-25: Florida-Specific SPF for Conversion a TWLTL median to a concrete Median

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-21.7578	2.2907	-26.2474	-17.2682	90.22	<0.0001
Log AADT	1	2.3674	0.2188	1.9386	2.7963	117.06	<0.0001
Dispersion	1	0.4643	0.1255	0.2733	0.7887		

Table 5-26: Florida-Specific SPF for Conversion a TWLTL median to a lawn Median

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-32.9459	9.4093	-51.3878	-14.5039	12.26	0.0005
Log AADT	1	3.3369	0.8921	1.5885	5.0853	13.99	0.0002
Dispersion	1	1.3034	0.3673	0.7502	2.2645		

The shown values in Table 5-25 and Table 5-26 are significant based on 95 percent confidence, and it is simple SPF. From these models, we are able to calculate the CMFs using EB Method. Table 5-27 shows the CMF results using Before-After with CG and EB.

Table 5-27: CMFs' Results for Concrete and Lawn Curb medians using Before-After with CG and EB

Median Type	Before-After with CG			Before-After with EB		
	CMF (Safety Effectiveness)	SE	Confidence Interval	CMF (Safety Effectiveness)	SE	Confidence Interval
Concrete	0.612 (38.80%)	0.038	0.537- 0.686	0.848 (15.20%)	0.056	0.739- 0.957
Lawn	0.549 (45.10%)	0.038	0.474- 0.624	0.874 (12.60%)	0.067	0.764- 0.984*

* This confidence interval is based on 90%.

As shown in table 5-27 in both methods, the treatment has a positive effect on both types. The conversion from TWLTLs to concrete curb medians helped to reduce crashes at least by 15.20% as shown in Before-After with EB. And, the conversion from TWLTLs to lawn curb medians helped to reduce crashes at least by 12.60% as shown in Before-After with EB. The confidence intervals are based on 95 percent except the confidence interval for lawn curb median, which is 90 percent using EB method. Also, we see that the confidence intervals for both types of medians did not cross 1, and they are less than 1; as a result, there is an expected reduction in crashes due to the implementation of this treatment for these types of medians. It is shown that both types of medians have similar safety effectiveness. There is not enough evidence to claim that the conversion to concrete curb median is safer than lawn curb median because the results of Before-After with CG is shown that the conversion from TWLTLs to lawn curb medians helped to reduce crashes by 45.10%; however, the conversion from TWLTLs to concrete curb medians helped to reduce crashes by 38.80% which is lower than the percent at lawn curb medians. So, what we can say is that both medians have similar effects due to the conversion, and both medians helped to reduce the number of crashes

CHAPTER 6. SUMMARY, CONCLUSIONS, AND FUTURE WORK

6.1 Summary

This research evaluated the safety effectiveness of conversion of TWLTLs to raised medians at urban areas in Florida using Before-After and Cross Sectional Studies. Also, it evaluated the safety effectiveness of this treatment on four and six lane roads and identified the safest. Moreover, we tried to identify which type of raised medians after the conversion is the safest.

Regarding Before-After and Cross Sectional Studies, we calibrated CMFs for all, F+I, head on, angle, and left turn crashes using Naïve, Before-After with CG, Before-After with EB, and Cross Sectional Methods. Table 6-1 provides summary results of Before-After and Cross Sectional Studies.

Table 6-1: Results of Before-After and Cross Sectional Studies.

Type of Crashes	Before-After Studies					Cross Sectional Studies	
	Naïve Method	Before-After with CG		Before-After with EB			
	CMF (Safety Effectiveness)	CMF (Safety Effectiveness)	SE	CMF (Safety Effectiveness)	SE	CMF (Safety Effectiveness)	SE
Total	0.545 (45.50%)	0.530 (47.00%)	0.0182	0.621 (37.90%)	0.059	0.660 (34.00%)	0.149
F+I (KABC)	0.650 (35.00%)	0.674 (32.60%)	0.0409	0.760 (24.00%)	0.093	0.623 (37.70%)	0.132
F+I (KAB)	0.651 (34.94%)	0.836 (16.40%)	0.0077	0.837 (16.30%)	0.130	0.617 (38.30%)	0.123
Head on	0.440 (56.00%)	0.271 (72.9%)	0.0653	0.525 (47.50%)	0.193	0.280 (72.00%)	0.169

