Final Report

Reducing Fatalities and Severe Injuries on Florida's High-Speed Multi-Lane Arterial Corridors

Part IV:
SAFETY IMPROVEMENTS ON MULTILANE ARTERIALS IN FLORIDA: A BEFORE AND AFTER EVALUATION

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16. Abstract
This study examines the safety effects of the improvements made on multi-lane arterials. The improvements were divided into two categories: 1) corridor level improvements, and 2) intersection improvements. Empirical Bayes method, which is one of the most accepted approaches for conducting before-after evaluations, has been used to assess the safety effects of the improvement projects. The Safety Performance Functions (SPFs) used in this study are negative binomial crash frequency models that use the information on average daily traffic *(adt)*, length of the segments, speed limit, and number of lanes for corridors. For intersections, the explanatory variables used are *adt*, number of lanes, speed limit on major road, and number of lanes on the minor road. The results of the analysis show that the resulting changes in safety following corridor level improvements vary widely. The overall effectiveness of each improvement type was positive in terms of reducing total, severe and rear-end crashes, except for roadway resurfacing projects, where the total number of crashes slightly increased. In all it can be concluded that FDOT is doing a good job in selecting the sites for treatment and it is very successful in improving the safety of the sections being treated although the main objective(s) of the treatments are not necessarily safety related.

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EXECUTIVE SUMMARY

This study examines the safety effects of the improvements made on multi-lane arterials. The improvements were divided into two categories: 1) corridor level improvements, and 2) intersection improvements. Empirical Bayes method, which is one of the most accepted approaches for conducting before-after evaluations, has been used to assess the safety effects of the improvement projects. Safety effects are estimated not only in terms of all crashes but also rear-end (most common type) as well as severe crashes (crashes involving incapacitating and/or fatal injuries) and also angle crashes for intersection improvements.

The Safety Performance Functions (SPFs) used in this study are negative binomial crash frequency estimation models that use the information on average daily traffic *(adt),* length of the segments, speed limit, and number of lanes for corridors. For intersections, the explanatory variables used are *adt*, number of lanes, speed limit on major road, and number of lanes on the minor road. GENMOD procedure in SAS was used to develop the SPFs. Corridor SPFs are segregated by crash groups (all, rear-end, and severe), length of the segments being evaluated, and land use (urban, suburban and rural).

The results of the analysis show that the resulting changes in safety following corridor level improvements vary widely. Although the safety effect of the corridor level improvements varied, the overall effectiveness of each improvement type was positive in terms of reducing total, severe and rear-end crashes, except for roadway resurfacing projects, where the total number of crashes slightly increased.

Evaluating additional improvements carried out with resurfacing activities showed that all (other than sidewalk improvements for total crashes) of them consistently led to

improvements in safety of multilane arterial sections. It leads to the inference that it may be a good idea to take up additional improvements if it is cost effective to implement them along with resurfacing. It was also found that the addition of turning lanes (left and/or right) and paving shoulders were two improvements associated with a project's relative performance in terms of reduction in rear-end crashes. No improvements were found to be associated with a resurfacing project's relative performance in terms of changes in (i.e., reducing) severe crashes.

For intersection improvements also the individual results of each project varied widely. Except for adding turn lane(s) all other improvements showed a positive impact on safety in terms of reducing the number of crashes for all the crash types (total, severe, angle, and rear-end) considered indicating that the design guidelines for this work type have to be revisited and safety aspect has to be considered while implementing them. In all it can be concluded that FDOT is doing a good job in selecting the sites for treatment and it is very successful in improving the safety of the sections being treated although the main objective(s) of the treatments are not necessarily safety related.

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.

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LIST OF ACRONYMS/ABBREVIATIONS

AADT	Annual Average Daily Traffic
CAR	Crash Analysis Reporting System
CATSS	Center for Advanced Transportation Systems Simulation
DOT	Department of Transportation
EB	Empirical Bayes
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HSIS	Highway Safety Information System
ITS	Intelligent Transportation Systems
NHTSA	National Highway Traffic Safety Administration
RCI	Roadway Characteristics Index
SPF	Safety Performance Function

CHAPTER 1. INTRODUCTION

Traffic safety is a major concern for the public. Traffic crashes result in injuries and fatalities, and cause traffic congestion. According to the National Highway Traffic Safety Administration (NHTSA), in 2003 there were 42,643 fatalities and 2,889,000 injuries in the United States alone (NHTSA, 2005). Among all the states, Florida is one of the states with high number and rates of fatalities in the nation. In 2003, 3,169 fatalities occurred on roadways in Florida, representing a 1% increase over the previous year. Traffic fatality rates are 24.55 per 100,000 drivers, 21.24 per 100,000 registered vehicles, and 18.62 per 100,000 of the population. The increase in fatalities in the state from 1975 through 2003 is 59% – the fourth highest increase in fatalities among all the states.

The U.S. congress passed the 1966 Highway Safety Act in order to improve highway safety, which requires the state departments of transportation (DOTs) to develop and implement safety improvement programs. The first step in the direction of reducing traffic-related fatalities/injuries is to identify the areas where fatalities/injuries frequently occur. Among different road types, principal and minor arterials account for 58% of the total fatal crashes in Florida (NHTSA, 2005). The proportion and the sheer number of fatal crashes on principal arterials (excluding freeways and toll roads) in Florida was highest in the nation (compared to any other state) in 2003. In particular, speeding-related fatalities on arterials with speed limits of 40 mph and above account for more than 54% of total fatalities.

Identification of hazardous locations based on crash history, obtaining the design plans, conducting engineering studies, identifying possible countermeasures and implementing them and evaluating the safety effectiveness of the improvements implemented are the various steps included in the safety improvement programs (Davis, 2000). Florida Department of Transportation (FDOT) is doing a great job in identifying the hazardous locations and implementing the possible countermeasures at those locations but the safety effect of the improvements is not known. This study aims at studying the safety effectiveness of the improvements carried out on multi-lane arterials by FDOT and verifying whether FDOT is actually successful in improving the safety at the treated locations. It is to be noted that the vast majority of the improvements are not specifically being made for safety reasons; however FDOT is keen to know if safety is always improving when adopting their procedures to arterial improvements.

The objectives of this present study are as follows:

1. Identify all the improvement projects that have been started and completed between the years 2003 and 2006 on multi-lane arterials in the state of Florida.
2. Obtain the information on additional improvements (if any) that are carried out during the project implementation.
3. Extract the crash data for the identified projects and also the roadway characteristics for the treatment sites.
4. Conduct an extensive literature review to learn about the state-of-art practices available for studying the safety effectiveness of improvements and choose the best method for carrying out the analysis (which is Empirical Bayes before and after methodology).
5. Identify the comparison group for the treatment sites and develop Safety Performance Functions (SPFs).
6. Estimate the safety effect of each of the improvements identified using the best method chosen for the study.

7. Based on the estimated safety effects of each resurfacing project along with the information on the other tasks completed with the respective project, make inferences on best practices to be undertaken along with the resurfacing process.
8. Conclude on whether FDOT is considering the safety aspect while implementing the improvement projects.

The report is organized as follows: Chapter 2 provides a review of the various methods available for evaluating before-after safety effects of an 'improvement' and limitations of each method and it also presents some of the previous before-after studies. Chapter 3 discusses the extensive data collection process carried out for this study. Chapter 4 explains the methodology used for the analysis. Chapter 5 describes the development of safety performance functions for intersections and segments. Chapter 6 presents the Empirical Bayes (EB) analysis and the results and Chapter 7 comprises the overall conclusions and directions of future research.

CHAPTER 2. LITERATURE REVIEW

2.1 Methodologies for Before- After Evaluation

The safety evaluation of any treatment applied to a site should compare the observed number (or rate, etc.) of crashes (of a given type) on that site after the treatment with the number of crashes that *would have occurred* in the after period had the treatment not been applied. Harwood et al. (2003) documented that there are three common ways to carry out the evaluations of treatments in terms of their safety effects:

- Naïve before- after evaluation
- Before- after evaluation with a comparison group *(cg)*
- Before- After evaluation by the Empirical Bayes (EB) approach

Harwood et al. (2003) also explained the differences in evaluation based on each of the above methods.

2.1.1 Naïve Before- After evaluation

The naïve before-after study involves simple comparison of crash frequencies/rates between the before and after periods of the treatment site. As Hauer (1997) pointed out the number of crashes that were reported in the before period by itself is not a good estimate for 'number of crashes that *would have occurred* in the after period had the treatment not been applied'. Because of the same reason the simple before-after comparison can lead to inaccurate and potentially misleading conclusions. The simple before-after study is subject to the following shortcomings because of which its validity is questionable:

1. Regression-to-the-mean
2. Maturation
3. Crash migration
4. Instability

2.1.1.1 Regression-to-the-mean

Regression-to-the-mean *(Rtm)* is the most common cause of erroneous conclusions in before and after study evaluations also known as Regression Artifacts. Regression is a phenomenon which operates to the greatest degree when the potential sites for treatment are chosen because of their extreme values of crashes or crash rates. The sites thus selected will have a large reduction in the crashes or crash rates, not truly due to the treatment, but due to the fact that the crash frequencies tend to regress to their long term mean values (Council et al., 1980).

The *Rtm* phenomenon can be better explained by an example given by Council et al. (1980). Assume that Figure 2.1 represents the number of crashes that have occurred at a certain location in 10 years. Although the average number of crashes per year is 20, the individual crash frequencies vary from 8 to 32. It can be seen from the figure that the number of crashes in the years 1971, 1972, 1975, and 1977 are greatly deviated from the average value. It can also be observed that these points have regressed towards the overall mean without any treatment having been applied. Let us further assume that in year 1973 the site was treated as a response to the large number of crashes that have occurred in 1972. The results of the before-after study would have shown a reduction of 28% of in the crash frequency. Knowing the after period scenario, we can tell that the reduction observed was not entirely due to the treatment, some part of it is due to the regression to the mean. Thus, not accounting for this phenomenon may result in significant results which may be erroneous.

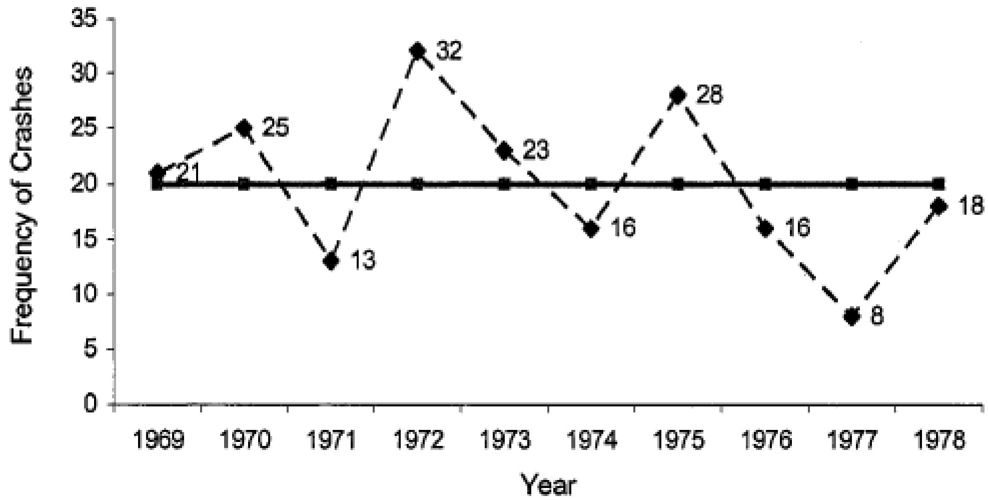


Figure 2-1:Example Demonstrating Regression-to-the-mean Phenomenon (Council et al. (1980)).

2.1.1.2 Maturation

Maturation is the second common threat to the validity of the effectiveness evaluation of a treatment using simple before-after design. According to Council et al. (1980) the most obvious example of this threat are crash trends over time. Hence while analyzing the effectiveness of a treatment the crash trends have to be considered in order to obtain accurate results. For example, if an evaluation of the treatment applied at a site shows a reduction in the frequency of crashes or crash rate, it is possible that the reduction is due to the treatment. However, there is equal chance that the observed change in the frequencies or rates of crashes is due to the extension of a continuing decreasing trend that had been occurring in years. Simply going by the results obtained from the evaluation may result in false conclusions.

Figures 2.2 to 2.4 illustrate the maturation shortcoming with an example. Figure 2.2 shows the observed crash frequencies before (B) and after (A) the application of treatment at a particular site. The resulting reduction in the crash frequency by the treatment is given by B-A in a simple before-after design. This is based on the assumption that had the treatment not been applied at the site the number if crashes in the after years would have been B as is shown in Figure 2.3. However considering the time trends of crashes at the site which is shown in Figure 2.4, it can be said that the crash reduction has been over estimated, since the crash trend is such that, even if the treatment had not been implemented the frequency would have dropped to somewhere close to the extension of the dotted line than what we have assumed previously. Thus it can be concluded that the simple before and after design cannot discount this problem (Council et al.,1980).

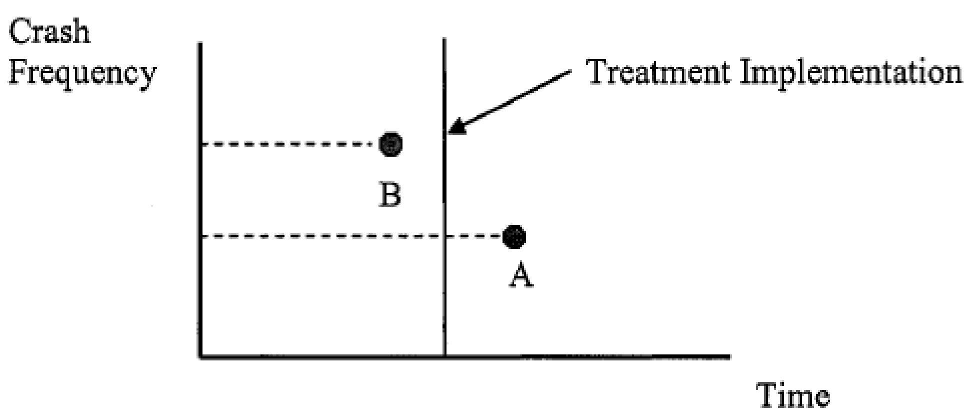


Figure 2-2: Crash Frequencies in the Before and After Period of the Treatment

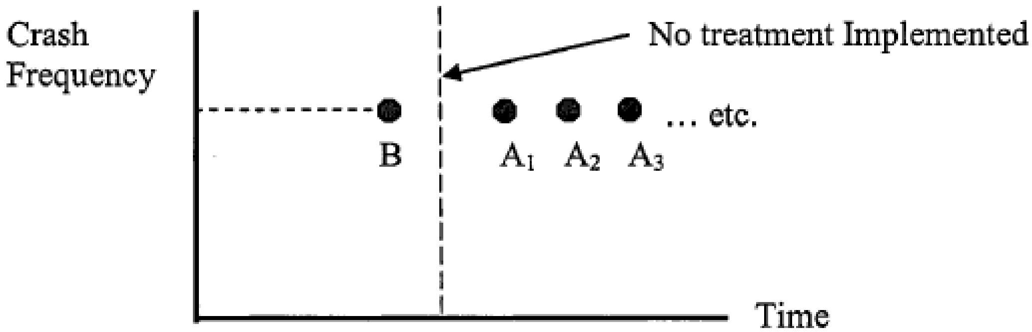


Figure 2-3: Estimated Crash Frequencies in the After Period had the Treatment not been Applied in Simple Before-after Design.

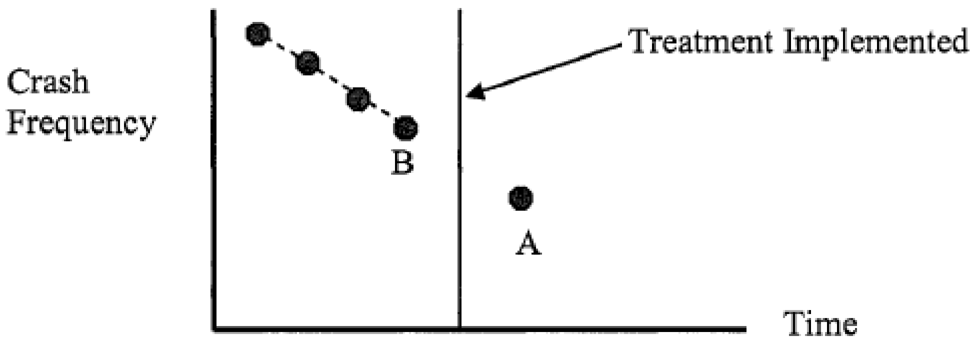


Figure 2-4: Time Trends in Crash Frequency

2.1.1.3 Crash Migration

Crash migration, as the name suggests is a threat caused due to the transfer of crashes from the treated site to surrounding locations as a result of the treatment. Crash migration can be geographic or non-geographic. Non-geographic migration refers to shift of crashes from a certain type to others or shift in severity levels as a consequence of the treatment. For example, installing red light running cameras at intersections can reduce angle crashes, but it may increase rear-end collisions. Unlike geographic migration, methods exist which control for non-geographic migration, so researchers are more concerned about geographic migration and hence crash migration generally refers to geographic migration (Pendleton, 1992).

Boyle and Wright (1984) argued that when a particular site is treated, the change will lowers the drivers` perception of risk and consequently increase the likelihood of crashes at the locations surrounding the treated site. They have suggested that evaluation of the treatment in terms of safety improvement should be based on the crash data collected over a wider area rather than simply the treated site; and thereby, allowing the change in the number of crashes to reflect the treatment effect at treated sites and as well as the crash migration effect at surrounding sites.

2.1.1.4 Instability

The final shortcoming to the validity of a simple before/after study is instability. This alternative explanation of effect refers to the chance or random fluctuations of the data. Since crash is a random event, the crash data over locations or over time will not remain constant, rather will fluctuate. The threat of instability as explained by Council et al. (1980) is that what might be interpreted as a treatment effect is, in reality, just only a random fluctuation of the observed data.

Instability, unlike other problems, can be overcome by using proper statistical techniques, rather than through the use of proper evaluation design (Council et al., 1980). Statistics with a degree of certainty can help in determining whether an observed change is real or only a chance occurrence, but will fail in determining the true cause of the change.

In summary it can be said that although the simple before-after design is a poor design, though easy to apply, and is associated with the above shortcomings because of which its validity is questionable.

2.1.2 Before-after Evaluation with a Comparison Group *(CG)*

Some of the problems faced by the simple before-after design are taken care by the *cg* method. A comparison group is a group of control sites which are similar to the treatment sites in terms of traffic volumes and geometric characteristics. In this method the number of crashes that could have occurred in the after period at the treatment site is estimated using the information of the crash data from the comparison groups. Mountain et al. (1992) said that this method can produce more accurate results compared to simple before-after method and the strength of this method increases as the similarity between the treatment sites and comparison sites increases.

Hauer (1997) stated that the central idea of using a comparison group is to identify a group of sites that remain unchanged and are similar to the treatment sites. The change in safety of the comparison group from before to after is indicative of how the safety at the treated sites would have changed and this belief is based on two fundamental assumptions:

1. The factors that affect safety at the treatment site would have changed the same way at the comparison group from the before to the after period.
2. The changes in various factors would influence the safety at the treatment site in the same way as they would have influenced the comparison group.

Under these assumptions, it is believed that the ratio of expected number of crashes in the after period at the treatment site, had the site been untreated, to the expected number of crashes in the before period at the treatment site would be equal to the ratio of the expected number of crashes in the after period to the expected number of crashes in the before period on the comparison group. It can be mathematically written as Equation 2.1.

$$\pi = \lambda^* r_c \quad (2.1)$$

Where, π = expected number of crashes in the after period had the treatment been not applied,

λ = expected number of crashes in the before period at the treatment site, and

r_c = ratio of the expected number of crashes in the after period to the expected number of crashes in the before period on the comparison group.

Griffith (1999) mentioned that there can be two types of comparisons in this method:

1. Before and after evaluation with yoked comparisons
2. Before and after evaluation with comparison groups

The first method involves one to one comparison between the treatment and the comparison site. The second method involves a group of comparison sites to compare with the treated sites. It is preferred to have more sites in the comparison group than the treatment group (Pendleton, 1991). Harwood et al., (2003) illustrated the conceptual approach involved in these two method using figures, shown in Figures 2.5 and 2.6.

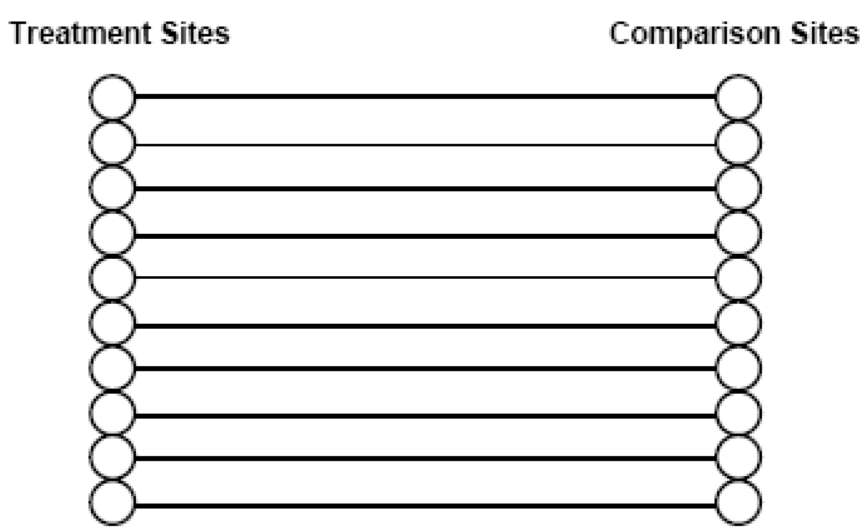


Figure 2-5: Before and After Evaluation Using Yoked Comparisons (Source: Harwood et al. , 2003)

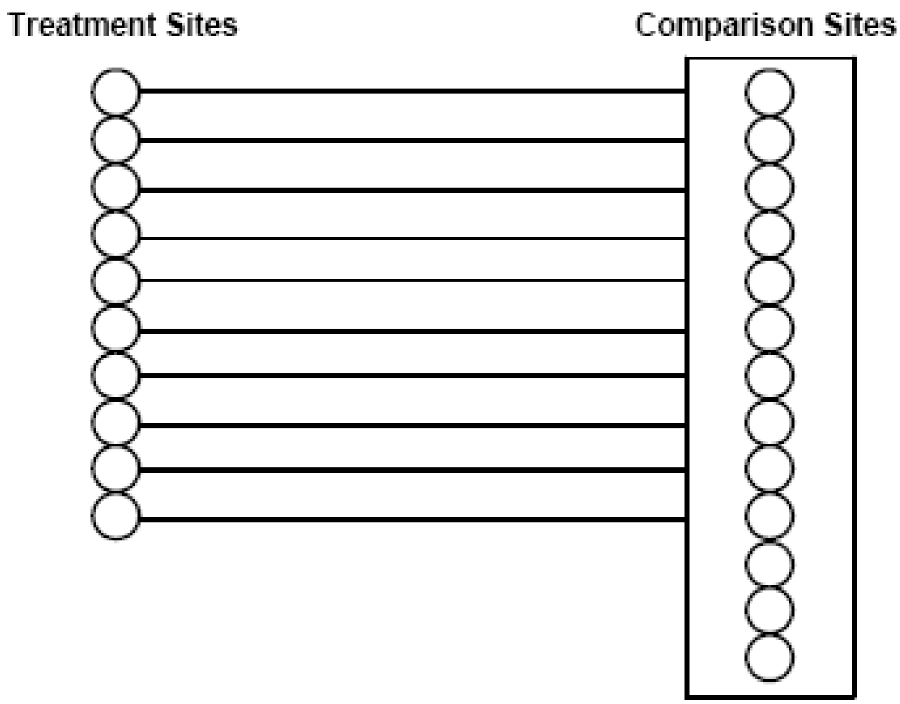


Figure 2-6: Before and After Evaluation with Comparison Group (Source: Harwood et al., 2003)

Another issue with the comparison group method is that it does not account for the changes in safety resulting from changes in traffic volume at the treatment sites that might result from the treatment itself (Hauer, 1997). Also, this method suffers from regression to the mean phenomenon as the simple before and after design (Hauer, 1997).

2.1.3 Before-after Evaluation by the Empirical Bayes (EB) Approach

As it is said earlier, the safety effect of any treatment for a given crash type is given by (B-A), where B is the expected number of crashes in the after period without the treatment, and A is the observed number of crashes in the after period. In both of the above methods the basis for estimating the expected numbers of crashes in the after period is the observed number of crashes in the before period, which itself may not be a good estimate of the expected number of crashes in the before period. The observed frequencies will not be a good estimate as it suffers from the regression to the mean phenomenon (Hauer, 1997).

The EB method can overcome the limitations faced by simple before-after and *cg* methods by not only accounting for *Rtm* effects, but also accounting for traffic volume changes. For the EB method, the expected number of crashes at the treatment site in the after period had the treatment not been made, is estimated from two clues; the crash history of the treatment site and the crash frequency expected at reference sites (Hauer, 1997). These expected crash frequencies at similar entities are estimated using Safety Performance Functions (SPFs). An SPF is a crash prediction model, which relates the frequency of crashes to the roadway characteristics (shoulder width, width of lanes, number of lanes, etc.) and traffic parameters (average daily traffic) of that roadway section. SPFs are modeled using the crash data from the before period at the reference sites. Harwood et al. (2003) illustrated the conceptual approach used in the EB method as shown in Figure 2.7.

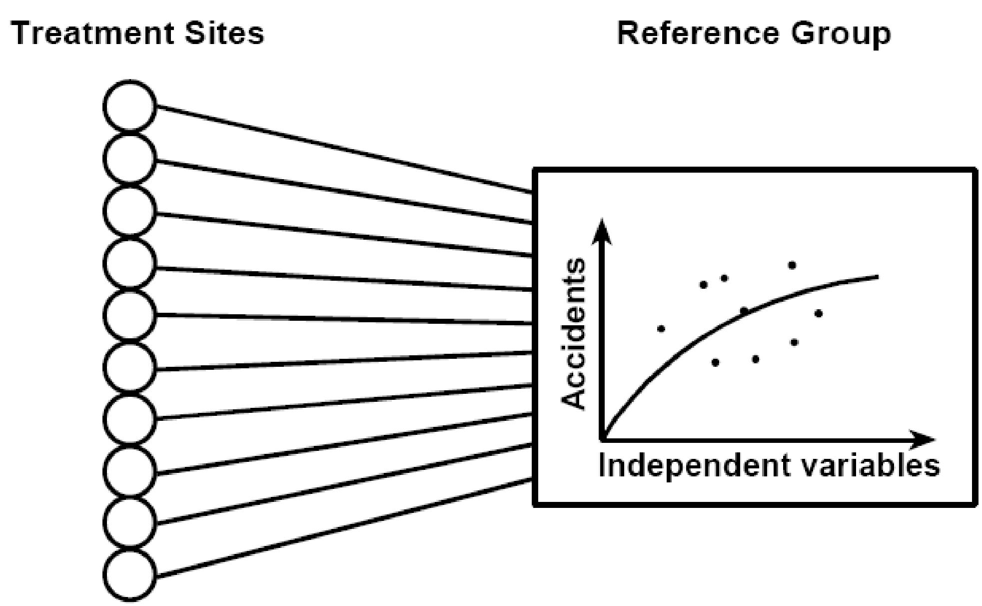


Figure 2-7: Before and After Evaluation with the EB Approach (Source: Harwood et al., 2003)

The information from the above mentioned clues are combined using a weighting procedure given by Hauer, 1997. The mathematical representation for the same is given by Equation 2.2.

*Expected number of crashes at the treatment site in the before period = weight*Expected number of crashes at reference site+ (1-weight)*Observed number of crashes in the before period at the treatment site.* (2.2)

The weight in this equation is calculated using the dispersion parameter obtained from the negative binomial crash prediction models, which are explained in detail in later chapters. The weight takes values between 0 and 1. When weight value nears 0, it implies that the observed number of crashes reflects the expected number of crashes, and when it nears 1, it implies that expected values from the SPF reflect the expected number of crashes at the treatment site.

The values obtained from Equation 2.2 are multiplied by some factors which account for traffic volume changes and different before and after periods to get the expected number of crashes at the treatment site had the improvement been not made. The resulting values are then compared to the observed number of crashes in the after period to estimate the safety effect of the improvement (Persaud et al., 2007).

2.2 Applications of EB Method

This section reviews the literature on various studies that were conducted to estimate the safety effect of improvements. Extensive literature review has been done and the findings of the study were presented here. The topics that were reviewed include, studies using Empirical Bayes for estimating the safety effect and other before-after evaluations.

2.2.1 Application on Corridor Level Improvements

Hanley et al. (2000) conducted a before and after study using EB approach to study the safety effect of five types of improvements in the state of California. The research focused on updating the crash reduction factors *(crf)* of four treatments (rumble-strip installation, shoulder widening, super-elevation correction, and curve correction) and developing *crf* for wet-pavement treatments. For the before-after study they have used all the projects which were completed between 1988 and 1992. BEATS, (Bayesian Estimation of Accidents in Transportation Studies) a Bayesian statistical analysis software was used for the analysis. The research revealed the importance of improving curve radius during super-elevation correction and lane- and/or shoulder-widening treatments on traffic safety. Because of the small sample size the study was not able to produce statistically significant results for other improvement projects like shoulder widening, super-elevation correction, and curve correction.

Pendleton (1996) analyzed the safety effect of raised pavement marking and speed limit changes in the state of Michigan using EB approach. The study used 17 locations where raised pavement markings were installed and 54 locations where the speed limit was either lowered or increased. The reference group for the raised pavement markings included 42 locations. The day time accidents at the reference sites were used as a control group. The treatment effect was analyzed using both, the before-after and EB approach. Although none of the approaches revealed any significant improvement in the safety resulting from the raised pavement markings, the percentage improvement obtained from EB approach are lesser than the simple before and after. The difference in results is again attributed to *Rtm* phenomenon.

Out of the 54 locations where the speed limit has been changed, 16 had an increase and 38 had a decrease in speed limit. The reference group used included 47 sites for decreased speed limit locations and 22 sites for the increased speed limit locations. In both of the cases there was no significant improvement in safety when analyzed using both the before-after and EB approach.

Lyon et al. (2008) in an effort to study low cost safety strategies, evaluated the safety effect of installation of Two-Way Left-Turn Lanes (TWLTLs) on two-lane roads using EB approach. The study included 144 sites in 4 different states (North Carolina, Illinois, California, and Arkansas) with a total of 47.5 miles (21.3 miles in North Carolina, 6.0 miles in Illinois, 6.8 miles in California, and 13.2 miles in Arkansas), where TWLTLs were installed. A total of 785 miles in Arkansas, 600 miles in California, 201 miles in Illinois, and 218 miles in North Carolina was used a reference group. SPFs are developed for each state and safety effect was analyzed. The study found that there was a significant reduction in total and rear-end crashes in all of the four states. It was also found in the study that installation of TWLTLs at rural locations was more effective in reducing crashes than the installation in urban locations. The study concluded that the installation of TWLTLs is a cost effective safety strategy, especially in reducing the rear-end collisions involving the lead vehicle making a left turn.

Persaud et al. (2004) used Empirical Bayes before-after procedure to study the crash reduction following the installation of centerline rumble strips on two-lane rural roads. Two-lane roads are known to have major crash problem involving vehicles crossing the centerline and either sideswiping or colliding head-on with the opposing vehicle. The study analyzed 210 miles of two-lane road in seven states where centerline rumble strips were installed. The results showed that the total number of crashes were reduced by 12 percent (95 % Confidence Interval –

7-18%), all injury crashes were reduced by 14 percent (95 % confidence interval - 5-23%), and head-on collisions and sideswipe crashes decreased by 25 percent (95 % confidence interval - 6-44%) as a result of the treatment.

2.2.1.1 Applications on Resurfacing Projects

Cleveland (1987) documented considerable information on the safety effects of two aspects of pavements condition improved by resurfacing projects: pavements roughness and skid resistance. The study emphasized the need to further study the safety effects of resurfacing with state-of-the-art experimental/analytical methods.

Since the study by Cleveland (1987) there have been some studies that undertook the task of assessing the impact of resurfacing. Hauer et al. (1994) studied the resurfacing projects on two-lane rural roads in the state of New York using the EB method. The study revealed that for the projects involving only resurfacing the safety initially declined (possibly due to drivers choosing higher speeds caused by changed visual cues provided by the resurfaced facility). For projects involving resurfacing with other additional improvements the safety, in fact, improved. McGee et al. (1995) identified lack of understanding of the impact of resurfacing on safety with additional improvements as a critical gap in understanding of influence of design features on safety.

In this regard, Hughes et al. (2001) aimed at determining the impacts of resurfacing with and without additional safety improvements. They studied resurfacing projects that were carried out in five states. The scope of that research, however, was limited to two-lane roads in rural and suburban areas with no access control and posted speed limits more than 45 mph. Although the results of the study were not thoroughly conclusive the effects of resurfacing were found to vary by state possibly due to differences in the individual site characteristics.

2.2.2 Applications on Intersection Improvements

Wang (1994) identified 13 intersections in the state of Minnesota where new traffic signals were installed and studied the safety effect of installing the traffic signals using the EB method. He defined a reference group of 79 intersections which were untreated and were similar to the treated sites with respect to daily entering traffic, number of approach legs, intersection configuration, etc. The acceptability of the reference group was also verified by checking how many of the intersections in the reference group are potential candidates for signal installation. The crashes that occurred between the period 1985 and 1990 and within a distance of 250 ft from the center of the intersection were used for analysis. The simple before and after comparison showed that there was a 30 percent reduction of in total number of crashes after installing the traffic signals and where as the EB method showed a reduction of 25 percent. The overestimation of the treatment effect by the simple before and after comparison was attributed to the *Rtm* bias.

Harwood et al. (2003) conducted a before and after study using three different approaches: 1. Before-and-after evaluation with yoked comparisons, 2. Before-and-after evaluation with a comparison group, and 3. Before-and-after evaluation by the Empirical Bayes, to evaluate the safety effect of providing left turn and right turn lanes for at grade intersections. The study aimed at not only evaluating the safety effectiveness of the improvements but also compared the results obtained from the different approaches. A total of 580 intersections were involved in the study out of which 280 are form the treatment group and rest form the reference group. The treatment group included three types of intersections, existing signalized, existing unsignalized, and newly signalized intersections from seven states in the United States. The analysis results showed that added left turn and right turn lanes are effective in reducing the total number of crashes at both signalized and un-signalized intersections in both urban and rural areas. The reduction in severe crashes was greater than the reduction in total number of crashes at some intersections and lesser at some intersections; overall the study did not find any indication on whether the addition of turn lanes is more or less effective in reducing severe than reducing total number of crashes. The main conclusion of the research was that the EB approach effectively evaluates the safety effectiveness of an improvement than the other two methods and it also recommended the use of EB method for before and after studies.

Yuan and Ivan (2001) evaluated the safety benefits of intersection alignment on two-lane highways in Connecticut using EB method. For calculating the weights used in the EB approach they used the variance and mean of the reference population crashes assuming no time trends in the crash occurrence and that the relationship between the frequency of crashes and exposure is linear. The authors recommended that the effect of the assumptions have to be considered in further research using EB approach. The results of the analysis showed that the improvement had varying effect on various crash types, however, the improvement was effective in reducing the total number of crashes. The percentage reduction in number of crashes estimated from the EB approach and the simple before and after study differed, and this difference is again attributed to *Rtm* phenomenon.

Persaud et al. (2001) studied the safety effect of conversion of stop controlled intersections and traffic signal controlled intersections to modern roundabouts. The study included a mix of rural, suburban, and urban intersections which were converted to roundabouts in seven states in United States. The rural intersections were all single lane designs, and urban intersections included both single and multi-lane designs. A before and after study using Empirical Bayes methodology was used for analyzing the safety effect. The total number of intersections analyzed was 23 (19 were previously controlled by stop signs, and 4 were controlled by traffic signals). The results of the study showed that there was a 40% reduction in total number of crashes, and 80% reduction in injury crashes after the conversion. The percentage of reductions varied with the intersection type, urban single lane design with stop controlled having the highest reduction in both total and injury crashes and urban multi-lane design with stop controlled having the least reduction in total number of crashes. This study also recommended the use of EB approach for future studies involving safety effect evaluation of treatments.

Persaud et al. (1997) studied the effect of converting one-way street intersections from signal to multiway stop control on intersection related crashes in Philadelphia. The study identified 199 intersections which were converted to multiway stop control from traffic signals. A before and after procedure with EB approach was used to analyze the safety effect. The comparison group of 71 intersections was used to estimate the safety performance functions. Crash estimates for the after period for various crash types were obtained and were compared with the observed values to estimate the percent reduction in crashes of each type following the conversion. The results showed a 24% decrease in total number of crashes, and for other crash types percentage reduction varied from 18% (pedestrian crashes) to 31.4% (fixed object crashes). The study concluded that intersections should be periodically evaluated and traffic signals should be removed where they are not warranted.

2.3 Safety Performance Functions

A Safety Performance Function is a mathematical relationship which relates the frequency of crashes at a roadway section with its traffic and geometric parameters. Shen (2007) mentioned that two types of SPFs are found in the literature: full SPFs and traffic SPFs. Full SPF is a crash prediction model involving both traffic parameters and geometric parameters as explanatory variables, whereas traffic SPF includes only annual average daily traffic *(aadt)* as the explanatory variable in predicting the crashes on a roadway section. The values obtained from the traffic SPF have to be adjusted by accident modification factors *(amfs)* to properly account for safety impacts of other geometric parameters, for example: lane width, shoulder width, number of lanes, median width, etc. Most of the *amfs* presently available are estimated either from a simple before-after study or the coefficients of the variables in the crash prediction models. The section below provides literature on existing SPFs on multilane roads.

2.3.1 Multilane Roads

Persaud, (1992) developed traffic SPFs for multilane highways without full access control using a sample of roadways in Ontario. Separate SPFs were developed for different land-use types and different median types (divided and undivided). The general form of SPF is given by Equation 2.3.

$$\text{Crashes/year/km} = c * (AADT)^{k} \tag{2.3}$$

Where, c and k are constants which depend on the crash type and roadway type. Table 2-1 shows the different values of c and k by crash type, land-use type, and median type.

Table 2-1: Parameter Estimates for SPFs of Multilane Roads without Full Access Control

Crash Type	Land Use	Median Type	C	K
Total	Rural	Divided	0.0084885	0.618
Total	Rural	Undivided	0.000056	1.129
Total	Urban	Divided/Undivided	0.0000524	1.146
Fatal+Injury	Rural	Divided	0.0013	0.687
Fatal+Injury	Rural	Undivided	0.0000078	1.219
Fatal+Injury	Urban	Divided/Undivided	0.0001045	0.98

Shen, (2007) developed traffic SPFs for multilane roadways in the state of Florida using four different types of regression models: Poisson Regression Model (PRM), Negative Binomial Regression Model (NBRM), Zero-Inflated Poisson regression (ZIP) model, and Zero-Inflated Negative Binomial regression (ZINB) model. The four models are statistically compared and the model that best fits the data is selected as the final SPF. Using the same methodology different SPFs are generated for different land-use and median type. Comparison of the different statistical models showed that ZINB is preferred than other models for urban divided multilane highways, rural divided multilane highways, and urban undivided multilane highways. However, due to insufficient data on rural undivided multilane highways no models were developed. Equation 2.4 gives the general form of ZINB model.

$$Total\ Crashes = \exp(a + b \times EXPO) \times (1 - \lambda) \quad (2.4)$$

Where, EXPO is the measure of exposure given by: *AADT*365*Segment Length*10*$^{-6}$

and $$\lambda = \frac{\exp(c - d \times EXPO)}{1 + \exp(c - d \times EXPO)} \quad (2.5)$$

Table 2-2 shows the ZINB regression parameter estimates for the different roadway types.

Table 2-2: ZINB regression Parameter Estimates for Multilane Highways

Crash Type	Land Use	Median Type	A	B	C	D
Total	Rural	Divided	0.1725	0.1273	3.5357	2.7611
Total	Urban	Undivided	2.83	0.105	2.18	0.0608
Total	Urban	Divided	1.7663	0.1117	1.09	0.1565

2.3.2 Intersections

2.3.2.1 Rural Signalized Intersections

Webb (1955) developed crash prediction model for rural signalized intersection using 96 signalized intersections on high speed roadways in the state of California. Equation 2.6 shows the model developed.

$$Crashes / year = 0.00703 \times AADT_{\min or\ road}{}^{0.29} \times AADT_{major\ road}{}^{0.51} \qquad (2.6)$$

Bennson et al. (1993) used Highway Safety Information System (HSIS) data rural signalized intersections and developed the following equation (Equation 2.7) to estimate the crashes at the signalized rural intersections. The only explanatory variables used are volumes on major and minor roads.

$$Crashes / year = 0.00703 \times AADT_{\min or\ road}{}^{0.3663} \times AADT_{major\ road}{}^{0.7213} \qquad (2.7)$$

2.3.2.2 Rural Unsignalized Intersections

McDonald (1953) used the data from rural unsignalized intersections of divided highways to develop a crash prediction model which relates the frequency of crashes per year with the volumes on major and minor road. Equation 2.8 gives the form of the equation.

$$Crashes / year = 0.000783 \times AADT_{\min or\ road}{}^{0.663} \times AADT_{major\ road}{}^{0.455} \qquad (2.8)$$

Bennson and McCoy (1993) used the data from HSIS data between the years 1985 and 1987 on 125 rural unsignalized intersections in the state of Minnesota to develop crash prediction models. These models also had only major and minor road volumes as explanatory variables. Equation 2.9 gives the form of the equation.

$$Crashes / year = 0.000379 \times AADT_{\min or\ road}{}^{0.831} \times AADT_{major\ road}{}^{0.256} \quad (2.9)$$

2.3.2.3 Urban Signalized Intersections

Persaud et al. (1995) developed SPFs for urban signalized intersections using the data from signalized intersection of one-way streets in Philadelphia. Models were developed for different crash types. Equation 2.10 shows the general form of the equation.

$$Crashes / year = a \times AADT_{\min or\ road}{}^{b} \times AADT_{major\ road}{}^{c} \quad (2.10)$$

Where, a, b, and c are parameter estimates given in Table 2-3.

Table 2-3: Parameter Estimates for SPFs of Urban Signalized Intersections

Crash Type	A	b	C
Right Angle and Turn Crashes	0.0002037	0.5491	0.354
Rear-end Crashes	0.0002099	0.6758	0
Pedestrian Crashes	0.0009039	0.515	0

Srinivasan et al. (2008) developed SPFs using negative binomial regression model for signalized urban intersections. 60 urban signalized intersections were used to develop the models. Equation 2.11 gives the form of the SPF.

Crashes/year = (yearly factor)*exp[-5.3782 + 0.5236*$ln(AADT_{major})$ + 0.2595*$ln(AADT_{minor})$ -0.3734*(4 - number of legs)] (2.11)

2.4 Summary

The first section of this chapter discusses the common ways of evaluating treatments using before and after methodologies, which are: 1. Naïve before-after evaluation, 2. Before and evaluation using a comparison group, and 3. Before and after evaluation using Empirical Bayes approach. The first two methods fail in accounting for *Rtm* bias, leaving EB approach as the best among the three before and after evaluation methods. Since EB approach accounts for *Rtm* bias and traffic volume changes over the period, it is used as the main tool for evaluating the improvement projects in this research.