Type of Crashes	Before-After Studies					Cross Sectional Studies	
	Naïve Method	Before-After with CG		Before-After with EB			
	CMF (Safety Effectiveness)	CMF (Safety Effectiveness)	SE	CMF (Safety Effectiveness)	SE	CMF (Safety Effectiveness)	SE
Angle	0.544 (45.6%)	0.403 (59.70)	0.0024	0.671 (32.90%)	0.133	0.532 (46.80%)	0.112
Left Turn	0.219 (78.20%)	0.489 (51.10%)	0.0098	0.296 (70.40)	0.105	0.276 (72.36%)	0.089

As a result of the four methods that are shown in Table 6-1, we can say that the treatment has a positive effect, and it helped to reduce the total crashes at least by 34.00% as shown in Cross Sectional Method with a 95% confidence, and the confidence interval is 0.368-0.952 based on 95 percent confidence. Also, it helped to reduce the F+I (KABC) crashes at least by 24.00% as shown in Before-After with EB Method with a 95% confidence, and the confidence interval is 0.577-0.942 based on 95 percent confidence interval. However, for the F+I (KAB) crashes, the treatment helped to reduce crashes at least by 16.30% as shown in Before-After with EB Method with a 90 percent confidence, and the confidence interval is 0.623-1.051 based on 90 percent confidence interval. We see that the confidence interval crossed 1, which means we are not sure if the treatment had any effect on this type of crashes based on 90 percent confidence interval. Also, it significantly helped to reduce the head on crashes at least by 47.50% as shown in Before-After with EB Method with a 95% confidence, and the confidence interval is 0.146-0.903 based on 95 percent confidence interval. Also, it helped to reduce the angle crashes at least by 32.90% as shown in Before-After with EB Method with a 95% confidence, and the confidence interval is 0.410-0.931 based on 95 percent confidence interval. Finally, the treatment significantly helped to reduce left turn crashes at least by 51.10% as shown in Before-After with

CG Method, and the confidence interval is 0.470-0.508 based on 95 percent confidence interval. As a result, we can say that the treatment in general has a positive effect on these types of crashes especially head on and left turn crashes by restricting turning maneuver, and based on 90 percent confidence interval, we are not sure if the treatment had any effect on F+I (KAB) crashes.

This research also evaluated the safety effectiveness of this treatment on four and six lane roads, and it has proved that the treatment is more effective on four lane roads than six lane roads. The treatment helped to reduce the crashes on four lane roads at least by 40%. On the other hand, the treatment helped to reduce the crashes on six lane roads at least by 16.80%. Here, we recommend the CMF values that calibrated using Before-After with CG to be used because the standard error of this method is the smallest. Thus, we can conclude that this treatment has a positive effect on both roads, and it will help to reduce crashes on four lane and six lane roads by 63.3% and 38.80%, respectively.

Also, we evaluated which type of the raised medians after the conversion is the most effective. Due to the sample size, we evaluated two types of raised medians, which are concrete curb and lawn curb medians. The conversion from TWLTLs to concrete curb medians helped to reduce crashes by 15.20% as shown in Before-After with EB Method. And, the conversion from TWLTLs to lawn curb medians helped to reduce crashes by 12.60% as shown in Before-After with EB Method. And, the Before-After with CG Method shows that the treatment is more effective on lawn curb medians rather than concrete curb medians. As a result, we can say that both medians have similar effects due to the conversion, and both medians helped to reduce the number of crashes.

6.2 Conclusion

In this study, we evaluated the safety effectiveness of conversion of TWLTLs to raised medians at urban areas. We developed CMFs using Before-After and Cross Sectional Studies. The obtained results from this study are that we can see clearly in Table 6-1 that the standard error of Before-After with CG Method for all types of crashes is the smallest. As a result, we recommend the CMFs that calibrated using this method. So, the CMF of total crashes is 0.530, which indicates the treatment helped to reduce crashes by 47.00%. For F+I (KABC) crashes, the CMF is 0.674, which means the treatment helped to reduce crashes by 32.60%. For F+I (KAB) crashes, the CMF is 0.836, which means the treatment helped to reduce crashes by 16.40%. For head on crashes, the CMF is 0.271, which indicates the treatment helped to reduce crashes by 72.90%. For angle crashes, the CMF is 0.403, which means the treatment helped to reduce crashes by 59.70%. Lastly, the CMF for left turn crashes is 0.489, which means that the treatment helped to reduce crashes by 51.10%. Thus, FDOT should consider these CMF values if they want to see the benefit to cost ratio to decide if it is worth to implement the treatment or not.