The second section of this chapter presents some of the available literature on the application of EB approach for evaluating the safety effect of treatments. It is interesting to note that all of the treatments except for resurfacing had conclusive results on their safety impact. None of the previous studies had any conclusive results on how additional improvements, when coupled with resurfacing, affect safety on multilane arterials with partial access control. And very little literature was available which studied the safety impact of improvement projects on multilane roads. It provided the motivation for the present study.

The third section of the chapter discusses the safety performance function, which are used in EB approach to estimate the number crashes at the treatment sites. The literature illustrates that there are two types SPFs: traffic and full SPFs. The differences between these two SPFs were discussed. It is worthwhile to note that in most of the previous studies only traffic SPFs were used. Using traffic SPFs and adjusting them with *amfs* to predict the crashes is not a good idea, because the AMFs presently available are either estimated from simple before and after studies or derived from the coefficients of crash prediction models. Hence for the present study full SPFs are developed to predict the crashes at the treatment sites.

CHAPTER 3. DATA PREPARATION AND PRELIMINARY ANALYSIS

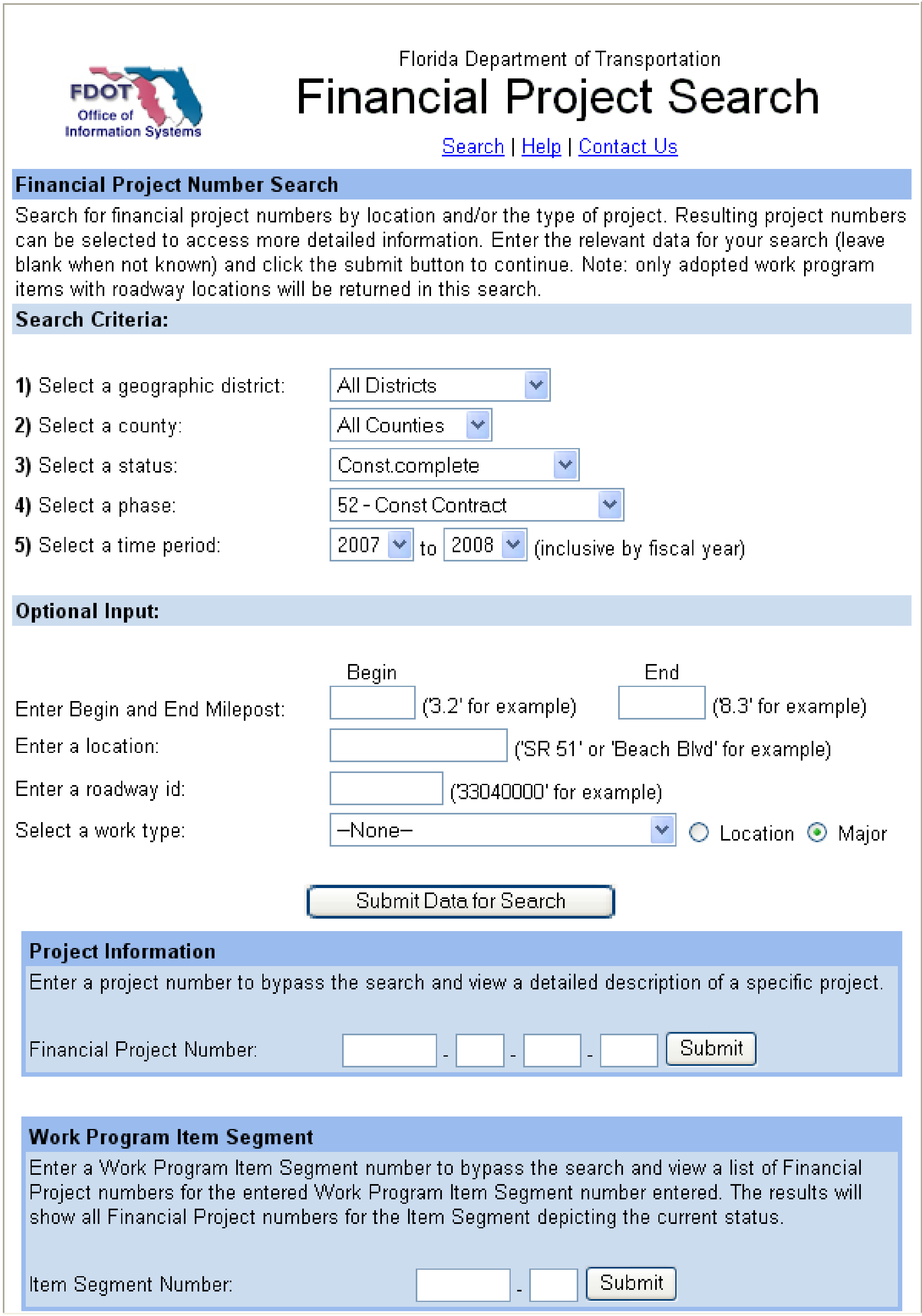
3.1 Data Preparation

Two sets of data are used in this study: i) information from the sites where treatment was applied and ii) information from reference sites to develop the SPFs. The information on all improvement projects on multilane arterials that were initiated and completed between the years 2003 through 2006 in the state of Florida were collected first.

3.1.1 Improvement Projects Data

The improvement projects data were collected from FDOT's financial project search website (Financial Management database, 2007) available on the intranet. Figures 3.1, 3.2, and 3.3 show the screen shots of the search page, search results, and a detailed description of a project respectively. The projects can be searched by district, county, state road number, and the financial project number. The database available on the website contains the projects' beginning dates, end dates, roadway ID`s, beginning mile point, ending mile point, etc. It was observed that some of the projects had multiple end dates (two or more projects' completion dates) and to overcome the problem it was decided to consider the latest end date to be the final construction end date. Since the end dates play an important role for the before and after studies, particularly in estimating the number of crashes during the after period, knowing the exact end date of the project is crucial and considering the latest end date as the final construction end date will not solve the problem. After contacting FDOT officials at the construction office it was found that FDOT maintains a database with all the important project dates and project costs (Construction

Office Reports, 2007) for all the projects. The required information was extracted from the database and was merged with the projects' data.


Florida Department of Transportation

Financial Project Search

Search | Help | Contact Us

Financial Project Number Search

Search for financial project numbers by location and/or the type of project. Resulting project numbers can be selected to access more detailed information. Enter the relevant data for your search (leave blank when not known) and click the submit button to continue. Note: only adopted work program items with roadway locations will be returned in this search.

Search Criteria:

1) Select a geographic district: All Districts

2) Select a county: All Counties

3) Select a status: Const.complete

4) Select a phase: 52 - Const Contract

5) Select a time period: 2007 to 2008 (inclusive by fiscal year)

Optional Input:

Enter Begin and End Milepost: Begin ('3.2' for example) End ('8.3' for example)

Enter a location: ('SR 51' or 'Beach Blvd' for example)

Enter a roadway id: ('33040000' for example)

Select a work type: --None-- Location Major

Submit Data for Search

Project Information

Enter a project number to bypass the search and view a detailed description of a specific project.

Financial Project Number: - - - Submit

Work Program Item Segment

Enter a Work Program Item Segment number to bypass the search and view a list of Financial Project numbers for the entered Work Program Item Segment number entered. The results will show all Financial Project numbers for the Item Segment depicting the current status.

Item Segment Number: - Submit

Figure 3-1: Screen shot of Financial Project Search page

FDOT Office of Information Systems

Florida Department of Transportation

Financial Project Search

Search | Help | Contact Us

Financial Project Search Results

District: All Districts
County: All Counties
Status: Const.complete
From: 2001 **To:** 2008
Phase: Const Contract
Location:
Roadway ID: 75280000
Work Type:
Begin Milepost:
End Milepost:

4 records were found. Page 1 of 1.

Fin. Proj. No.	Work Program Location Roadway Location	Description (From) (To)	Current Status Date
242493-1-52-01	I-4 INTERCHANGE SR400;OSCE.- SEMIN.	@ JOHN YOUNG PKWY/33RD ST	CONST.COMPLETE 7/23/2007
242496-1-52-01	I-4 AUXILIARY LANES SR400;OSCE.- SEMIN.	FROM E OF KIRKMAN ROAD TO W OF TURN PIKE	CONST.COMPLETE 3/30/2006
242499-1-52-01	I-4 SR400;OSCE.- SEMIN.	FROM SR500/600 OBT TO SR436	CONST.COMPLETE 3/5/2007
405515-1-52-01	I-4 AUXILLARY LANES SR400;OSCE.- SEMIN.	FROM SR 536 TO BEE-LINE	CONST.COMPLETE 4/8/2003

« Previous Next »
1

All information in this application is retrieved from the Financial Management (FM) Database.

Figure 3-2: Screen Shot of the Search Results

Florida Department of Transportation

Financial Project Search

Search | Help | Contact Us

Financial Project Detail

Fin. Proj. No: 242496-1-52-01
Description: I-4 Auxiliary Lanes from E Of Kirkman Road to W Of Turn Pike
District: Fifth
Major Work: Add Lanes & Rehabilitate Pvmnt
Project Manager: Blb-wsa
Federal Project: 0042 187 i
Transportation System: Intrastate Interstate

Contracts

Active	Inactive
T5043	21268

Work Program Status History

Status	Date
Const.complete	3/30/2006
Under Construction	3/9/2006
Const.complete	10/9/2003
Under Construction	3/11/2002
Contract Executed	8/24/2001
Awarded	8/3/2001
Bids Received	6/22/2001
Advertised	5/25/2001
Bids Received	5/23/2001
Advertised	5/18/2001
Pre-const.underway	5/18/2001
Adopted, Not Begun	5/18/2001
Advertised	3/15/2001
Plans&row In Talla.	2/13/2001
Pre-const.underway	3/6/1998
Candidate Line Item	8/24/1995

Additional Work Program Information

Version	AD (Adopted)
Current Status	Const.complete
Managing District	08
County	75 Orange
Contract Class	1 To Be Let
Unit Of Measure	M -- Metric

2 Roadway Locations were found. Page 1 of 1.

Roadway Location	County
SR400;OSCE.- SEMIN.	ORANGE

Roadway ID: 75280000
Project Length (miles): 1.3
Beginning Sect. Pt: 10.28
Ending Sect. Pt: 11.58
No. of Lanes: 4
No. of Lanes Added: 2
Type of Work: Add Lanes & Rehabilitate Pvmnt

Roadway Location	County
SR91;OSCEOLA-LAKE	ORANGE

Roadway ID: 75470000
Project Length (miles): 0.045
Beginning Sect. Pt: 10.366
Ending Sect. Pt: 10.411
No. of Lanes: 2
No. of Lanes Added: 0

Figure 3-3: Screenshot of Financial Project Detail

The other problem with the data is the data field which carries information on the type of work involved in the project. The Financial Project search website's database has only the major type of work involved in the project; however, it is not always true that any project involves only one type of work. For example, if a project's major work is resurfacing, it may involve other additional works such as widening the lanes, median modification, shoulder widening, signing work, pavement marking, and if the project is at the intersection then it may also involve some added turn lanes, changes in traffic signal timing, and other works. It is always good to identify the additional works done in the project that will help in judging or attributing the changes in the crashes or crash rates to the causes which lead to these changes.

After contacting FDOT officials we found a website (Project Plans, 2008) which has the detailed plans for all the projects. The projects can be searched either by roadway ID or by the Financial Project number. The search provides all the project plans for that particular project. From looking at the plans it can be inferred the works involved in the project. The following figures show the snapshots from the project plans website of a project whose major work is related to traffic safety. Although the major work description mentions that the project is a safety project it does not discuss all of the activities performed in the scope of the project. However from the projects plans the additional works can be identified, for example Figure 3.4 shows that the pavement has been widened as a part of the project, Figure 3.5 indicates that the shoulder has been widened and Figure 3.6 shows that some changes have been made in signing and pavement marking.

Later while searching through the FDOT's infonet website a database was found which has all the projects` contract documents. The database can be searched by financial project number (Contract Documents, 2008). The search will result all the important documents of the project, among which is the contract documents. The contract document includes a brief description of the major work and all the additional work associated with a particular project. A snapshot of one of the contract document is shown in Figure 3.7.

Through a combination of project plans and the contract documents a fairly complete picture of the nature of work taking place in a project can be established.

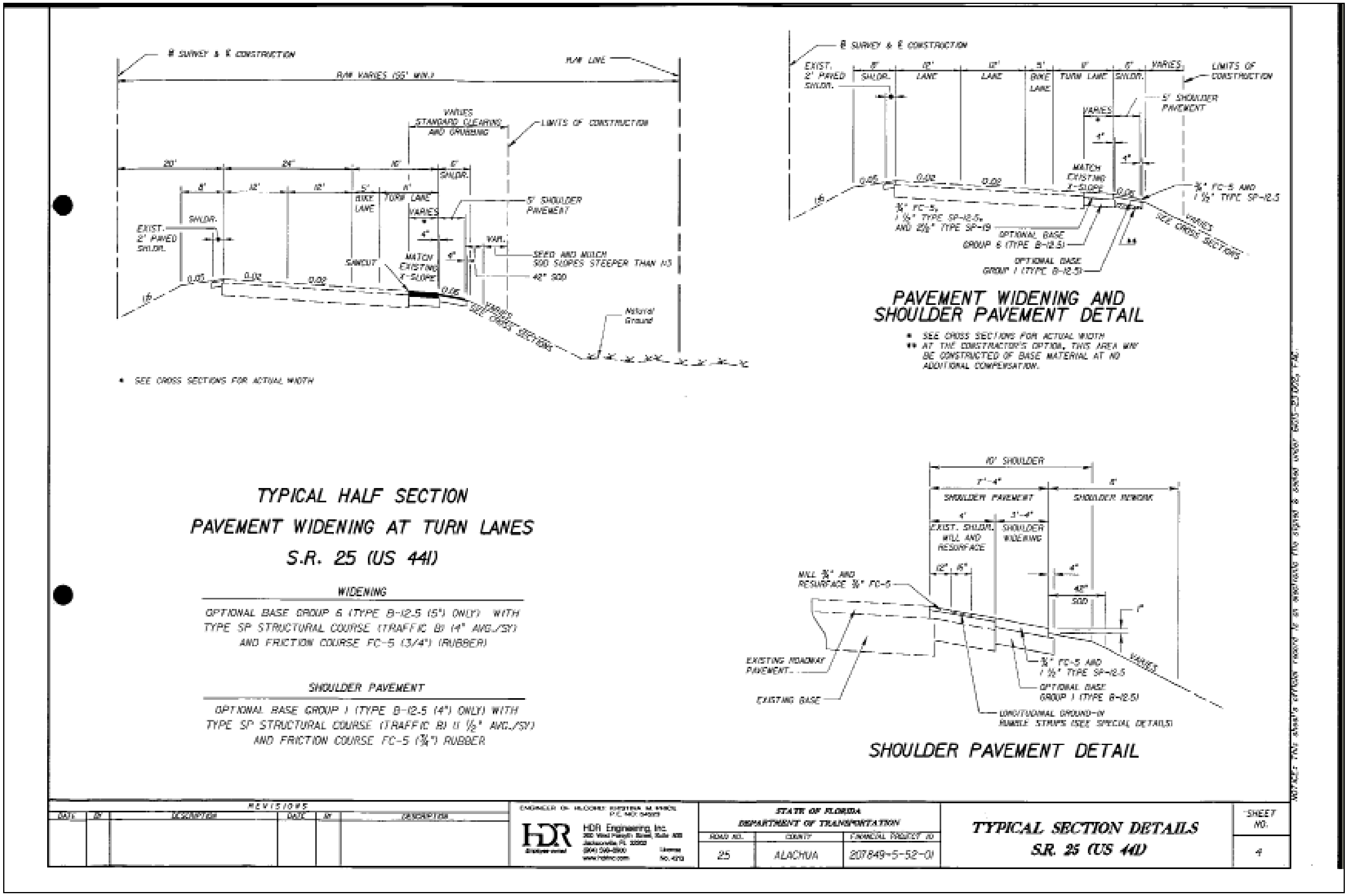


Figure 3-4: Pavement Widening

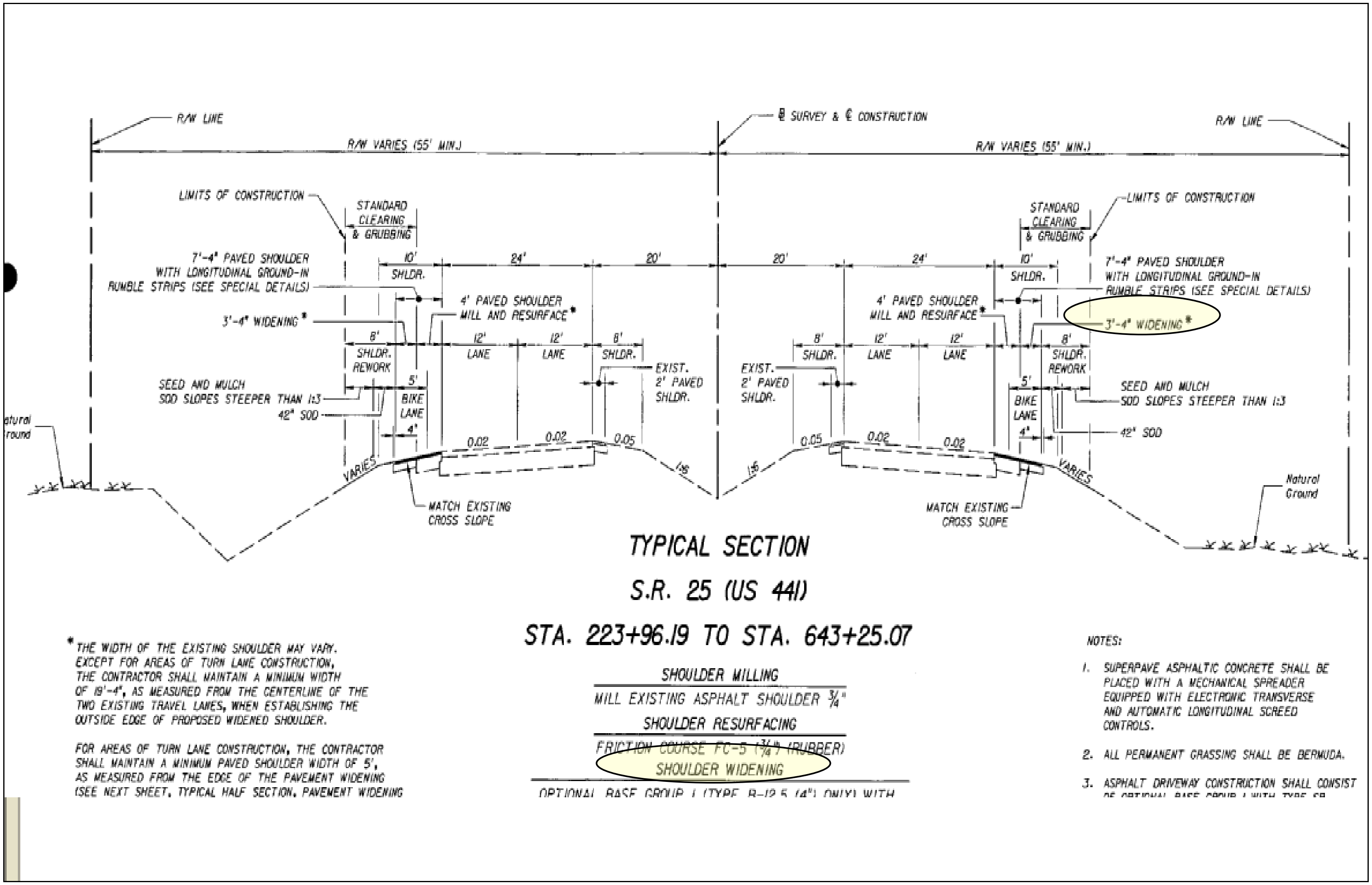
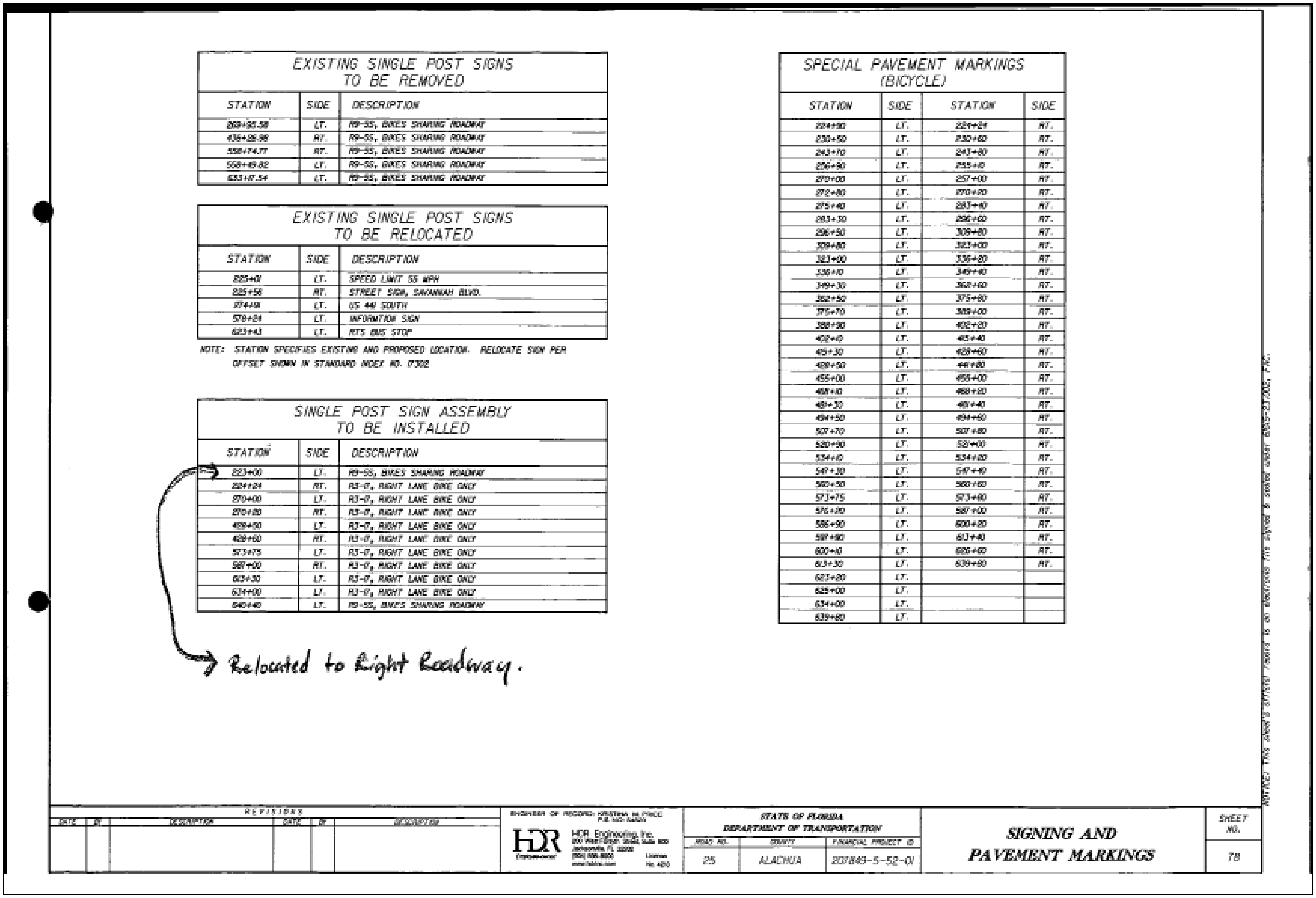


Figure 3-5: **Project Plan Showing Shoulder Widening**



EXISTING SINGLE POST SIGNS TO BE REMOVED

STATION	SIDE	DESCRIPTION
269+95.58	LT.	R9-5S, BIKES SHARING ROADWAY
436+26.96	RT.	R9-5S, BIKES SHARING ROADWAY
558+74.77	RT.	R9-5S, BIKES SHARING ROADWAY
558+49.82	LT.	R9-5S, BIKES SHARING ROADWAY
633+87.54	LT.	R9-5S, BIKES SHARING ROADWAY

EXISTING SINGLE POST SIGNS TO BE RELOCATED

STATION	SIDE	DESCRIPTION
225+01	LT.	SPEED LIMIT 55 MPH
225+56	RT.	STREET SIGN, SAVANNAH BLVD.
374+18	LT.	US 441 SOUTH
578+24	LT.	INFORMATION SIGN
623+43	LT.	RTS BUS STOP

NOTE: STATION SPECIFIES EXISTING AND PROPOSED LOCATION. RELOCATE SIGN PER OFFSET SHOWN IN STANDARD INDEX NO. 17302

SINGLE POST SIGN ASSEMBLY TO BE INSTALLED

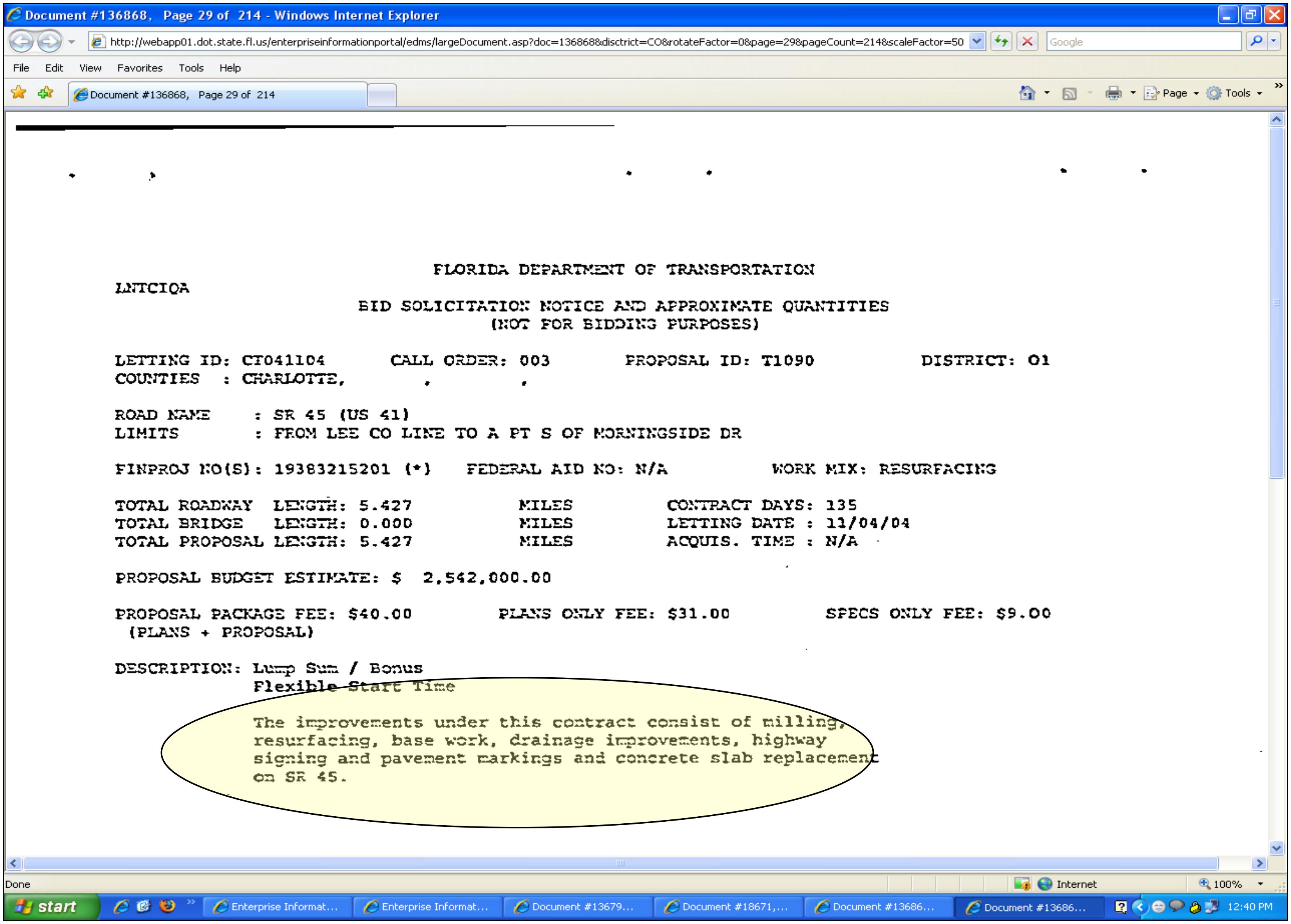
STATION	SIDE	DESCRIPTION
223+00	LT.	R9-5S, BIKES SHARING ROADWAY
224+24	RT.	R3-17, RIGHT LANE BIKE ONLY
270+00	LT.	R3-17, RIGHT LANE BIKE ONLY
270+20	RT.	R3-17, RIGHT LANE BIKE ONLY
428+50	LT.	R3-17, RIGHT LANE BIKE ONLY
428+60	RT.	R3-17, RIGHT LANE BIKE ONLY
573+75	LT.	R3-17, RIGHT LANE BIKE ONLY
587+00	RT.	R3-17, RIGHT LANE BIKE ONLY
613+30	LT.	R3-17, RIGHT LANE BIKE ONLY
634+00	LT.	R3-17, RIGHT LANE BIKE ONLY
640+40	LT.	R9-5S, BIKES SHARING ROADWAY

Relocated to Right Roadway.

SPECIAL PAVEMENT MARKINGS (BICYCLE)

STATION	SIDE	STATION	SIDE
224+90	LT.	224+24	RT.
230+50	LT.	230+60	RT.
243+70	LT.	243+80	RT.
256+90	LT.	255+10	RT.
270+00	LT.	257+00	RT.
272+80	LT.	270+20	RT.
275+40	LT.	283+40	RT.
283+30	LT.	296+60	RT.
296+50	LT.	309+80	RT.
309+80	LT.	323+00	RT.
323+00	LT.	336+20	RT.
336+10	LT.	349+40	RT.
349+30	LT.	362+60	RT.
362+50	LT.	375+80	RT.
375+70	LT.	389+00	RT.
388+90	LT.	402+20	RT.
402+10	LT.	415+40	RT.
415+30	LT.	428+60	RT.
428+50	LT.	441+80	RT.
455+00	LT.	455+00	RT.
468+10	LT.	468+20	RT.
481+30	LT.	481+40	RT.
494+50	LT.	494+60	RT.
507+70	LT.	507+80	RT.
520+90	LT.	521+00	RT.
534+10	LT.	534+20	RT.
547+30	LT.	547+40	RT.
560+50	LT.	560+60	RT.
573+75	LT.	573+80	RT.
576+20	LT.	587+00	RT.
586+90	LT.	600+20	RT.
597+90	LT.	613+40	RT.
600+10	LT.	626+60	RT.
613+30	LT.	639+80	RT.
623+20	LT.		
626+00	LT.		
634+00	LT.		
639+80	LT.		

Figure 3-6: Snapshot Showing Changes in Signing and Pavement Marking



FLORIDA DEPARTMENT OF TRANSPORTATION

LNTCIQA

BID SOLICITATION NOTICE AND APPROXIMATE QUANTITIES
(NOT FOR BIDDING PURPOSES)

LETTING ID: CT041104 CALL ORDER: 003 PROPOSAL ID: T1090 DISTRICT: 01
COUNTIES : CHARLOTTE,

ROAD NAME : SR 45 (US 41)
LIMITS : FROM LEE CO LINE TO A PT S OF MORNINGSIDE DR

FINPROJ NO(S): 19383215201 (*) FEDERAL AID NO: N/A WORK MIX: RESURFACING

TOTAL ROADWAY LENGTH: 5.427 MILES CONTRACT DAYS: 135
TOTAL BRIDGE LENGTH: 0.000 MILES LETTING DATE : 11/04/04
TOTAL PROPOSAL LENGTH: 5.427 MILES ACQUIS. TIME : N/A

PROPOSAL BUDGET ESTIMATE: $ 2,542,000.00

PROPOSAL PACKAGE FEE: $40.00 PLANS ONLY FEE: $31.00 SPECS ONLY FEE: $9.00
(PLANS + PROPOSAL)

DESCRIPTION: Lump Sum / Bonus
Flexible Start Time

The improvements under this contract consist of milling, resurfacing, base work, drainage improvements, highway signing and pavement markings and concrete slab replacement on SR 45.

Figure 3-7: Contract Document Showing the Work Done in a Resurfacing Project

3.1.1.1 Crash Data for the Projects

The crashes that occurred at the project locations were downloaded from the Crash Analysis Reporting System (CAR) database for the years 2002 till 2007. The crash data was merged with the project data and the total number of crashes that occurred at the project locations in the before and after periods were identified for each project.

The project data that were collected from the FDOT`s website had 478 projects, involving 29 different types of major work. The 478 projects identified also include roadway sections which are two-lanes; however, the two-lane roads were eliminated for the final analysis. The projects were analyzed by the type of work. Table 3-1 show the number projects for each type of major work. These work types were again reclassified based on the major work and the other additional work done in the project.

Table 3-1: Frequency Table for Major Work Involved in the Project

Major Work	Major work Code(MWC)	Frequency	Minimum Project length	Maximum Project length	Average project length
Resurfacing	1	288	0.014	24.284	2.778027778
Add Lanes & Reconstruct	2	46	0.024	6.669	2.452934783
Bridge-repair/rehabilitation	3	19	0.042	6.342	0.575894737
Add Lanes & Rehabilitate Pavement	4	6	0.268	3.321	1.4935
Add Turn Lane(s)	6	11	0.001	1.845	0.411454545
Replace Low Level Bridge	7	2	0.264	0.293	0.2785
Intersection (minor)	9	11	0.02	0.887	0.296363636
Add Left Turn Lane(s)	10	12	0.004	4.102	0.7925
Safety Project	11	12	0.001	8.069	1.203583333
Widen/resurface Exist Lanes	12	10	0.294	19.874	4.4387
Sidewalk	14	5	0.246	3.618	1.6474

Major Work	Major work Code(MWC)	Frequency	Minimum Project length	Maximum Project length	Average project length
Drainage Improvements	15	7	0.022	7.928	2.204857143
Signing/pavement Markings	17	6	0.832	9.79	4.226
Intersection (major)	18	2	0.258	1.221	0.7395
Rigid Pavement Rehabilitation	19	3	0.327	1.048	0.768333333
Traffic Signals	20	7	0.002	3.9	0.791857143
Bridge Replacement	21	3	0.1	0.246	0.180333333
Miscellaneous Construction	22	3	0.347	1.898	1.284
Add Right Turn Lane(s)	23	4	0.056	0.109	0.07925
Construct/reconstruct Median	24	4	0.551	2.037	1.2845
Traffic Ops Improvement	26	4	0.159	0.45	0.26075
Bridge-replace And Add Lanes	27	1	0.084	0.084	0.084
Skid Hazard Overlay	28	4	0.984	10.219	3.8925
Bike Path/trail	30	1	1.702	1.702	1.702
Flexible Pavement Reconstruct.	31	3	0.25	1.437	0.979
Add Thru Lane(s)	36	1	1.004	1.004	1.004
Bridge Rehabilitation	37	1	0.163	0.163	0.163
Pave Shoulders	45	1	5.48	5.48	5.48
Traffic Control Devices/system	50	1	2.24	2.24	2.24
Total		478			

3.1.2 Reclassification of Projects

There were 12 projects out of the total 478 projects under consideration in which the major work in the project is safety related, when these projects were analyzed to see whether there is improvement in safety in terms of crash reduction it was found that there was no significant reduction in the number of crashes or crash rates. Looking at the other work done in these kinds of projects, it was found that the majority of these safety related projects are resurfacing projects with some other minor work. The rest of the safety projects involved construction of sidewalks, improving traffic signal timing, etc… These projects were reclassified as either resurfacing or other types of projects according to the additional work. In the same way, all of the projects were reclassified according to the major work and the other additional work involved.

After reclassification it was found that there are 307 projects with their major work as resurfacing. From the preliminary analysis done using the crash data from 2002 to 2007 it was found that there was no significant difference in the crash frequencies in the before and the after periods for the projects with resurfacing as their major work. Therefore it was decided to find a better way to sub divide the resurfacing projects and then analyze them. The project data set contains 21 variables which indicate the additional work done in each of the projects. These variables are coded as categorical variables, which takes a value 1 when that particular kind of work is done and 0 if not. The following is the list of the additional work involved in the projects:

- Milling and resurfacing
- Widening
- Traffic signal update
- Traffic signal installation
- Signing and pavement marking
- Guardrail improvement
- Guardrail installation
- Pave shoulder

- Shoulder widening
- Adding a shoulder
- Drainage improvements
- Adding left turn lanes
- Adding right turn lanes
- Adding lanes
- Lighting improvements
- Adding/ improving a sidewalk
- Median widening
- Access improvement
- Flexible pavement repair
- Bridge repair
- Adding/ improving a bike path

Not all of the above mentioned additional improvements involve the same amount of resources; some of them require extensive resources which are referred from here on as major improvements and the rest as minor improvements. NCHRP Project 17-9(2), “Impact of Resurfacing Projects With and Without Additional Safety Improvements,” designates improvements such as guardrail, removal of roadside objects, lighting, etc… as minor improvements. The same idea has been extended and the following types are considered as minor improvements for our analysis:

- Signal update
- Guardrail improvement

- Guardrail installation
- Paving a shoulder
- Shoulder widening
- Drainage improvements
- Adding a shoulder
- Lighting improvements

The remaining improvements are treated as major improvements except for signing and pavement marking as it is assumed that if a road is resurfaced then the signing and pavement marking is done for that roadway.

With this idea of minor and major improvements the resurfacing projects are divided into 3 categories namely.

- Projects involving only resurfacing
- Projects involving resurfacing with minor improvements
- Projects involving resurfacing with major improvements

Figure 3-8 shows the flowchart for determining the sub-division of resurfacing projects.

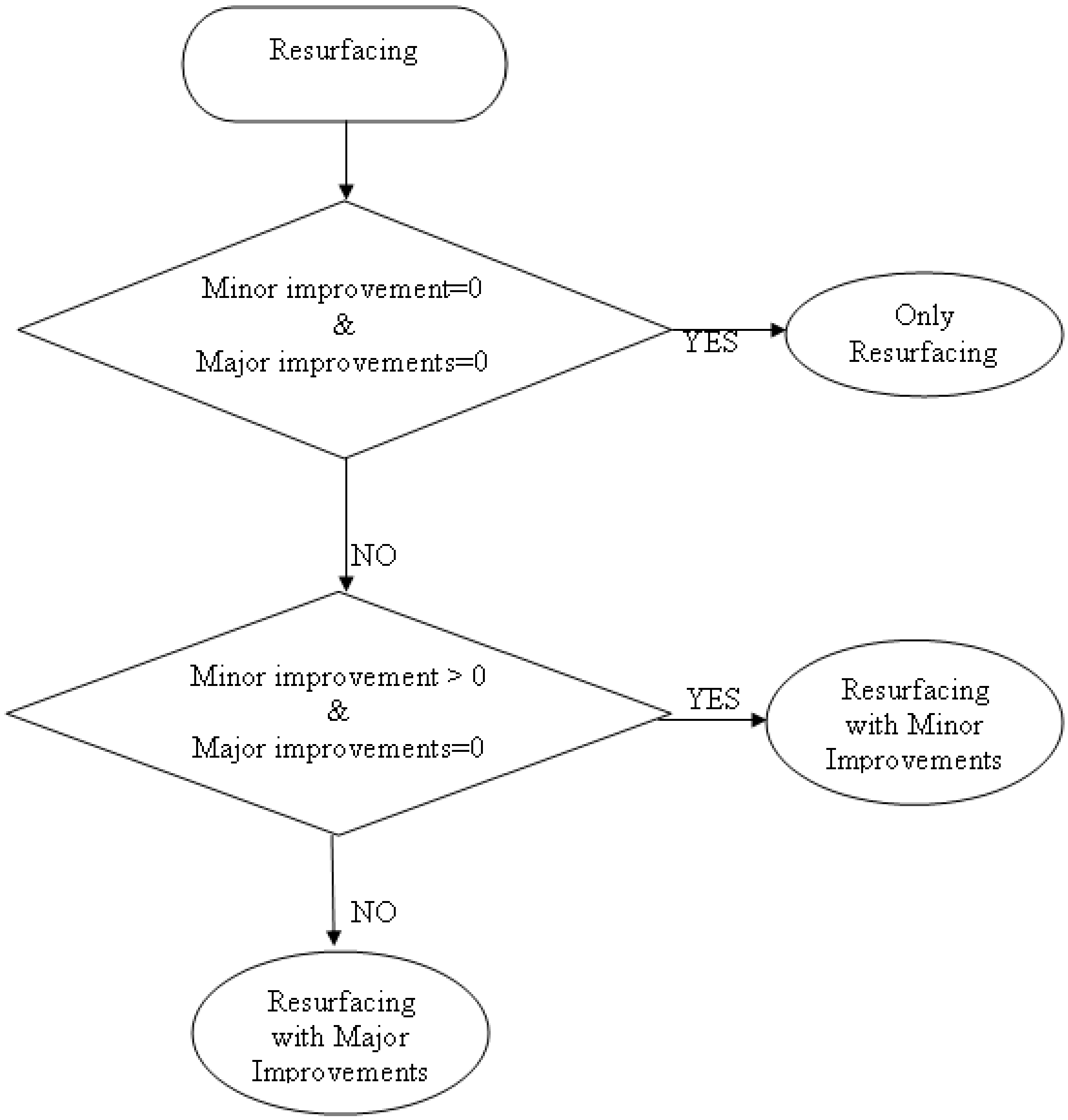


Figure 3-8: Flow Chart Showing the Classification of Resurfacing Projects

Now that the projects are reclassified it will be good to know how the data looks in terms of how many project types are there and the number of projects in each type. Table 3-2 shows the average project length for each project type and the number of projects for each type.

Table 3-2: Average Project Length and Number of Projects for Each Project Type

Major work	CODE	Frequency	Total length	Minimum length	Maximum length	Average length
Add Lanes	**2**	53	122.8	0.024	6.669	2.317
Bridge repair	**3**	25	5.945	0.042	0.5	0.2378
Add Turn Lane(s)	**6**	12	4.726	0.001	1.845	0.3938
Intersection (minor)	**9**	11	3.26	0.02	0.887	0.2964
Add Left Turn Lane(s)	**10**	13	17.579	0.004	8.069	1.3522
Side Walk	**14**	6	8.5	0.246	3.618	1.4167
Drainage Improvements	**15**	7	15.434	0.022	7.928	2.2049
Signing/pavement Markings	**17**	6	25.356	0.832	9.79	4.226
Intersection (major)	**18**	2	1.479	0.258	1.221	0.7395
Rigid Pavement Rehabilitation	**19**	3	2.305	0.327	1.048	0.7683
Traffic Signals	**20**	7	5.543	0.002	3.9	0.7919
Add Right Turn Lane(s)	**23**	4	0.317	0.056	0.109	0.0793
Construct/reconstruct Median	**24**	4	5.138	0.551	2.037	1.2845
Traffic Operations Improvement	**26**	4	1.043	0.159	0.45	0.2608
Skid Hazard Overlay	**28**	4	15.57	0.984	10.219	3.8925
Bike Path/trail	**30**	1	1.702	1.702	1.702	1.702
Flexible Pavement Reconstruct.	**31**	3	2.937	0.25	1.437	0.979
Pave Shoulders	**45**	2	6.742	1.262	5.48	3.371
Only resurfacing	**101**	46	156.906	0.219	13.267	3.411
Resurfacing with Minor Improvements	**102**	141	454.561	0.014	24.284	3.2238
Resurfacing with Major Improvements	**103**	120	239.486	0.001	14.451	1.9957

Crash frequencies can only be used if there is not a significant change in the *aadt* volume. The *aadt's* for the project locations are extracted from RCI database which is maintained by FDOT. The next section deals with *aadt`s* data extraction effort for the projects and the problem faced with RCI data.