We have reviewed the previous studies, which showed the results of total and injury crashes, and there were no studies that have analyzed the crash types in details using multiple methods as we did in this study. Some studies observed the effect of conversion from a TWLTL to a raised median, and they observed a reduction in total crashes. Bonneson and McCoy (1997) found that the percent of reduction in total crashes due to this treatment is 33%, and Maze and Plozak (1997) found that the percent of reduction in total crashes due to this treatment is 36.4%. Some Studies observed the effect of this treatment on total and injury crashes. Parsonson (1993) found that the effect of conversion of TWLTLs to raised medians in total and injury crashes is positive, and the reduction percent of total and injury crashes are 37% and 48%, respectively. Schultz (2011) found that the treatment helped to reduce total and injury crashes by 39% and 44%, respectively. On the other hand, some studies have reported high increase in crash rates after the installation of raised medians such as Phillips (2004). We can see that what we found regarding the percent of reduction for total and F+I crashes due to the implementation of this treatment is similar to some of the previous studies. Importantly, all of our data were collected from Florida. So, we can say that our results are applicable in Florida.

In this study, we also evaluated the safety impact of this treatment on four versus six lane roads. We identified that this treatment has a positive effect on both roads, and it is more effective on four lane roads rather than six lane roads. It is important to see which road has a better safety impact than the other, so when we have limited resources, we should treat first the four lane roads because the treatment is more effective on four lane rather than six lane roads.

Moreover, we evaluated which type of raised medians after the conversion is more effective. We found that both medians have positive and similar effects due to the conversion. Based on our result, we cannot say one is better than the other. However, we can say that the conversion to concrete curb or lawn curb medians has similar safety effect. We have not looked at other types of raised median due to the sample size. So, we recommend for future studies to investigate different types of raised medians and evaluating their safety effectiveness and exploring the type of raised median that is the safest.

Indeed, this treatment has a positive effect on the roads, and what we found are similar with most of the previous studies; however, the percent of reduction is different. Once our data were collected only from Florida State, we can say that our results are applicable in Florida State. Also, we did thorough analyses of this treatment on dangerous types of crashes, which are head on, angle, and left turn, and it has been proven that the treatment significantly has a positive effect on the road. Also, we have proved that the treatment is more effective on four lane rather than six lane roads, so four lane roads have the priority if we have limited resources. Moreover, we evaluated which type of the raised medians after the conversion is the most effective. However, we have not reached our goal from this part, and we recommend more investigation by having large sample size to see which type of raised median is the most effective after the conversion from TWLTL.

6.3 Suggestions for Future Work

In this section, we provide some suggestions and recommendations for further studies. First, due to the sample size, we were not able to evaluate more than two types of raised median. So, it is recommended to look at different types of raised medians by having large sample size and evaluate their safety effectiveness and decide which type of raised median is the safest. Second, one of the recommendations is to investigate the median opening issue. It is recommended to investigate different types of median opening and see which type is the safest and what is the recommended number of openings per mile based on some essential variables, such as traffic volume, type of road, and number of lanes. Finally, we suggest calibrating crash modification function (CMFunction) for this treatment, and it should have ADT, driveway density, and other important variables in the equation.

APPENDIX A: SEGMENT’S INFORMATION

Table A-1: Traffic Volume and Number of Lanes for the Treated and Comparison Segments

Segment's No.	Treated Group			Comparison Group			
	Length (Mile)	Average ADT (vpd)	No. of lanes	No. of Segments	Length (Mile)	Average ADT (vpd)	No. of lanes
1	0.317	43500	3	2	1.226	39500	3
2	0.252	56000	3	3	0.873	60000	3
3	0.368	56000	3	2	0.968	58000	3
4	0.18	49000	3	3	0.404	44510	3
5	0.24	49000	3	3	0.791	49000	3
6	0.739	49000	3	6	1.748	47000	3
7	0.522	28000	2	5	1.489	26150	2
8	0.119	28000	2	2	0.28	24250	2
9	0.457	16400	2	6	1.38	16300	2
10	0.245	60500	3	2	0.736	59125	3
11	0.349	60500	3	2	0.763	60562	3
12	0.358	54000	3	2	0.888	59000	3
13	0.198	54000	3	3	0.447	59000	3
14	0.438	49500	3	3	0.79	50575	3
15	0.104	49500	3	1	0.562	50575	3
16	0.336	30000	2	3	1.227	27000	2
17	0.735	30000	2	13	2.988	28692	2
18	0.12	30000	2	1	0.49	27750	2
19	0.118	30000	2	2	0.317	29625	2
20	0.401	30000	2	9	2.02	28639	2
21	0.42	39000	2	5	1.591	33750	2
22	0.14	39000	2	3	0.498	35000	2
23	0.252	30500	3	9	0.786	31569	3
24	0.164	16000	2	3	0.549	14000	2
25	0.191	28000	2	3	0.853	27916	2
26	0.121	17700	2	2	0.62	16150	2
27	0.17	34500	2	2	0.65	31250	2
28	0.144	34500	2	1	0.828	31250	2
29	0.287	61000	3	1	0.402	59125	3
30	0.306	30000	2	2	1.254	27000	2
31	0.142	30000	2	2	0.631	27000	2
32	0.137	30000	2	2	0.245	28250	2
33	0.2	30000	2	1	0.402	27000	2
Total	9.27	------	-----	109	29.696	-----	-----

Table A-2: Traffic Volume and Number of Lanes for the Cross Sectional's Segments

Segment's No.	TWLTLs			Raised Medians		
	Length (Mile)	Average ADT (vpd)	No. of lanes	Length (Mile)	Average ADT (vpd)	No. of lanes
1	0.513	36834	3	1.425	27000	3
2	0.713	36834	3	0.25	29165	2
3	0.157	30500	3	0.182	25850	3
4	0.11	34834	3	0.217	38141	3
5	0.11	47000	3	0.55	39833	3
6	0.486	47000	3	0.263	26523	3
7	0.146	47000	3	1.783	29667	2
8	0.277	47000	3	0.39	27333	2
9	0.406	47000	3	0.423	33167	3
10	0.562	45000	3	0.266	26000	2
11	0.102	38500	3	0.29	27667	2
12	0.184	38500	3	0.3	29900	2
13	0.294	32334	3	0.242	33033	2
14	0.408	32334	3	0.62	50573	3
15	0.089	42000	3	0.164	37864	3
16	0.185	45667	3	0.129	37864	3
17	0.232	45334	3	0.152	32166	3
18	0.264	45000	3	0.427	13600	2
19	0.409	32334	3	0.245	37833	2
20	0.344	32334	3	0.442	27111	2
21	0.314	32334	3	0.17	20666	2
22	0.364	21651	2	0.313	20666	2
23	0.267	21651	2	0.562	23166	2
24	0.309	21651	2	0.211	35666	2
25	0.161	25834	2	0.436	35666	2
26	0.219	25834	2	0.364	35666	2
27	0.387	25834	2	0.166	35666	2
28	0.413	23500	2	0.723	40166	3
29	0.402	28500	2	0.216	25666	2
30	0.158	23934	2	0.175	37000	2
31	0.276	14834	2	0.304	17733	2
32	0.298	12467	2	0.509	34500	3
33	0.263	12467	2	0.31	42000	3
34	0.122	12467	2	0.363	41462	3
35	0.161	12467	2	0.316	29500	3
36	0.409	14800	2	0.152	29500	3
37	0.334	43667	3	0.257	33833	3
38	0.209	43667	3	0.395	33833	3