3.1.3 Extraction of AADTs from Roadway Characteristics Inventory Data

The RCI is a database maintained by FDOT, which has all the roadway characteristics information of all the roads in the state of Florida. Each of the roadways is divided into many small sub-divisions. These sub-divisions are believed to have uniform characteristics throughout their length.

Each of these sub-divisions has information on 123 variables, a few of which are COUNTYDOT, RDWYID, BEGSECPT, ENDSECPT, SECTADT, etc… These variables indicate the county and the roadway that the sub-division belongs to, the beginning mile point of the subsection, the ending mile point of the subsection, the *aadt* on the sub-division, and other geometric information of the sub-division.

The data is available in a comma separated text format. There are some variables which carry the information of local names, beginning section names, and ending section names. It is sometimes possible for these variables to take more than one name which are also comma separated. Hence, when the data are exported to any statistical software, such as MS ACCESS or SAS which delimits the variables by comma, these multiple valued variables are erroneously recognized as multiple variables which in turn results in shifting of the columns. Table 3-3 shows a sample of shifted columns. The variable RDACESS only takes the value 1, 2 or 3 but it can be seen from the table that it is taking a value 06 which is due to the shifting of the columns as explained before. Table 3-4 shows shifted values of *aadt.*

Table 3-3: Table showing Shifted Columns

County Number	LOCAL NAM	ACCESS	RTESGNCD	TYPEROAD	FUNCLASS	RDACCESS	TOLLROAD
32	SR 25	US 41		0	0	06	3
32	SR 25	US 41		0	0	06	3
32	SR 25	US 41		0	0	06	3
32	SR 25	US 41		0	0	06	3

Table 3-4: Table Showing Shifted Columns

AVGKFACT	AVGTFACT	SECTADT	ACMANCLS	AUXLNTYP	AUXLNUM	AUXLNWTH
55.00	10.71	14.02	004300	04		
55.00	10.71	14.02	001600	04		
55.00	10.71	14.02	001600	04		
55.00	10.71	14.02	001600	04		

All of the data which had a shift in the columns are identified and corrected. Table 3-5 and 3-6 show the corrected versions of Tables 3-3 and 3-4.

Table 3-5: Corrected Version of Table 3-3

County Number	LOCALNAM	ACCESS	RTESGNCD	TYPE ROAD	FUNCLASS	RDACCESS	TOLLROAD
32	SR 25/US41		0	0	06	3	
32	SR 25/US41		0	0	06	3	
32	SR 25/US41		0	0	06	3	
32	SR 25/US41		0	0	06	3	

Table 3-6: Corrected Version of Table 3-4

AVGKFACT	AVGTFACT	SECTADT	ACMANCLS	AUXLNTYP	AUXLNUM	AUXLNWTH
10.71	14.02	004300	04			
10.71	14.02	001600	04			
10.71	14.02	001600	04			
10.71	14.02	001600	04			

After correcting the RCI data, the RCI sub-divisions for each of the projects were identified and their *aadt* related weights were determined; weights for *aadt* were calculated by dividing sub-division length by the total project length. Then these weights of each sub-division were multiplied with their respective *aadt*s and the values thus obtained were added to get the *aadts* for each project.

3.2 Preliminary Analysis of Projects` Crash Data

The 478 projects identified were analyzed to verify if there is a significant change in safety in terms of reduction in number of crashes resulting from the improvement. As it is said earlier the 478 projects also include some two-lane roadway sections. For the preliminary analysis these two-lane sections are also used, however, since the main objective of this research is to analyze multi-lane arterials, the final analysis includes only those projects which have number of lanes more than 4. The total number of crashes in the before period including all the 478 projects are 44,225 of which 4,344 are severe (fatal or incapacitating). The total number of crashes in the after period is 32,156 of which 2,750 are severe. It is important to note that the mean of the projects' before and after periods are not same, hence the number of crashes in the before and after period cannot be compared.

The number of crashes in each of the before and after are normalized by the duration of their respective periods to obtain crashes per year for the before and after period. A simple before-after comparison of crashes per year using a paired t-test was performed for each major work to check if any of the improvement resulted in significant change in safety. Table 3-7 show the results of the paired t-test. The mean here represents the mean of difference in the number of crashes per year between before and after periods for all the projects involving the same major work. Positive value of mean implies that there is a reduction in the number of crashes per year in the after period and negative values imply that there is an increase in number of crashes per year in the after period. The last column shows if the mean is significant at a significance level of 0.05. Out of the 21 major work types analyzed only 3 had a significant decrease in the total number of crashes per year and 2 work types had a significant increase. It can be seen that resurfacing with minor improvements projects had an increase in number of crashes per year where as only resurfacing and resurfacing with major improvements projects have no significant change resulting from the improvements. Figure 3-9 shows the bar chart of mean values of the difference in crashes per year between before and after period by each major work type.

Table 3-7: Statistics for the Difference in Crashes per Year between the Before After Periods and Paired T-test

Statistics for Difference in crashes per year						T-Tests				Significant change
major work	Major work code(MWC)	N	Mean	Std. Dev.	Std. Err.	DF	t-Value	Pr > |t| (two tail)	p (one tail)	
Add Lanes	**2**	53	1.1506	19.808	2.7208	52	0.42	0.6741	0.33705	no
Bridge repair	**3**	25	0.7279	1.7608	0.3522	24	2.07	0.0497	0.02485	yes (decrease)
Add Turn Lane(s)	**6**	12	9.1529	25.516	7.3659	11	1.24	0.2399	0.11995	no
Intersection (minor)	**9**	11	1.7996	3.9624	1.1947	10	1.51	0.1629	0.08145	yes (decrease)
Add Left Turn Lane(s)	**10**	13	-1.875	6.0452	1.6766	12	-1.12	0.2853	0.14265	no
Drainage Improvements	**15**	7	-10.7	18.352	6.9365	6	-1.54	0.1737	0.08685	yes (increase)
Signing/pavement Markings	**17**	6	-5.227	9.6682	3.947	5	-1.32	0.2427	0.12135	no
Intersection (major)	**18**	2	4.9558	14.645	10.355	1	0.48	0.7158	0.3579	no
Rigid Pavement Rehabilitation	**19**	3	0.5155	6.6848	3.8594	2	0.13	0.906	0.453	no
Traffic Signals	**20**	7	-0.311	3.4803	1.3154	6	-0.24	0.821	0.4105	no
Add Right Turn Lane(s)	**23**	4	1.1913	3.0545	1.5272	3	0.78	0.4922	0.2461	no
Construct/reconstruct Median	**24**	4	6.5706	10.251	5.1254	3	1.28	0.2899	0.14495	no
Traffic Ops Improvement	**26**	4	6.9615	12.855	6.4274	3	1.08	0.3581	0.17905	no
Skid Hazard Overlay	**28**	4	-2.186	14.984	7.492	3	-0.29	0.7895	0.39475	no
Bike Path/trail	**30**	1	40.836	.	.	0	.	.	.	
Flexible Pavement Reconstruct.	**31**	3	21.959	21.325	12.312	2	1.78	0.2164	0.1082	yes (decrease)
Overhead Signing	**44**	1	3.8748	.	.	0	.	.	.	
Pave Shoulders	**45**	2	-6.561	8.5233	6.0269	1	-1.09	0.473	0.2365	no
Only resurfacing	**101**	46	-2.766	22.883	3.374	45	-0.82	0.4166	0.2083	no
Resurfacing with Minor Improvements	**102**	141	-2.375	14.588	1.2285	140	-1.93	0.0552	0.0276	yes (increase)
Resurfacing with Major Improvements	**103**	120	1.0912	11.872	1.0837	119	1.01	0.316	0.158	no

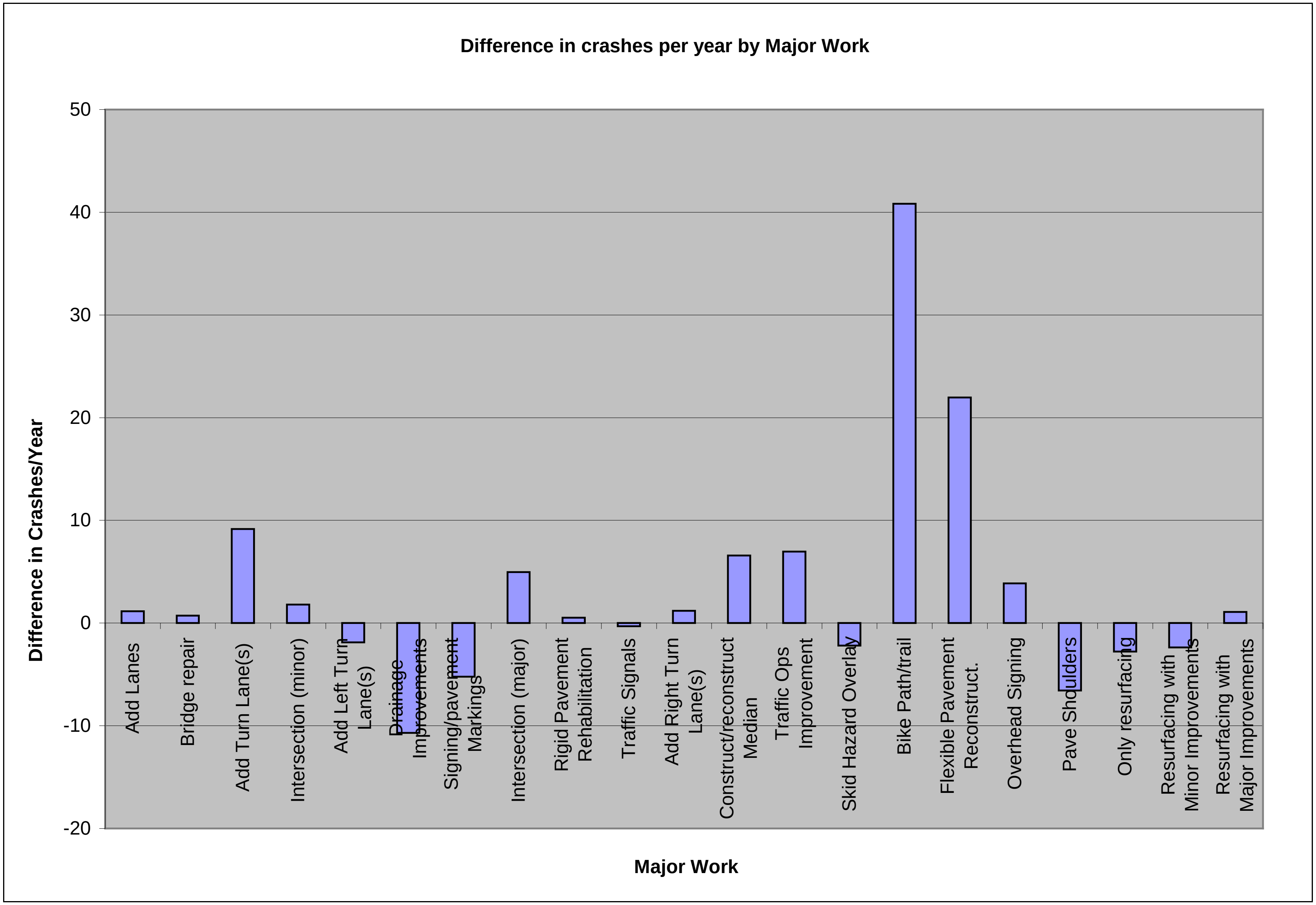


Figure 3-9: Histogram Showing Average Difference in Crash per Year (positive value indicates that crash per year in the before period is greater than that in the after period's.)

The *aadts* for all the project locations for the before and after periods was extracted using the procedure mentioned earlier. A Paired T-test was conducted between the before period and after period *aadts* to check if there is any significant change in the *aadt*. Table 3-8 shows the results of the Paired T-test.

Table 3-8: Paired T-test for AADT

Statistics					T-Tests		
Difference	**N**	**Mean**	**Std. Dev.**	**Std. Err.**	**DF**	**t Value**	**Pr > |t|**
mean_before_sect_aadt - mean_after_sect_aadt	478	-776.4	2321.6	105.2	477	-7.38	<.0001

The low p-value suggests the rejection of null hypothesis i.e. there is a significant increase in the *aadt* in the after periods. Since there is a change in the *aadt* in the before and after period, crash frequencies is not an ideal measure for safety. Hence projects are analyzed with crash rate as a measure of safety to check whether there is a significant change. Table 3-9 shows the mean difference in crash rates between the before and after periods for each project type and the paired t-test results. Figure 3-10 shows the histogram of average difference in crash rates for each project type. It can be seen from the plot that in most of the project types there is reduction in crash rates but when looking at the p-values most of them are not significant. Only in 6 out of 21 major work types analyzed there is a significant reduction in crash rates, i.e. there is an improvement in safety. There is no case in which the safety deteriorated significantly. It is interesting to note that for the projects with their major work as resurfacing, there is a reduction in crash rates only in those cases in which some other major improvements are made along with resurfacing; thereby indicating that resurfacing when accompanied by some major improvements is more effective in terms of improving safety than only resurfacing or resurfacing with minor improvements.

Table 3-9: Statistics for Crash Rates and T-tests

Difference in Crash rates							T-Tests				Significant change
major work	CODE	N	Mean	Std Dev	Std Err	DF	t Value	Pr > |t|	one tail (t test)	
Add Lanes	**2**	53	1.0591	6.1113	1.0001	52	1.06	0.2945	0.14725	no
Bridge repair	**3**	25	0.6362	0.7718	0.1977	24	3.22	0.0037	0.00185	yes (decrease)
Add Turn Lane(s)	**6**	12	1.9496	2.4975	1.0177	11	1.92	0.0818	0.0409	yes (decrease)
Intersection (minor)	**9**	11	1.4875	1.7958	0.7749	10	1.92	0.0839	0.04195	yes (decrease)
Add Left Turn Lane(s)	**10**	13	-0.743	2.0031	0.7747	12	-0.96	0.3566	0.1783	no
Drainage Improvements	**15**	7	-2.972	3.9965	2.3441	6	-1.27	0.2518	0.1259	no
Signing/pavement Markings	**17**	6	-2.629	4.6391	3.0341	5	-0.87	0.4258	0.2129	no
Intersection (major)	**18**	2	0.28	1.6394	2.5983	1	0.11	0.9317	0.46585	no
Rigid Pavement Rehabilitation	**19**	3	2.1984	2.5477	2.8252	2	0.78	0.5179	0.25895	no
Traffic Signals	**20**	7	0.2108	1.1851	0.6951	6	0.3	0.7719	0.38595	no
Add Right Turn Lane(s)	**23**	4	1.0534	0.958	0.8455	3	1.25	0.3013	0.15065	no
Construct/reconstruct Median	**24**	4	4.3565	4.2959	3.7917	3	1.15	0.3339	0.16695	no
Traffic Ops Improvement	**26**	4	1.5866	1.118	0.9868	3	1.61	0.2062	0.1031	yes (decrease)
Skid Hazard Overlay	**28**	4	-0.091	2.7678	2.4429	3	-0.04	0.9725	0.48625	no
Bike Path/trail	**30**	1	7.88	.	.	0			.	
Flexible Pavement Reconstruct.	**31**	3	6.7505	2.1432	2.3765	2	2.84	0.1048	0.0524	yes (decrease)
Overhead Signing	**44**	1	-0.186	.	.	0			.	
Pave Shoulders	**45**	2	-1.954	1.0907	1.7286	1	-1.13	0.4611	0.23055	no
Only resurfacing	**101**	46	0.829	5.0027	0.8893	45	0.93	0.3562	0.1781	no
Resurfacing with Minor Improvements	**102**	141	-0.867	9.9522	0.9361	140	-0.93	0.3557	0.17785	no
Resurfacing with Major Improvements	**103**	120	0.7294	4.2757	0.4398	119	1.66	0.0999	0.04995	yes (decrease)

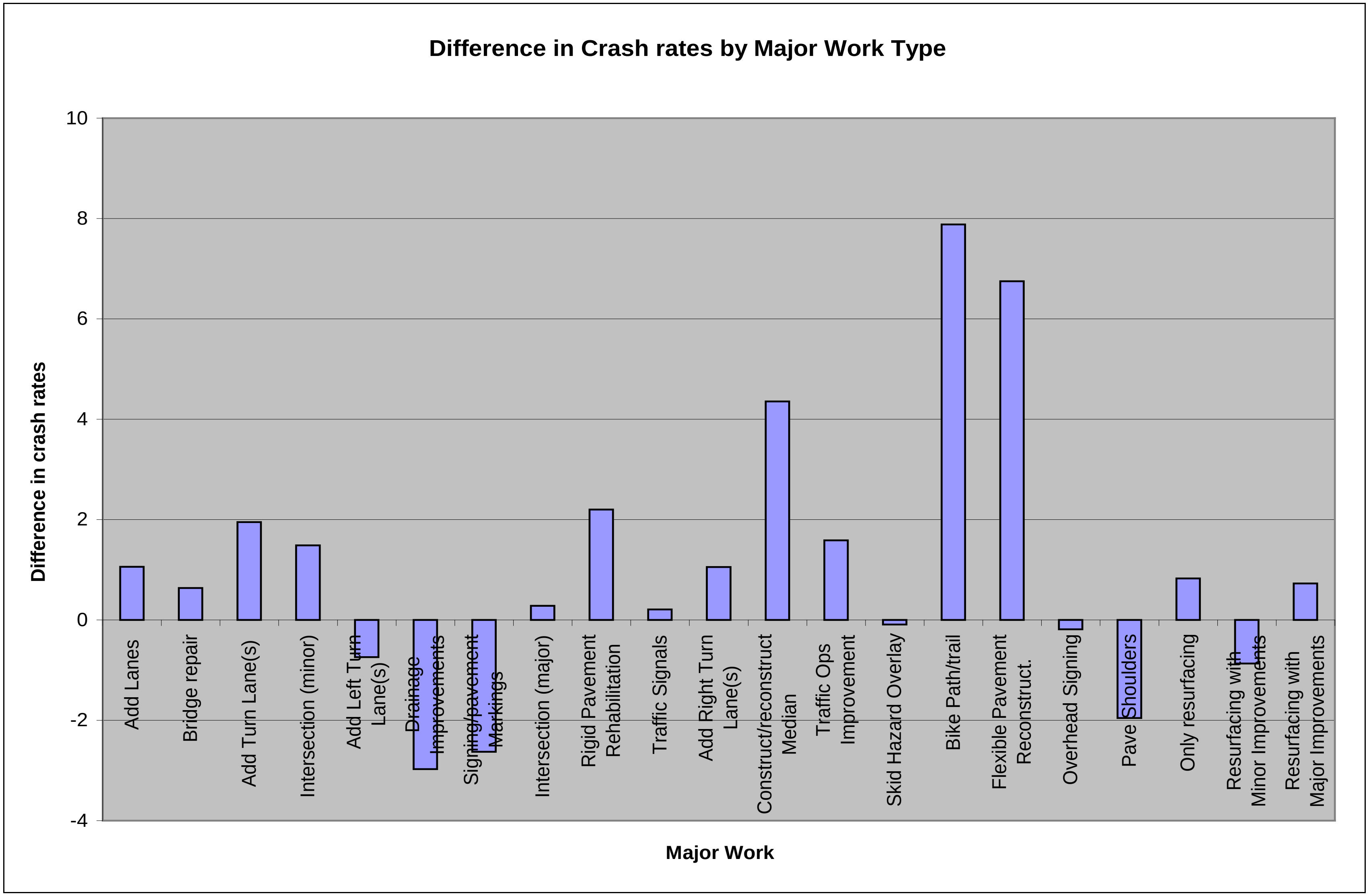


Figure 3-10: Histogram Showing Average Difference in Crash Rates (positive value indicates that crash rate in the before period is greater than the after period's.)

Crashes are categorized as 5 types in terms of injury severity:

1. No injury
2. Possible injury
3. Non-incapacitating injury
4. Incapacitating injury
5. Fatal injury

Among the above categories, 4 and 5 are considered as severe injuries. The projects are analyzed for the trends in severe crashes in the after periods. Figure 3-11 shows the histogram of percentage of crashes for each severity level in the before and after periods.

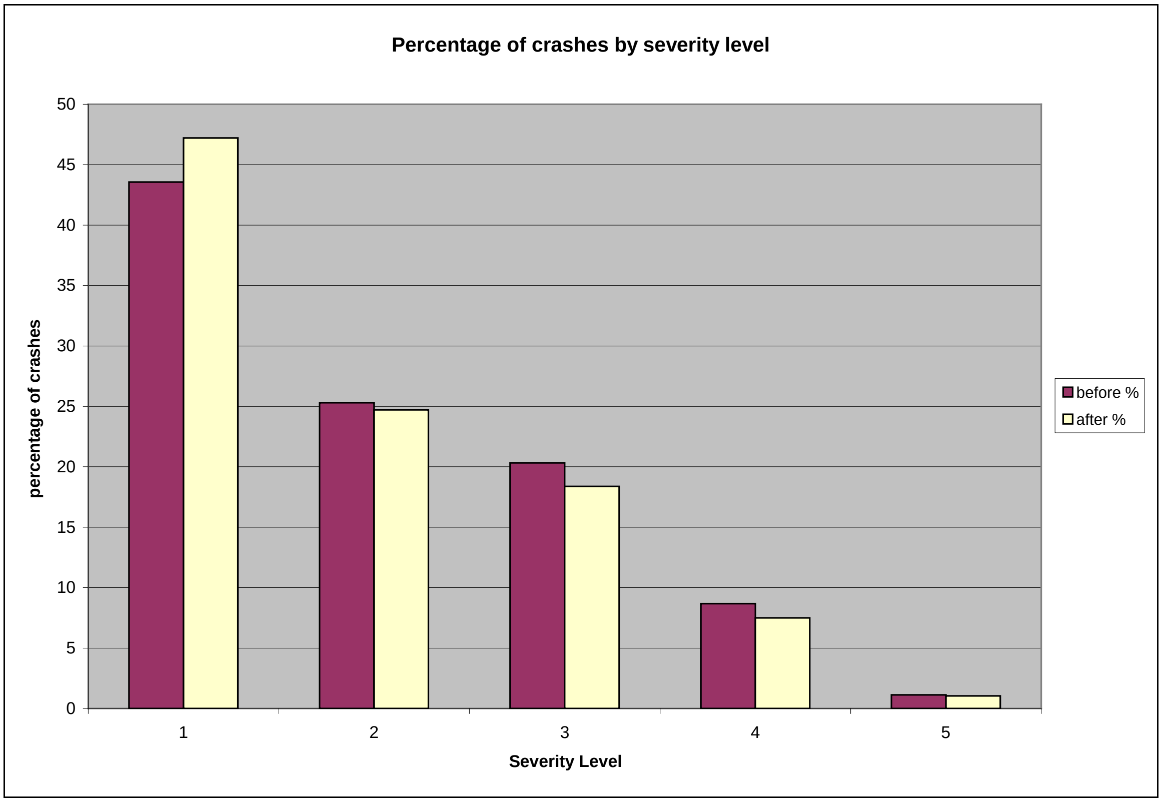


Figure 3-11: Percentage of Crashes by Severity Level in Before and After Periods

It can be seen from the plot that there is a decrease in the percentage of crashes with severity levels 2, 3, 4 and 5 in the after periods. As it is observed that there is a reduction in the severe crashes in the after periods, hence the projects are analyzed to check whether this holds true for each project type. Table 3-10 shows the statistics for the difference in the proportion of severe crashes in before and after periods. Figure 3-12 shows the bar plot of the same. Paired T-tests are conducted to check whether the differences are significant or not. The results of the T-tests are shown in the same table, Table 3-10. It can be seen from the plot that in all the cases except for 3 project types there is a reduction in the proportion of severe crashes. But all reductions are not significant. Only in 5 out of 21 major work types analyzed the reduction is significant. While considering the crash rates we found that resurfacing when done with some major improvements is effective, but when the same types of projects are considered for proportion of severe crashes we found that resurfacing with minor improvements is better in terms of reducing the severe crashes, indicating the need for further analysis.

During the analysis it was found that some of the improvements are intersection related. Crash patterns at the intersections and crash patterns over a corridor will not be the same; hence they should be analyzed separately. All the projects which involve only intersection improvements are identified using the Video Log application available on the intranet and crash data and RCI data for the same was extracted from the previously mentioned databases. The analysis for these intersection improvements and corridor level improvements will be discussed in detail in the next chapters.

Table 3-10: Difference in the Proportion of Severe Crashes in Before and After Periods

Difference in Proportion of Severe Crashes										T-Tests				
major work	CODE	N	total crashes in the before period	total crashes in the after period	total severe crashes in the before period	total severe crashes in the after period	Mean	Std Dev	Std Err	DF	t Value	Pr > |t|	one tail	Significant change
Add Lanes	2	53	2889	2646	296	234	0.0093	0.1287	0.0177	52	0.53	0.5994	0.2997	no
Bridge repair	3	25	235	121	15	11	-0.027	0.3936	0.0787	24	-0.35	0.73	0.365	yes (increase)
Add Turn Lane(s)	6	12	1488	323	133	28	0.0853	0.1689	0.0488	11	1.75	0.1081	0.05405	yes (decrease)
Intersection (minor)	9	11	304	82	46	7	0.1251	0.2077	0.0626	10	2	0.0737	0.03685	yes (decrease)
Add Left Turn Lane(s)	10	13	429	325	46	27	0.1141	0.2752	0.0763	12	1.49	0.1608	0.0804	yes (decrease)
Drainage Improvements	15	7	485	961	39	70	0.007	0.0229	0.0086	6	0.81	0.4491	0.22455	no
Signing/pavement Markings	17	6	1082	670	58	43	0.0581	0.1496	0.0611	5	0.95	0.3853	0.19265	no
Intersection (major)	18	2	384	131	90	14	0.05	0.0398	0.0281	1	1.78	0.3261	0.16305	no
Rigid Pavement Rehabilitation	19	3	310	292	28	20	0.0204	0.0274	0.0158	2	1.29	0.3268	0.1634	no
Traffic Signals	20	7	418	269	52	25	0.0569	0.1669	0.0631	6	0.9	0.402	0.201	no
Add Right Turn Lane(s)	23	4	97	90	6	7	-0.287	0.5058	0.2529	3	-1.14	0.3388	0.1694	no
Construct/reconstruct Median	24	4	563	131	60	12	0.0292	0.0463	0.0232	3	1.26	0.2969	0.14845	no
Traffic Ops Improvement	26	4	333	122	18	8	-0.07	0.1659	0.0829	3	-0.85	0.4594	0.2297	no
Skid Hazard Overlay	28	4	1200	554	75	24	0.0063	0.0146	0.0073	3	0.86	0.4518	0.2259	no
Bike Path/trail	30	1	343	52	28	3	0.0239	.	.	0	.	.	.	
Flexible Pavement Reconstruct.	31	3	362	96	33	5	0.089	0.0908	0.0524	2	1.7	0.2317	0.11585	no
Overhead Signing	44	1	1017	2428	70	163	0.0013	.	.	0	.	.	.	
Pave Shoulders	45	2	387	127	45	9	0.1435	0.1506	0.1065	1	1.35	0.4063	0.20315	no
Only resurfacing	101	46	5518	4678	513	423	0.0266	0.1459	0.0215	45	1.23	0.2234	0.1117	no
Resurfacing with Minor Improvements	102	141	10874	7054	1098	657	0.0248	0.183	0.0154	140	1.61	0.1104	0.0552	yes (decrease)
Resurfacing with Major Improvements	103	120	9463	6860	931	660	0.0146	0.1755	0.016	119	0.91	0.3646	0.1823	no

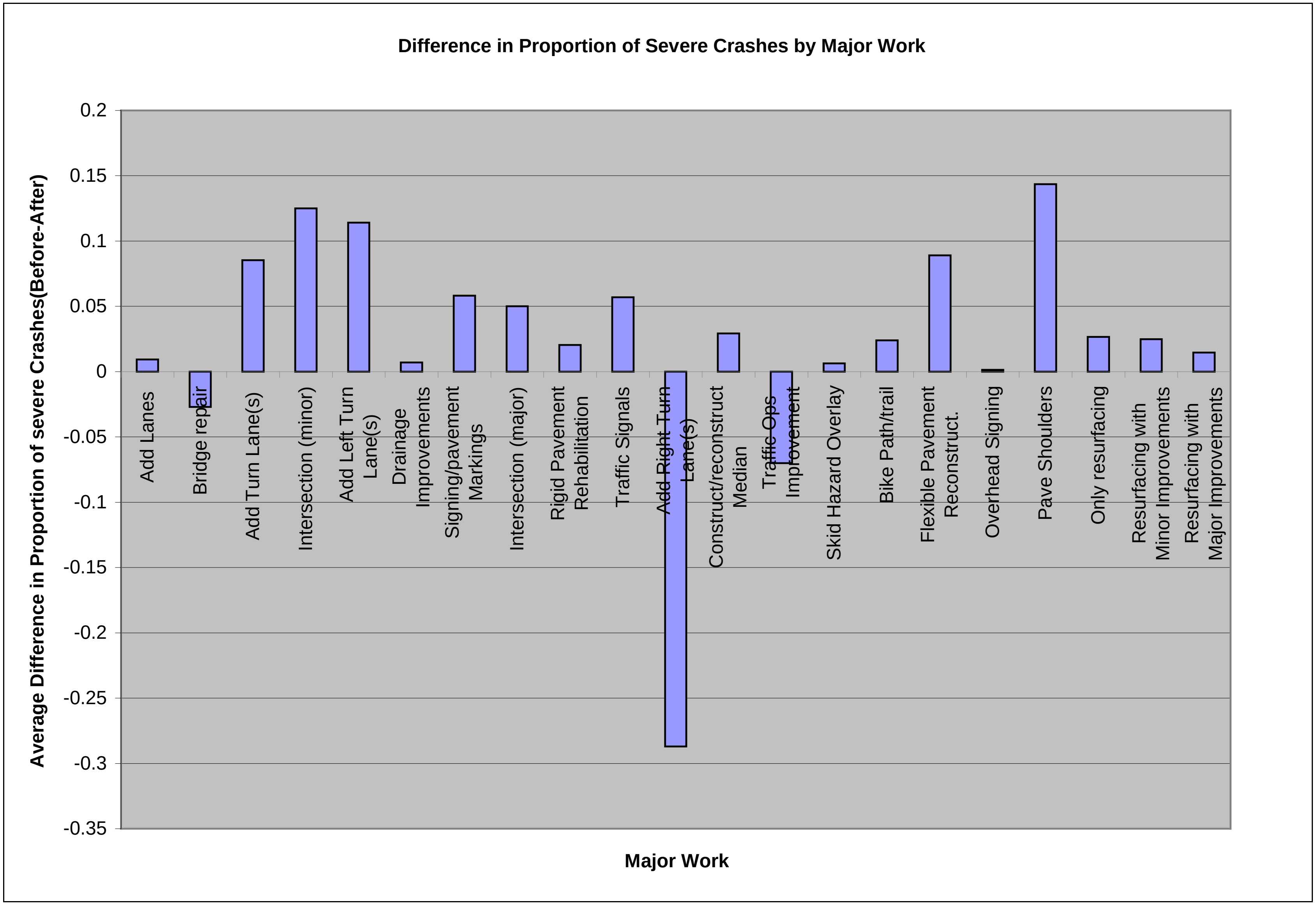


Figure 3-12: Bar Chart Showing Average Difference in the Proportion of Severe Crashes for Each Project Type (positive value indicates that the proportion of severe crashes in the before period is more than the after period's)

3.3 Reference Group

The next step in data collection was to collect the information on the reference sites. Continuous roadway sections of multilane arterials, having the same number of lanes and speed limit as the treated sites, were identified from the state of Florida. A total 2780 of such sections are identified which varied from 0.1 mile to 25 miles in length. These sections were then limited to those sections having the same length range as the corridor level improvement projects. The crash data, geometric and traffic characteristics for these sections are obtained from the aforementioned CAR and RCI databases.

As mentioned earlier, intersection projects and corridor projects are analyzed separately. For a before and after study using EB method a reference population should be identified to generate the safety performance functions. Identifying intersections for the reference group is a difficult task and is not similar as identifying reference group for corridor level projects. Hence, the intersection data from previous research by Abdel-Aty and Wang (2005) was used as the reference population.

Abdel-Aty and Wang (2005) has identified 476 signalized intersections along 41 corridors in Orange, Miami-Dade, and Brevard counties in the state of Florida for modeling crashes at signalized intersections and analyzing the spatial correlations among the intersections and to identify significant factors for crash occurrence. The same set of intersections along with some more intersections in Seminole and Hillsborough counties in Florida are used a reference population in this study. Considering the intersections in other counties the total number of intersections used for reference population are 615. For each of the intersections the crash data and roadway characteristics information was extracted from the CAR and RCI databases. The next chapters discuss the methodology and generating safety performance function using the reference population data.

CHAPTER 4. EMPIRICAL BAYES METHODOLOGY

This chapter illustrates the steps involved in the evaluation process of a treatment using EB approach. The EB method combines two different sets of *evidence* to estimate the number of crashes at the treatment site: the crash history of the treatment site and the crash frequency expected at reference sites (Hauer, 1997), which can be written in the mathematical form as in Equation 4.1(Hauer, 1997):

$$\hat{E}_i = (\gamma_i \times y_i \times n) + (1 - \gamma_i)\eta_i \tag{4.1}$$

η_i = Observed number of crashes at the treatment site during the before period (represents the 'evidence' from the reference sites).

Where n = Number of years in the before period,

$$\gamma_i = \frac{1}{1 + k \times y_i \times n} \tag{4.2}$$

k = Dispersion parameter

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

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, model fit using the crash data from the before period of the reference group:

$$y_i = e^{(\beta_0 + \beta_1 x_1 + \beta_2 x_2 + \ldots + \beta_n x_n)} \tag{4.3}$$

Where β_i*'s* = regression parameters,

x_1 and x_2 here are logarithmic values of *aadt* and section length,

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. This is used to estimate the relative weight of the two sets of evidences (Equations 4.1 and 4.2).

The standard deviation (σ_i) for the estimate in Equation 4.1 is given by:

$$\hat{\sigma}_i = \sqrt{(1 - \gamma_i) \times \hat{E}_i} \tag{4.4}$$

The estimates obtained from Equation 4.1 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 4.1 are to be adjusted for traffic volume changes and different before and after periods (Hauer, 1997; Noyce et al., 2006). The adjustment factors for which are given as below:

Adjustment for *aadt* (ρ_{AADT}):-

$$\rho_{AADT} = \frac{AADT_{after}^{\ \alpha_1}}{AADT_{before}^{\ \alpha_1}} \tag{4.5}$$

Where, $AADT_{after}$ = *aadt* in the after period at the treatment site,

$AADT_{before}$ = *aadt* in the before period at the treatment site and

α_1 = Regression coefficient of *aadt* from the SPF.

Adjustment for different before-after periods (ρ_{time}):-

$$\rho_{time} = \frac{m}{n} \tag{4.6}$$

Where, m = Number of years in the after period and

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:

$$\hat{\pi}_i = \hat{E}_i \times \rho_{AADT} \times \rho_{time} \tag{4.7}$$

The index of effectiveness ($\hat{\theta}_i$) of the treatment is given by:

$$\hat{\theta}_i = \frac{\hat{\lambda}_i / \hat{\pi}_i}{1 + \left(\hat{\sigma}_i^{\,2} \big/ \hat{\pi}_i^{\,2} \right)} \tag{4.8}$$

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

The percentage reduction ($\hat{\tau}_i$) in crashes of particular type at each site i is given by:

$$\hat{\tau}_i = (1 - \hat{\theta}_i) \times 100\% \tag{4.9}$$

The effectiveness ($\hat{\theta}$) of the treatment averaged over all projects involving the same treatment would be given by (Persaud, 2004):

$$\hat{\theta} = \frac{\sum_{i=1}^{k} \hat{\lambda}_i \Big/ \sum_{i=1}^{k} \hat{\pi}_i}{1 + \left(\text{var}(\sum_{i=1}^{k} \hat{\pi}_i) \Big/ (\sum_{i=1}^{k} \hat{\pi}_i)^2 \right)} \tag{4.10}$$

Where, k = total number of projects involving the same type of treatment, and

$$\text{var}(\sum_{i=1}^{k} \hat{\pi}_i) = \sum_{i=1}^{k} \rho_{AADT}{}^2 \times \rho_{time}{}^2 \times \text{var}(\hat{E}_i) \quad \text{(Hauer, 1997)} \tag{4.11}$$

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 4.11.

$$\hat{\sigma} = \sqrt{\frac{\theta^2 \left[\left(\text{var}(\sum_{i=1}^{k} \hat{\pi}_i) \Big/ (\sum_{i=1}^{k} \hat{\pi}_i)^2 \right) + \left(\text{var}(\sum_{i=1}^{k} \hat{\lambda}_i) \Big/ (\sum_{i=1}^{k} \hat{\lambda}_i)^2 \right) \right]}{\left[1 + \left(\text{var}(\sum_{i=1}^{k} \hat{\pi}_i) \Big/ (\sum_{i=1}^{k} \hat{\pi}_i)^2 \right) \right]^2}} \tag{4.12}$$

Where, $\text{var}(\sum_{i=1}^{k} \hat{\lambda}_i) = \sum_{i=1}^{k} \lambda_i$ (Hauer, 1997) (4.13)

Equation 4.7 is used in the analysis to estimate the 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.

CHAPTER 5. SAFETY PERFORMANCE FUNCTIONS

As discussed in the previous chapter the EB method requires SPFs in order to estimate the expected number of crashes at the treatment site. This chapter presents the method of SPFs development. Two types of SPFs can be found in the literature: full SPFs and traffic SPFs. Full SPF is a crash prediction model involving both traffic parameters and geometric parameters as explanatory variables, whereas traffic SPF includes only *aadt* as the explanatory variable in predicting the crashes on a roadway section (Shen, 2007). In this study full SPFs are developed and applied with more parameters than just the *aadt*. This is considered a major contribution since most previous studies used only *aadt*.

SPF is a regression model which predicts crashes on a given roadway section. There are several statistical methods to model crash occurrence on a roadway. Many researchers in the past used Poisson regression models to estimate the crash occurrence, assuming that crash occurrence follows a Poisson distribution. The Poisson regression is valid when the data is not dispersed, or in other words when the mean of the distribution is equal to the variance. However, it was found by many researchers that crash data is over-dispersed (variance is higher than the mean), hence the use of Poisson regression models to estimate the crash occurrence may give less accurate results (Caliendo, 2007). Negative binomial regression is a good statistical model to handle the over-dispersed data.

5.1 Negative Binomial Regression

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).

$y_i|\lambda_i$ ~ Poisson (λ_i)

λ ~ Gamma (a,b)

Then, P(y_i) ~ Negbin (λ_i, k)

$$= \frac{\Gamma(1/k + y_i)}{y_i!\Gamma(1/k)}\left(\frac{k\lambda_i}{1+k\lambda_i}\right)^{y_i}\left(\frac{1}{1+k\lambda_i}\right)^{1/k} \quad (5.1)$$

Where, y = number of crashes on a roadway section per period,

λ= Expected number of crashes per period on the roadway section, and

k= over-dispersion parameter

The expected number of crashes on a given roadway section per period can be estimated by Equation 5.2.

$$\lambda = \exp(\underline{\beta}^T \underline{X} + \varepsilon) \quad (5.2)$$

Where, $\underline{\beta}$ is a vector of regression of parameter estimates, and

$\underline{X}$ is a vector of explanatory variables, and

$\exp(\varepsilon)$ is 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 5.3.

$$\text{var}(y) = \lambda + k\lambda^2 \quad (5.3)$$

As k → 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 5.4.

$$l(\underline{\beta}, k) = \prod_i \frac{\Gamma(1/k + y_i)}{y_i!\Gamma(1/k)} \left(\frac{k\lambda_i}{1 + k\lambda_i} \right)^{y_i} \left(\frac{1}{1 + k\lambda_i} \right)^{1/k} \quad (5.4)$$

Using the above methodology negative binomial regression models were developed and were used to estimate the number of crashes at the treated sites. The next section deals with the SPF development using Statistical Analysis Software (SAS) for each of the reference population, the corridor and the intersection.

5.2 SPFs for Corridors

As said earlier a total of 2780 continuous roadway sections of multilane arterials having the same number of lanes and speed limit throughout the section were identified from the state of Florida. The section lengths varied from 0.1 mile to 25 miles in length. These sections were then limited to those sections having the same length range as the corridor improvement projects. For the final analysis only those corridor projects were considered which has a section length of 0.5 mile or more. And it was found that the maximum section length of the improvement projects after eliminating the two-lane roads is 9 miles. Since the improvement projects with section lengths ranging from 0.5 miles to 9 miles were included in the analysis, the sections in the reference population whose lengths fall in the range 0.5 miles to 9 miles were only used for SPF development. The total number of sections in the reference population which fell in the above specified range was 1758.

It is worth mentioning that the access density was considered a potential variable in the SPF, but the precise information on the corresponding variable was found to be missing in the database. Fortunately, the information, where available, was strongly correlated with land use (urban, sub-urban, and rural). Therefore, the reference sites were separated according to their land use and SPFs for three crash types (total, severe, and rear-end) were generated using PROC GENMOD procedure in SAS for each land use category. The above classification resulted in nine different SPFs.

First, nine different negative binomial crash frequency estimation models were generated (for each of the three different crash types and three land use categories). These models were compared with models that were estimated for different length groups (with arbitrary thresholds; e.g., 0.5 to 1.5 miles, 1.5 to 3 miles and so on). It was observed that the coefficients of the parameters varied significantly from the overall model(s) and for models with disaggregated length groups. Hence, it was decided to fit several models based on different length groups. The length thresholds were determined by clustering the section lengths of the different corridor level improvement projects into three groups: (0.5, 1.25] miles, (1.25, 3] miles, and greater than 3 miles. Figure 5-1 illustrates the classification tree used in developing the SPFs. Table 5-1 shows the descriptive statistics of the reference group.

Disaggregating SPFs by lengths of the sections under examination is advantageous for one more reason. The over-dispersion parameter estimated for the negative binominal regression model is suspected to vary by lengths of the segments under consideration (Hauer, 2001). Using SPFs segregated into three different length groups ensures that the assumption of a constant dispersion parameter is not violated in a serious way. Nine groups of SPFs developed for each crash group (total, severe, and rear-end crashes) are depicted in Figure 5-1.