Segment's No.	TWLTLs			Raised Medians		
	Length (Mile)	Average ADT (vpd)	No. of lanes	Length (Mile)	Average ADT (vpd)	No. of lanes
39	0.402	43667	3	0.255	33833	3
40	0.095	52334	3	0.4	33833	3
41	0.151	43667	3	0.19	40500	3
42	0.15	43667	3	0.143	40500	3
43	0.357	20200	2	0.12	60500	3
44	0.162	20200	2	0.277	60500	3
45	0.343	20200	2	0.397	45666	3
46	0.202	20200	2	0.264	45666	3
47	0.28	24667	2	0.208	42000	3
48	0.211	21534	2	0.534	41666	3
49	0.106	21534	2	0.149	39166	3
50	0.232	21534	2	1.132	39166	3
51	0.244	26834	2	0.604	39166	3
52	0.31	26834	2	1.511	39166	3
53	0.09	27500	2	0.787	39166	3
54	0.155	26834	2	1.428	54000	3
55	0.258	24834	2	0.282	28833	3
56	0.371	24834	2	0.153	28833	3
57	0.251	24834	2	0.313	28833	3
58	0.17	9500	2	0.505	28833	3
59	0.071	11300	2	0.478	27500	3
60	0.2	11000	2	0.61	26666	3
61	0.108	11000	2	1.082	36666	3
62	0.151	10100	2	0.856	17866	2
63	0.178	10100	2	0.442	54266	3
64	0.069	11000	2	0.117	54266	3
65	0.036	11000	2	0.288	9366	2
66	0.074	33667	2	0.157	9366	2
67	0.221	33667	2	0.308	12366	2
68	0.044	33667	2	0.347	33000	2
69	0.828	29500	2	0.253	23000	3
70	0.424	29500	2	0.245	23000	3
71	0.142	29500	2	1.174	15000	2
72	0.064	31834	2	0.243	42833	3
73	0.292	31834	2	0.261	43500	3
74	0.09	27334	3	0.323	42333	3
75	0.044	27334	3	0.35	38500	3
76	0.055	27334	3	0.258	30166	3
77	0.065	27334	3	0.538	34333	3
78	0.104	33500	3	0.448	24000	2

Segment's No.	TWLTLs			Raised Medians		
	Length (Mile)	Average ADT (vpd)	No. of lanes	Length (Mile)	Average ADT (vpd)	No. of lanes
79	0.121	26500	3	0.551	26833	2
80	0.04	26500	3	0.765	27000	2
81	0.084	24500	2	0.914	27000	2
82	0.248	24500	2	0.776	19400	2
83	0.217	23500	2	0.444	19400	2
84	0.173	23500	2	0.836	19400	2
85	0.211	17367	2	0.526	19400	2
86	0.227	29500	2	2.436	15400	2
87	1.053	21650	2	1.079	27333	2
88	0.201	21650	2	0.267	25233	2
89	0.333	18000	2	0.604	22333	2
90	0.103	32000	2	0.307	40333	3
91	0.523	47333	3	0.43	42166	3
92	0.547	47333	3	0.997	42166	3
93	0.244	47166	3	0.22	37333	3
94	1.05	10700	2	0.952	37333	3
95	1.24	20666	2	0.318	37166	2
96	1.44	20666	2	1.27	8600	2
97	1.71	37000	3	0.281	20666	2
98	0.334	47833	3	1.48	20666	2
99	0.512	47833	3	0.747	37000	3
100	0.682	31115	3	0.364	37833	3
Average	0.3015	28850	-----	0.497	32000	------

APPENDIX B: SOME SIGNIFICANT MODELS FOR DIFFERENT TYPES OF CRASHES

Table B-1: SPF for Conversion 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	-16.9747	2.4672	-21.8104	-12.1390	47.34	< 0.0001
Log AADT	1	1.8049	0.2374	1.3396	2.2703	57.79	< 0.0001
Length	1	2.2935	0.5766	1.1635	3.4236	15.82	<0.0001
Dispersion	1	1.2464	0.1902	0.9242	1.6809		

Table B-2: SPF for Conversion 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	-16.7270	2.7202	-22.0585	-11.3954	37.81	< 0.0001
Log AADT	1	1.8551	0.2609	1.3437	2.3664	50.55	< 0.0001
Dispersion	1	1.5287	0.2201	1.1528	2.0272		