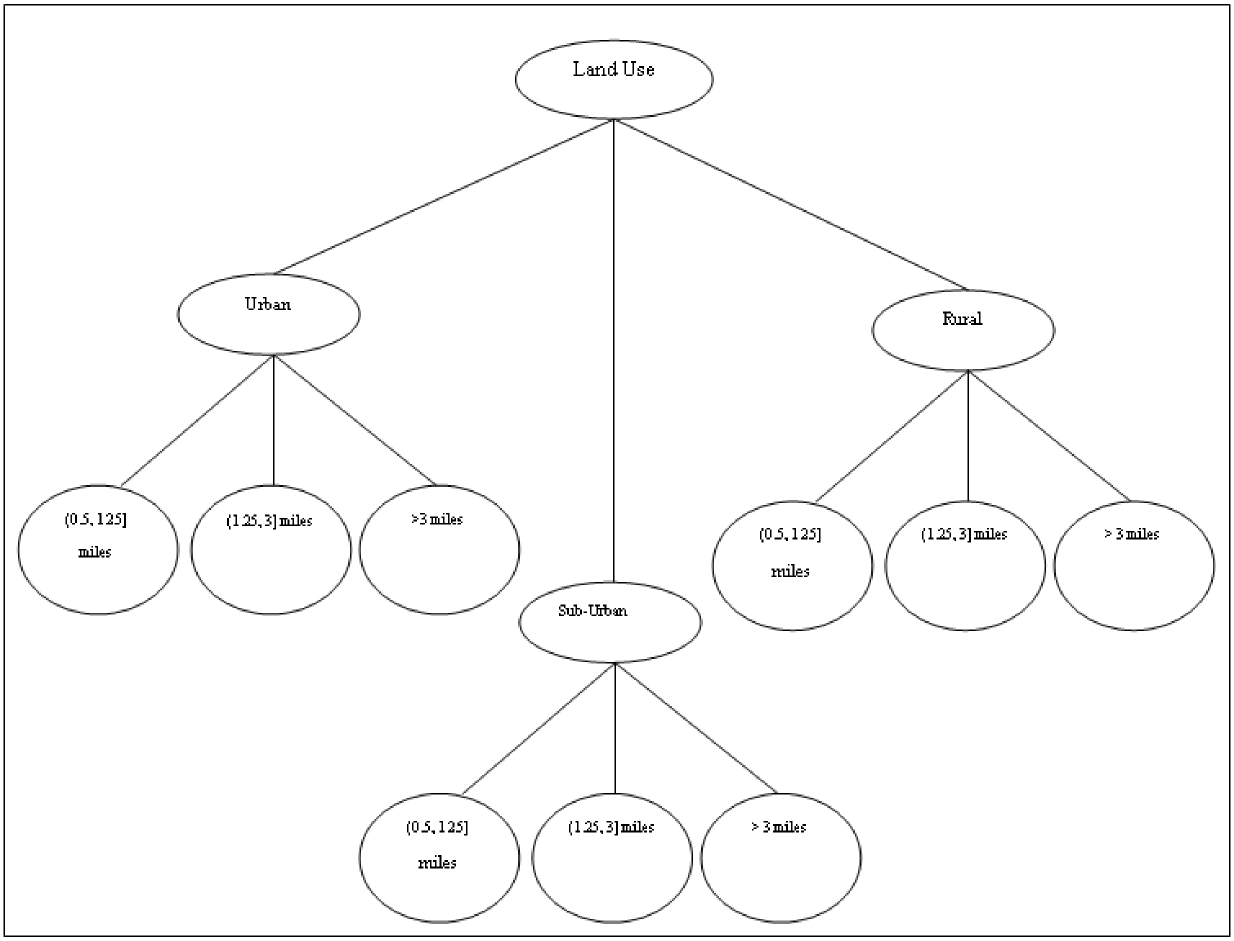


Figure 5-1: Nine groups of SPFs Estimated for Total, Rear-end, and Severe Crashes

The following step is to estimate SPFs for each crash type using the information from the reference sites. Using PROC GENMOD procedure in SAS, negative binomial models were fitted for the frequency of reference group crashes with the explanatory variables *adt*, length of the section, number of lanes, and speed limit. Of the explanatory variables, logarithms of *adt* and section lengths were measured on a continuous scale and number of lanes and speed limit were used as nominal variables. Number of levels for categorical variables considered are three (for number of lanes—4 lanes, 5 lanes, and 6 lanes), and six (for speed limit—with thresholds on 40, 45, 50, 55, 60, and 65 mph).

Table 5-1: Descriptive Statistics of the Corridors Reference Group

	0.5 < section length <=1.5	1.5 < section length <=3.0	3.0 < section length <=9.0
Number of sections	690	624	344
Minimum ADT	1000	3300	2700
Average ADT	26630.47	30359.71	29447.32
Maximum ADT	89500	87950	93587
Minimum(Total Crashes/year)	0	0	0
Average(Total Crashes/year)	20.08	52.14	107.25
Maximum(Total Crashes/year)	225	489	785
Minimum(Severe Crashes/year)	0	0	0
Average(Severe Crashes/year)	1.68	4.58	9.35
Maximum(Severe Crashes/year)	23	42	60
Minimum(Rear-end Crashes/year)	0	0	0
Average(Rear-end Crashes/year)	7.24	19.26	39.45
Maximum(Rear-end Crashes/year)	97	146	390

With three different groups of crashes (total, severe, and rear-end) there were a total of 27 different SPFs that were estimated. In the following sections SPFs for each crash type are presented.

5.2.1 Total Crashes

As said earlier a total of 9 different SPFs for total crashes are developed based on different land-use categories and section lengths. The variables considered important in the model are log*(adt)*, log(length), speed limit, and number of lanes. Only those variables were selected which are significant at a significance level of 0.05.

5.2.1.1 Urban Multi-lane Roads

5.2.1.1.1 Section Lengths Ranging from (0.5, 1.25] Miles

Negative Binomial models were fitted using SAS with the variables which were considered important. It was found that all of the variables considered were significant at the 0.05 level. The speed limit has only 4 values for this class of sections: 40, 45, 50, and 50. Table 5.2 shows the parameter estimates and summary of statistics of the final model.

It can be seen from the model that *adt* has a nearly linear relationship with total number of crashes when all other values are kept constant. The expected number of crashes on a section were found to increase with decreasing speed limit, in other words it can be said expected crash frequency on a section and speed limit are negatively correlated. The number of crashes was found to increase with the increase in number of lanes, this can be explained by the fact that as the number of lanes increase there will be more lane changing conflict points, hence higher chance of crash occurrence. The dispersion value of 0.454 confirms that the data is over-dispersed and supports the use of negative binomial regression. The deviance to degrees of freedom *(df)* ratio is nearly equal to one, implying that the model fits the data well (UCLA, SAS notes).

Table 5-2: SPF for Total Crashes on Urban Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	363	416.3998	1.1471
Pearson Chi-Square	363	472.3036	1.3011
Log Likelihood		25842.8562	

Analysis Of Parameter Estimates									
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-6.5964	0.7418	-8.0503	-5.1425	79.07	<.0001
Log(ADT)		1	0.9924	0.0745	0.8463	1.1384	177.29	<.0001
Log(length)		1	0.9313	0.1431	0.6509	1.2117	42.37	<.0001
Speed limit	55	1	-1.7831	0.3702	-2.5086	-1.0576	23.2	<.0001
Speed limit	50	1	-1.3724	0.18	-1.7252	-1.0195	58.11	<.0001
Speed limit	45	1	-0.5852	0.0826	-0.7471	-0.4234	50.26	<.0001
Speed limit	40	0	0	0	0	0	.	.
# of lanes	6	1	0.2689	0.0957	0.0814	0.4564	7.9	0.0049
# of lanes	5	1	0.5541	0.2934	-0.0211	1.1292	3.57	0.059
# of lanes	4	0	0	0	0	0	.	.
Dispersion		1	0.454	0.0378	0.3799	0.5282		

5.2.1.1.2 Section Lengths Ranging from (1.25, 3.0] Miles

Negative Binomial regression models were fitted using SAS. The same variables were used as previous model for the initial model and it was found that number of lanes is not a significant variable for this length range. The speed limit has only 5 levels for these sections. Table 5-3 shows the parameter estimates of the model and the goodness of fit statistics. The ratio of the deviance to *df* is close to one implying that model fit the data properly. The dispersion value of 0.3113 supports the use of negative binomial regression for the data.

It can be seen from the model that as the speed limit of the section increases the expected number of crashes on it decreases, except for speed limit of 60. It can also be seen that the parameter estimates for log(*adt*), log(Length), and speed limit are significantly different from the model in Table 5-2 justifying the SPFs modeling based on section lengths.

Table 5-3: SPF for Total Crashes on Urban Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	335	364.1508	1.087
Pearson Chi-Square	335	411.5435	1.2285
Log Likelihood		87685.9213	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > Chi Sq**
Intercept		1	-9.5102	0.7314	-10.9437	-8.0767	169.07	<.0001
Log(ADT)		1	1.2784	0.0717	1.138	1.4188	318.35	<.0001
Log(length)		1	1.0095	0.1294	0.7559	1.2631	60.87	<.0001
Speed limit	60	1	-1.2321	0.3856	-1.9878	-0.4764	10.21	0.0014
Speed limit	55	1	-1.3969	0.2289	-1.8455	-0.9484	37.26	<.0001
Speed limit	50	1	-1.01	0.1218	-1.2488	-0.7712	68.71	<.0001
Speed limit	45	1	-0.4466	0.0666	-0.577	-0.3161	45	<.0001
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.3113	0.0249	0.2626	0.3601		

5.2.1.1.3 Section Lengths Ranging from (3.0, 9.0] Miles

Negative binomial SPFs were also developed for the section with lengths greater than 3.0 miles and less than or equal to 9.0 miles. Table 5-4 shows the model estimates and goodness of statistics. The ratio of deviance to *df* is 1.0796, which is close to one implying that the model fit the data properly. It can be seen from the model that *adt* and section length are not linearly related to the total number of crashes. The speed limit had only 4 levels, with speed limit 40 as the base case. The parameter estimates of the model show that the total number of crashes occurring on a segment is negatively correlated with the speed limit of the section. Dispersion value of 0.2505 indicates that the data is over-dispersed and justifies the use of Negative Binomial regression model for the data.

Table 5-4: SPF for Total Crashes on Urban Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	150	161.9375	1.0796
Pearson Chi-Square	150	169.7753	1.1318
Log Likelihood		121701.2302	

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-8.1631	1.0284	-10.1788	-6.1474	63	<.0001
Log(ADT)		1	1.1281	0.0982	0.9356	1.3206	131.92	<.0001
Log(length)		1	1.2436	0.1746	0.9014	1.5857	50.74	<.0001
Speed limit	55	1	-1.0841	0.3704	-1.8101	-0.358	8.56	0.0034
Speed limit	50	1	-1.1045	0.1842	-1.4655	-0.7436	35.97	<.0001
Speed limit	45	1	-0.5756	0.0883	-0.7487	-0.4025	42.46	<.0001
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.2505	0.0283	0.195	0.306		

It can be seen from the above three models that the parameter estimates of the same variables changed with the length of the sections. Comparing the dispersion parameter values it can be said that urban sections with lengths less than 0.5 miles are more dispersed than the sections with lengths more than 0.5 miles. It can also be seen that in all of the models the total number of crashes decreased with increase in speed limit.

5.2.1.2 Sub-Urban and Rural Multi-Lane Roads

Negative binomial regression models were developed for sub-urban and rural roads for different section length classes in the similar way as it was done for urban roads. Table 5-5 shows the summary of all the models developed for total number of crashes. Detailed output from the SAS for the models is presented in the appendix of this report.

It can be seen from the table that not all of the explanatory variables are significant in all the models. For example the number of lanes is not a significant variable for sections' lengths more than 1.25 miles. It may also be observed that the coefficients for the same variables vary widely across the models. It indicates that the approach of separate models for each category is indeed a better one.

It can be seen in the models that the parameter estimate of the *adt* is never equal to one indicating that the relationship between the total number of crashes and *adt* is non-linear. The total number of crashes was seen to be decreasing with increase in speed limit in all the SPFs except for rural section SPFs. For rural sections no particular trend was observed to exist between the total number of crashes and speed limit.

Table 5-5: SPFs for Total Crashes by Each Category

Total Crashes										
Parameter		0.5 miles<total length <= 1.25 miles			1.25 miles <total length <= 3 miles			> 3 miles		
		Urban	Sub Urban	Rural	Urban	Sub Urban	Rural	Urban	Sub Urban	Rural
		Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
Intercept		-6.596	-8.641	-4.118	-9.510	-8.909	-15.088	-8.163	-10.317	-7.308
log(ADT)		0.992	1.146	0.680	1.278	1.171	1.392	1.128	1.295	0.974
log(length)		0.931	0.854	1.138	1.009	0.934	1.282	1.243	0.915	0.806
speed limit	65	-	0.207	-1.790	-	-1.013	2.574	-	-0.450	-0.650
speed limit	60	-	-1.886	-0.829	-1.232	-1.370	3.005	-	-1.122	-0.872
speed limit	55	-1.783	-0.837	-0.729	-1.396	-0.690	2.67	-1.084	-0.617	-0.542
speed limit	50	-1.372	-0.324	0.337	-1.01	-0.187	2.818	-1.104	-0.022	-0.987
speed limit	45	-0.585	-0.126	0	-0.446	-0.158	3.520	-0.575	0.106	0
speed limit	40	0	0	-	0	0	0	0	0	-
# of lanes	6	0.268	0.245	-0.092	-	-	-	-	-	-
# of lanes	5	0.554	0.110	-	-	-	-	-	-	-
# of lanes	<4	0	0	0	-	-	-	-	-	-
Dispersion		0.454	0.466	0.650	0.311	0.237	0.419	0.250	0.416	0.232

(Base cases for the variables measured on nominal scale are highlighted)

5.2.2 Severe Crashes

5.2.2.1 Urban Multi-Lane Roads

5.2.2.1.1 Section Lengths Ranging from (0.5, 1.25] Miles

SPFs for severe (incapacitating and fatal) crashes are developed using SAS. The starting variables considered for these models are the number of lanes, speed limit, *adt*, and section length. Table 5-6 shows the model statistics and parameter estimates for the model. It was found that the number of lanes is not a significant variable at a significance level of 0.05. The coefficient of *adt* is almost equal to 1 implying that the frequency of severe crashes is somehow linearly related to *adt* when all other parameters are kept constant. The ratio of deviance to *df* is 1.1131, which is close to 1, implying that the model fits the data properly. The value of dispersion indicates that the data is dispersed and therefore supports the use of negative binomial regression modeling.

Table 5-6: SPF for Severe Crashes on Urban Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	365	406.2873	1.1131
Pearson Chi-Square	365	404.5762	1.1084
Log Likelihood		-78.4331	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-9.5065	1.1175	-11.6968	-7.3162	72.36	<.0001
Log(ADT)		1	1.0218	0.1092	0.8077	1.2359	87.5	<.0001
Log(length)		1	1.1304	0.2047	0.7292	1.5316	30.5	<.0001
Speed limit	55	1	-1.3403	0.6629	-2.6395	-0.041	4.09	0.0432
Speed limit	50	1	-0.4658	0.2656	-0.9863	0.0547	3.08	0.0794
Speed limit	45	1	-0.2335	0.1136	-0.4562	-0.0109	4.23	0.0398
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.3959	0.0756	0.2478	0.544		

5.2.2.1.2 Section Lengths Ranging from (1.25, 3.00] Miles

Table 5-7 shows the parameter estimates and the goodness of fit statistics for the SPF. It can be seen from the model that *adt*, section length, and speed limit are the only significant variables for the model.

Table 5-7: SPF for Severe Crashes on Urban Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	335	375.6139	1.1212
Pearson Chi-Square	335	397.3013	1.186
Log Likelihood		1760.1612	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-10.3655	0.9895	-12.3049	-8.4261	109.74	<.0001
Log(ADT)		1	1.1079	0.0956	0.9206	1.2952	134.41	<.0001
Log(length)		1	0.9128	0.1645	0.5903	1.2352	30.79	<.0001
Speed limit	60	1	-1.8584	1.0552	-3.9265	0.2098	3.1	0.0782
Speed limit	55	1	-0.2569	0.2719	-0.7897	0.276	0.89	0.3448
Speed limit	50	1	-0.5672	0.1648	-0.8903	-0.2441	11.84	0.0006
Speed limit	45	1	-0.1013	0.083	-0.264	0.0615	1.49	0.2225
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.3088	0.0404	0.2296	0.3881		

5.2.2.1.3 Section Lengths Ranging from (3.0, 9.00] Miles

Negative binomial regression models were fit to the data using SAS. Table 5-8 shows the model parameter estimates and goodness of fit statistics for the model. It is interesting to note that for this length range neither speed limit nor number of lanes were significant. From the model it can be said that for the sections with same *adt*, the severe crashes increase with the increase in the length of the section.

Table 5-8: SPF for Severe Crashes on Urban Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit							
Criterion	**DF**	**Value**	**Value/DF**				
Deviance	153	169.6614	1.1089				
Pearson Chi-Square	153	169.7844	1.1097				
Log Likelihood		3575.5041					
Analysis Of Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1	-6.7843	1.0998	-8.94	-4.6287	38.05	<.0001
Log(ADT)	1	0.757	0.1023	0.5564	0.9575	54.74	<.0001
Log(length)	1	1.0069	0.1761	0.6618	1.352	32.7	<.0001
Dispersion	1	0.1961	0.0325	0.1324	0.2598		

5.2.2.2 Sub-Urban and Rural Multi-lane Roads

Table 5-9 shows the summary of all the models including urban roads for severe crashes. Detailed SAS output for all the models is presented in the Appendix.

It is worth mentioning that the number of severe crashes was very low for rural sections of lengths 0.5 to1.25 miles. To ensure that a meaningful sample size is available to estimate the negative binomial regression models rural sections of lengths between 0.5 and 1.25 miles were combined with the suburban sections of the same length groups (hence identical coefficients in corresponding rows of Table 5-9). Except for urban sections with less than 3 miles, in all other SPFs speed limit was found not to be significant in the models for severe crashes. Number of lanes is found not to be significant in all the SPFs.

Table 5-9: SPFs for Severe Crashes by Each Category

Parameter		Severe Crashes								
		0.5 miles<total length <= 1.25 miles			1.25 miles <total length <= 3 miles			> 3 miles		
		Urban	Sub Urban	Rural	Urban	Sub Urban	Rural	Urban	Sub Urban	Rural
		Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
Intercept		-7.258	-6.446	-6.446	-7.531	-9.967	-8.763	-6.670	-10.862	-9.018
log(ADT)		1.022	0.684	0.684	1.108	1.016	0.903	0.757	1.118	1.017
log(length)		1.130	0.592	0.592	0.903	1.191	0.887	1.007	0.865	0.301
speed limit	65	-	-	-	-	-	-	-	-	-
speed limit	60	-	-	-	-1.858	-	-	-	-	-
speed limit	55	-1.340	-	-	-0.257	-	-		-	-
speed limit	50	-0.466	-	-	-0.567	-	-		-	-
speed limit	45	-0.234	-	-	-0.101	-	-		-	-
speed limit	40	0	-	-	0	-	-		-	-
# of lanes	6		-	-		-	-	-	-	-
# of lanes	5		-	-		-	-	-	-	-
# of lanes	4		-	-		-	-	-	-	-
Dispersion		0.396	0.679	0.679	0.309	0.148	0.683	0.196	0.342	0.149

(Base cases for the variables measured on nominal scale are highlighted)

5.2.3 Rear-end Crashes

Rear-end crashes are the most common type of crashes. These crashes may be related to the skid resistance of the pavement. Table 5-10 shows the parameter estimates for rear-end crashes for each category. The detailed SAS output for all the models is presented in the Appendix of this report. It can be seen from the table that the number of lanes was not significant in any of the models. It can be seen from the table that the speed limit is significant in all the models except for urban and sub-urban with section lengths less than or equal to 3.0 miles.

Table 5-10: SPFs for Rear-end Crashes by Each Category

Parameter		Rear-end Crashes								
		0.5 miles<total length <= 1.25 miles			1.25 miles <total length <= 3 miles			> 3 miles		
		Urban	Sub Urban	Rural	Urban	Sub Urban	Rural	Urban	Sub Urban	Rural
		Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate	Estimate
Intercept		-14.688	-14.677	-13.214	-14.538	-15.328	-23.934	-12.203	-17.575	-14.816
log(ADT)		1.672	1.607	1.468	1.642	1.689	2.475	1.407	1.892	1.636
log(length)		0.824	0.696	0.851	1.174	0.905	0.855	1.197	0.845	0.829
speed limit	65	-	-	-2.761	-	-1.282	-	-	-0.602	-1.079
speed limit	60	-	-	-0.840	-1.602	-2.396	-	-	-1.403	-1.539
speed limit	55	-2.009	-	-0.733	-1.065	-0.646	-	-0.742	-0.399	-1.054
speed limit	50	-1.229	-	0.423	-0.903	-0.069	-	-0.761	0.221	-1.122
speed limit	45	-0.452	-	0	-0.348	0.014	-	-0.362	0.401	0
speed limit	40	0	-	-	0	0	-	0	0	-
# of lanes	6	-	-	-	-	-	-	-	-	-
# of lanes	5	-	-	-	-	-	-	-	-	-
# of lanes	4	-	-	-	-	-	-	-	-	-
Dispersion		0.450	0.793	1.232	0.287	0.324	0.726	0.231	0.534	0.299

(Base cases for the variables measured on nominal scale are highlighted)

5.3 SPFs for Intersections

Some of the projects identified involved only intersection improvements. Since crash patterns at intersection differ from that of a corridor, they were analyzed separately. As said earlier, 615 intersections from 5 counties across Florida were identified as the reference group. It was found that some of the intersections were on two-lane roads, which are not of interest for the present analysis, as the analysis focuses on multi-lane roads only. After eliminating the two-lane road intersections, the total number of intersections left for SPF formulation was 519. It should be noted that all the intersections were 4 legged signalized intersections. There were only few improvement projects which involved unsignalized intersections and the reference population for the unsignalized intersections was not available, hence unsignalized intersection improvements were not analyzed.