Table B-3: SPF for Conversion a TWLTL to a Raised Median (F+I (KABC) Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-20.3213	2.4679	-25.1582	-15.4844	67.81	< 0.0001
Log AADT	1	2.0751	0.2404	1.6039	2.5464	74.48	< 0.0001
Length	1	2.2876	0.6800	0.9548	3.6203	11.32	0.0008
Dispersion	1	0.8677	0.1567	0.6091	1.2361		

Table B-4: SPF for Conversion a TWLTL to a Raised Median (F+I (KABC) Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-22.0225	2.5451	-27.0108	-17.0341	74.87	< 0.0001
Log AADT	1	2.3059	0.2433	1.8291	2.7828	89.83	< 0.0001
Dispersion	1	1.0227	0.1739	0.7328	1.4273		

Table B-5: SPF for Conversion a TWLTL to a Raised Median (F+I (KAB) Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-20.1384	2.6644	-25.3605	-14.9162	57.13	< 0.0001
Log AADT	1	1.9912	0.2582	1.4851	2.4973	59.47	< 0.0001
Length	1	2.6994	0.6735	1.3795	4.0194	16.07	<0.0001
Dispersion	1	0.7995	0.1749	0.5207	1.2276		

Table B-6: SPF for Conversion a TWLTL to a Raised Median (F+I (KAB) Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-21.9643	2.8134	-27.4785	-16.4500	60.95	< 0.0001
Log AADT	1	2.2485	0.2684	1.7223	2.7746	70.16	< 0.0001
Dispersion	1	1.0717	0.2070	0.7340	1.5649		

Table B-7: SPF for Conversion a TWLTL to a Raised Median (angle Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-26.8477	3.0984	-32.9155	-20.7700	75.05	< 0.0001
Log AADT	1	2.6010	0.2969	2.0191	3.1829	76.75	< 0.0001
Length	1	1.9898	0.6809	0.6551	3.3244	8.54	0.0035
Dispersion	1	0.6660	0.1910	0.4790	1.2571		

Table B-8: SPF for Conversion a TWLTL to a Raised Median (angle Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-28.0497	3.2114	-34.3440	-21.7554	76.29	< 0.0001
Log AADT	1	2.7758	0.3050	2.1780	3.3736	82.82	< 0.0001
Dispersion	1	0.9421	0.2133	0.6045	1.4682		

Table B-9: SPF for Conversion a TWLTL to a Raised Median (Left Turn Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-31.1183	3.1003	-37.1948	-25.0419	100.75	< 0.0001
Log AADT	1	2.9559	0.2907	2.3860	3.5257	103.36	< 0.0001
Length	1	2.2505	0.5463	1.1798	3.3212	16.97	<0.0001
Dispersion	1	0.4391	0.1648	0.2104	0.9162		

Table B-10: SPF for Conversion a TWLTL to a Raised Median (Left Turn Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-30.3452	3.3499	-36.9109	-23.7796	82.06	< 0.0001
Log AADT	1	2.9529	0.3158	2.3339	3.5719	87.41	< 0.0001
Dispersion	1	0.7467	0.2306	0.4077	1.3676		

Table B-11: SPF for Adding a Raised Median (Left Turn Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-20.5058	4.4025	-29.1344	-11.8771	21.70	<0.0001
Log AADT	1	1.9312	0.4207	1.1066	2.7559	21.07	<0.0001
Median	1	-2.0837	0.3713	-2.8114	-1.3560	31.49	<0.0001
Length	1	1.9620	0.5040	0.9742	2.9498	15.15	<0.0001
Dispersion	1	1.7287	0.4738	1.0102	2.9582		

Table B-12: SPF for Adding a Raised Median (Left Turn Crashes)

Analysis of Maximum Likelihood Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Wald Chi-Square	Pr > ChiSq
Intercept	1	-18.9587	4.4276	-27.6367	-10.2807	18.33	<0.0001
Log AADT	1	1.8309	0.4251	0.9977	2.6641	18.55	<0.0001
Median	1	-1.2860	0.3174	-1.9082	-0.6639	16.42	<0.0001
Dispersion	1	2.2887	0.6016	1.3673	3.8308		

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