Crash data and roadway characteristics data for the above identified intersections were extracted from CAR and RCI databases. Only those crashes which occurred within a radius of 250 ft from the center of the intersection were considered as the crashes related to the intersection and were used for modeling SPFs. The improvements made on intersections will be analyzed for their resulting reductions in crashes for four types: total crashes, severe crashes, rear-end crashes, and angle crashes. Hence, SPFs were developed using the reference population for these four crash types. Table 5-11 shows the descriptive statistics for the reference group of intersections.

Table 5-11: Descriptive Statistics for Intersection Reference Population

Total number of Intersections = 519			
	Minimum	**Average**	**Maximum**
AADT (Major Road)	3500	41536.7	96000
Total Crashes	1	11.93	69
Severe Crashes	0	0.75	6
Rear-end Crashes	0	4.36	24
Angle Crashes	0	2.33	15

5.3.1 Total Crashes

Negative binomial models were fitted for the data using SAS. The explanatory variables considered for modeling were *aadt* on major road, speed limit on major road, number of through lanes on major road, and number through lanes on minor road. Among the variables considered, *aadt* was treated as continuous and the others were considered as categorical variables with speed limit on the major roadway having two levels (less than or equal to 40 and greater than 40 mph), number of lanes on major road having 4 levels (4, 5, 6, and 7), and number of lanes on minor road having 5 levels (2, 3, 4, 5, and 6). Although the traffic information for the minor road was available, it was not used in the model formulation as the data for the same was not available for the improvement projects.

Table 5-12 shows the model statistics and the parameter estimates. The ratio of deviance to *df* is nearly equal to 1, implying that the negative binomial model properly fit the data. It was found that the number of lanes on the major road was not a significant variable at a significance level of 0.05 for predicting the total number of crashes at the intersection. It can be seen from the model that as the number of lanes on the minor increase the total number of crashes increase this is likely because the number of lanes is an indicator of traffic volume. As the volume increases the likelihood of a crash increases and hence as the number of lanes increase the total number of crashes increase. It is interesting to find from the model that the total number of crashes decrease with increasing speed limit on the major road. The dispersion value of 0.4248 indicates that the data is dispersed and justifies the use of negative binomial regression for modeling the data.

Table 5-12: SPF for Total Crashes at 4- legged Signalized Intersections

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	544.0541	1.0605
Pearson Chi-Square	512	555.7536	1.0833
Log Likelihood		10351.95	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-4.6142	0.8459	-6.2722	-2.9563	29.75	<.0001
Log(AADT_major)		1	0.6603	0.0803	0.5029	0.8177	67.58	<.0001
# of through lanes minor	6	1	0.5005	0.2234	0.0626	0.9383	5.02	0.0251
# of through lanes minor	5	1	0.9251	0.4850	-0.0254	1.8757	3.64	0.0564
# of through lanes minor	3 or 4	1	0.4332	0.0673	0.3014	0.5651	41.46	<.0001
# of through lanes minor	2	0	0	0	0	0	.	.
Speed limit_major	>=45	1	-0.2187	0.0642	-0.3446	-0.0928	11.59	0.0007
Speed limit_major	<= 40	0	0.0000	0.0000	0.0000	0.0000	.	.
Dispersion		1	0.4248	0.0316	0.3628	0.4867		

5.3.2 Severe Crashes

As it is mentioned earlier, severe crashes here refer to two severity levels (fatal and incapacitating). In the similar way SPF were developed for severe crashes. Table 5-13 shows the parameter estimates and the goodness of fit statistics for the model. Number of lanes on major road was found not to be significant for severe crashes also. Unlike the total crashes severe crashes increase with increase of speed limit on major road. This can be explained by the fact that as the speed of the vehicle is high the likelihood of a severe injury in case of a crash increases, thus the expected number of severe crashes increases with increase in speed limit. From the goodness of fit statistics it can be seen that the value of deviance/*df* is 1.0493 which is nearly equal to one implying that the model properly fit the data.

Table 5-13: SPF for Severe Crashes at 4-legged Signalized Intersections

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	537.2204	1.0493
Pearson Chi-Square	512	518.7868	1.0133
Log Likelihood		-476.430	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-5.0971	1.442	-7.9234	-2.2709	12.49	0.0004
Log(AADT_major)		1	0.4233	0.136	0.1568	0.6899	9.69	0.0019
# of through lanes minor	6	1	-0.1775	0.436	-1.032	0.6771	0.17	0.684
# of through lanes minor	5	1	0.2057	0.7675	-1.2985	1.71	0.07	0.7886
# of through lanes minor	4	1	0.3885	0.1193	0.1547	0.6222	10.61	0.0011
# of through lanes minor	3	1	0.664	0.1917	0.2882	1.0398	11.99	0.0005
# of through lanes minor	2	0	0	0	0	0	.	.
Speed limit_major	>=45	1	0.3212	0.1089	0.1078	0.5346	8.71	0.0032
Speed limit_major	<= 40	0	0	0	0	0	.	.
Dispersion		1	0.1615	0.0937	-0.0221	0.3452		

It can be seen from the above two models that the total number of crashes were seen to be decreasing with increase in speed limit on the major road, whereas the number of severe crashes were found to be increasing with increase in speed limit. The total number crashes at intersections increased with increase in number of through lanes on the minor road, whereas severe crashes decreased with increase in number of through lanes on the minor road.

5.3.3 Rear-end Crashes

Rear-end and angle crashes are the most common types of crashes. Severe (here refers to fatal, incapacitating, and/or incapacitating injuries) rear-end crashes occur on roadway segment and intersection with nearly equal probability, hence this crash type was considered for analyzing the safety effect of improvements made on corridor level and intersection projects. Figure 5-2 shows the distribution of different crash types on all multi-lane arterials by severity and type.

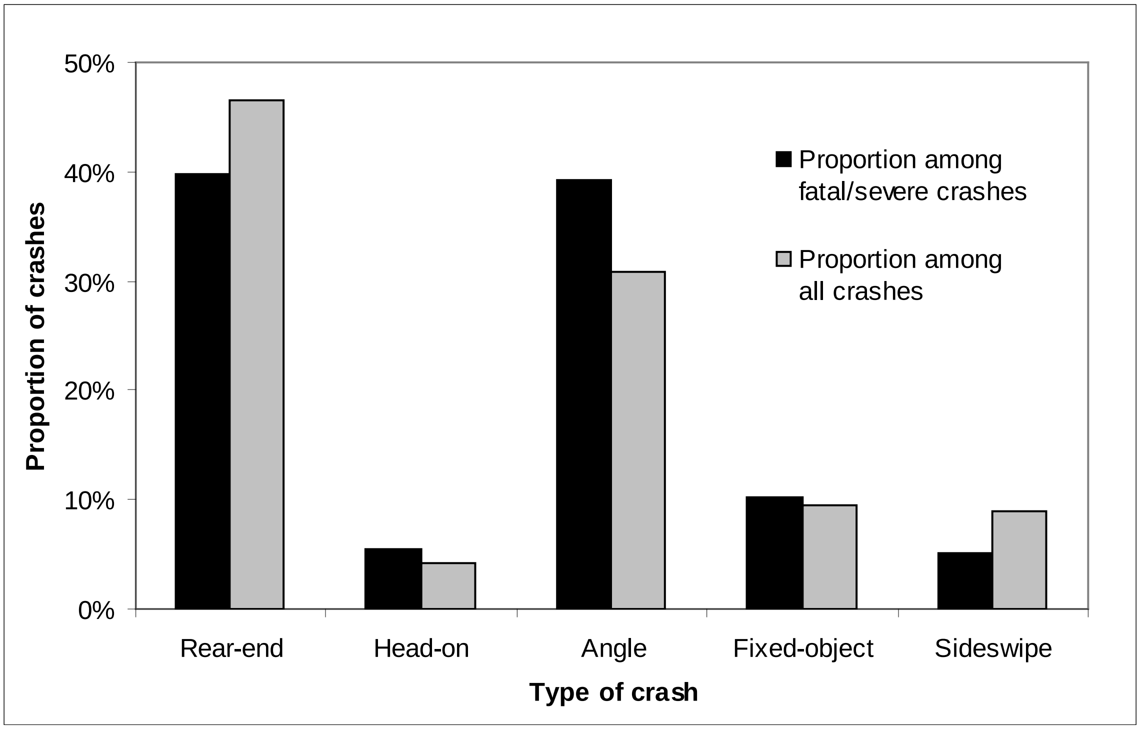


Figure 5-2: Distribution of Crashes on Multi-lane Arterials by Severity and Type Characterized by First Harmful Event

Table 5-14 shows the parameter estimates and the goodness of fit statistics for the model fit for read-end crashes. The severe crashes at an intersection tend to increase with the increase in the number of lanes in the minor road and also with the increase in speed limit of the major road. The dispersion value indicates that the data is dispersed and justifies the use of negative binomial model fit for the data.

Table 5-14: SPF for Rear-end Crashes at 4-legged Signalized Intersections

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	580.9163	1.1346
Pearson Chi-Square	512	537.0849	1.049
Log Likelihood		1473.876	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-8.8668	1.0078	-10.842	-6.8916	77.41	<.0001
Log(AADT_major)		1	0.9468	0.0951	0.7604	1.1331	99.17	<.0001
# of through lanes minor	6	1	0.5445	0.2382	0.0776	1.0113	5.22	0.0223
# of through lanes minor	5	1	0.3582	0.5297	-0.6799	1.3963	0.46	0.4988
# of through lanes minor	4	1	0.4666	0.0798	0.3102	0.6231	34.16	<.0001
# of through lanes minor	3	1	0.4244	0.1478	0.1347	0.7141	8.24	0.0041
# of through lanes minor	2	0	0	0	0	0	.	.
Speed limit_major	>=45	1	0.1573	0.0718	0.0166	0.298	4.8	0.0285
Speed limit_major	<= 40	0	0	0	0	0	.	.
Dispersion		1	0.3987	0.0427	0.3151	0.4823		

5.3.4 Angle Crashes

As it is indicated earlier, angle crashes are among the most common types of crashes. It should also be noted that angle crashes are more common at intersections than on segments. It is also interesting to note that more than 70% of angle crashes occurring at intersections result in fatal, incapacitating or non-incapacitating injury. Figure 5-3 shows the distribution of fatal/capacitating/non-incapacitating crashes on multi-lane arterials by segment location and type characterized by first harmful event.

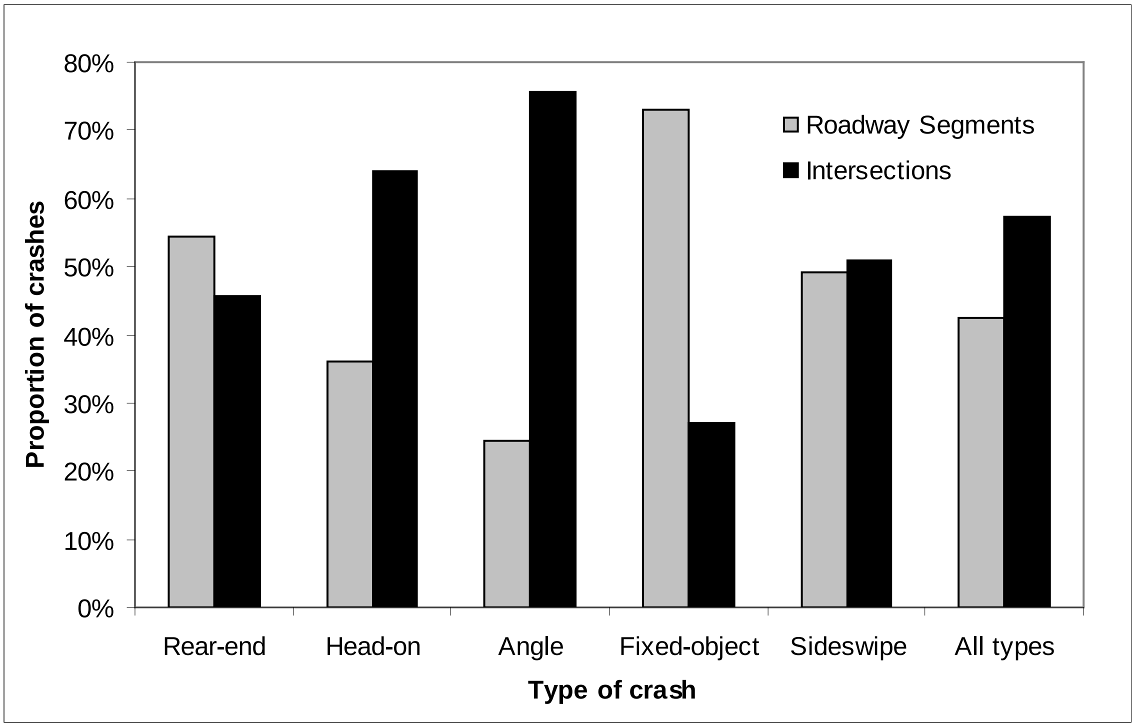


Figure 5-3: Distribution of Fatal/Severe Crashes on Multi-lane Arterials by Segment Location and Type Characterized by First Harmful Event

Table 5-15 shows the parameter estimates and the goodness of fit statistics for the model fit for angle crashes. It can be seen from the model that angle crashes decrease with increase in speed limit of the major road. The next chapter discusses the application of the EB method to the projects and the results.

Table 5-15: SPF for Angle Crashes at 4-legged Signalized Intersections

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	512	577.3064	1.1276
Pearson Chi-Square	512	545.5673	1.0656
Log Likelihood		-26.9209	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-4.5284	1.2235	-6.9265	-2.1303	13.7	0.0002
Log(AADT_major)		1	0.5022	0.1159	0.275	0.7293	18.78	<.0001
# of through lanes minor	6	1	0.2921	0.3098	-0.315	0.8993	0.89	0.3456
# of through lanes minor	5	1	0.849	0.6322	-0.3901	2.0882	1.8	0.1793
# of through lanes minor	4	1	0.3744	0.0994	0.1797	0.5691	14.2	0.0002
# of through lanes minor	3	1	0.5749	0.182	0.2182	0.9316	9.98	0.0016
# of through lanes minor	2	0	0	0	0	0	.	.
Speed limit_major	>=45	1	-0.2655	0.0909	-0.4437	-0.0874	8.53	0.0035
Speed limit_major	<= 40	0	0	0	0	0	.	.
Dispersion		1	0.5637	0.069	0.4284	0.6989		

CHAPTER 6. ANALYSIS AND RESULTS

The projects used for preliminary analysis of treatments` safety effectiveness included two-lane roads. Since this study focuses only on multi-lane arterials, the two lane roads were excluded for the final analysis. Also only those corridor level improvement projects are considered for final analysis, which have a minimum length of 0.5 miles. After excluding the projects with the above criteria, we were left with 182 projects (162 Corridor level and 20 intersection improvement). Tables 6-1 and 6-2 show the number of corridor level and intersection improvement projects respectively by major work type. It can be seen from the table that out of the 162 corridor level improvement projects, most of them (136 projects) have their major work as resurfacing and the rest 26 had improvements such as adding lanes, rigid pavement rehabilitation, etc.

Table 6-1: Corridor Level Improvement Projects by Major Work

Corridor Level Improvement Projects		
Type of Improvement	**Code**	**Number of Projects**
Add Lanes & Reconstruct	**2**	16
Rigid Pavement Rehabilitation	**19**	2
Construct/reconstruct Median	**24**	3
Skid Hazard Overlay	**28**	2
Bike Path/trail	**30**	1
Flexible Pavement Reconstruct.	**31**	2
Resurfacing	**1**	136
Total		162

Table 6-2: Intersection Projects by major work

Intersection Projects		
Type of Improvement	**Code**	**Number of Projects**
Add Turn Lane(s)	**6**	4
Add Left Turn Lane(s)	**10**	6
Drainage Improvements	**15**	1
Traffic Signals	**20**	4
Add Right Turn Lane(s)	**23**	1
Resurfacing	**1**	4
Total		20

6.1 Corridor Level Improvement Projects

6.1.1 Improvement Projects with Major Work other than Resurfacing

The EB method explained above was applied for all the 26 corridor level improvement projects under consideration. The SPFs were used according to the project lengths for estimating the expected number of crashes at the treatment sites in the before period. Necessary correction factors were applied to obtain the predicted values in the after period. Using the equation shown in Chapter 4 the percent reductions in crashes for each crash type were calculated. Tables 6-3, 6-4, and 6-5 show the results of EB analysis for total, severe, and rear-end crashes respectively for all the improvement projects except for resurfacing. Tabulated information include length of section treated, major work involved, number of lanes, added lanes (if any), number of days in the before period, number days in the after period, mean *adt* in the before period, mean *adt* in the after period, crash frequency in the before period, crash frequency in the after period, speed limit and land-use (1=urban, 2- suburban, and 3-rural). The information also includes number of crashes in the before period estimated from SPF, weights used in EB estimation (Equation 4.2), EB estimate of crashes (Equation 4.1), adjustment factor for *adt* (Equation 4.5), adjustment factor for difference in period (Equation 4.6), EB estimates of number of crashes in after period (Equation 4.7), index of effectiveness of the treatment (Equation 4.8), percentage reduction in number of crashes (Equation 4.9), and variance of the estimated number of crashes obtained from EB. It can observed from the tables that the percentage reductions resulting from the treatment varied with the major work involved in the project and they also varied wit in the projects with the same major work. It can be seen from Table 6-3 that among the 26 projects only 5 had an increase in total crashes (i.e. negative values of percentage reductions). Similarly from Table 6-4, only 3 of the projects had an increase in severe crashes; from Table 6-5, only 4 of the projects had an increase in rear-end crashes.

Three overall indices of effectiveness (corresponding to total, rear-end and severe crashes) were estimated by equation (4-10). Based on these indices and the overall percentage reduction in the numbers of crashes were also calculated along with corresponding standard deviations. Tables 6-6, 6-7, and 6-8 show the overall indices of effectiveness obtained by EB method and also by naïve before after comparison for total, severe, and rear end crashes respectively. Although some of the projects did not have a reduction in the crashes, the overall percentage reductions for each type of improvement is positive, implying that the improvements are effective in reducing the number crashes (total, severe, and rear-end) or in other words the improvements are effective in improving the safety of the roadway section treated. Thus, it can be concluded that FDOT is doing a good job at incorporating the safety aspects in the general improvement projects. In other words, FDOT has been successful in improving the safety of the corridors in the improvement projects. It can be seen that the percentage reductions obtained by EB method are greater than those obtained by naïve before after comparison; it implies that the site selection for treatment is not based on a quick response to high crash frequencies observed, rather it is based on thorough analysis of the safety of the site and also accounting for regression to the mean phenomenon.

It is also worthwhile to note that the improvement projects presented in Tables 6-6 mostly included only the major work, very few of them had been treated with additional improvements, and hence the percentage reductions obtained from the EB analysis can also be used as crash reduction factors resulting from the improvement involved in the project.

Table 6-3: EB analysis for Total Crashes for All the Improvement Projects except for Resurfacing

ID	total_length	Major_Work(Code)	# of lanes	Added lanes	before_period (in days)	after_period (in days)	mean_before_sect_adt	mean_after_sect_adt	before_crash_freq	after_crash_freq	Speed limit	LandUse (1-urb, 2-suburb,3-rur)	SPF_total	weight_total	eb_total	adj_adt_total	adj_bef_aft_period	pred_Aft_total	ind_eff_total	percent_reduction_total	var_pred_Aft_total
1	1.284	2	4	2	615	552	38080	49500	9	7	55	2	19.88	0.112	11.73	1.36	0.898	14.32	0.46	53.966	18.95
2	1.004	2	4	2	1092	882	26349	29521	67	56	45	1	18.61	0.038	66.57	1.119	0.808	60.19	0.916	8.422	47.33
3	1.311	2	4	2	600	1591	41296	48213	72	95	50	2	36.86	0.065	71.26	1.199	2.652	226.5	0.418	58.239	2141.2
4	2.384	2	4	2	958	384	27725	27155	146	169	45	2	41.59	0.037	144.6	0.976	0.401	56.58	2.937	-193.692	8.34
5	3.321	2	4	2	734	657	32274	34463	131	98	60	2	22.35	0.051	126.6	1.089	0.895	123.4	0.788	21.195	111.25
6	2.509	2	4	2	930	528	40248	43473	113	78	65	3	30.98	0.029	112	1.113	0.568	70.79	1.087	-8.688	27.46
7	1.505	2	4	2	762	686	37000	34000	170	149	50	1	28.21	0.052	164.3	0.898	0.9	132.7	1.115	-11.471	82.17
8	0.888	2	4	2	1189	439	37122	38693	184	52	40	1	41.89	0.016	183.2	1.042	0.369	70.5	0.727	27.255	10.27
9	4.557	2	4	2	533	648	52816	49413	331	338	50	2	169.7	0.01	330.2	0.917	1.216	368.3	0.915	8.463	453.65
10	1.967	2	4	2	671	747	38535	43329	142	148	45	2	51.11	0.043	139.9	1.147	1.113	178.7	0.824	17.635	279.06
11	1.133	2	5	1	1007	700	52579	54377	148	64	40	1	129.2	0.006	149.3	1.034	0.695	107.3	0.591	40.897	55.08
12	0.986	2	4	2	378	1308	45250	47437	76	251	45	1	31.3	0.064	73.23	1.048	3.46	265.5	0.942	5.809	3269.72
13	0.639	2	4	2	1130	385	34503	40844	38	18	45	2	16.82	0.04	38.56	1.213	0.341	15.94	1.065	-6.514	2.62
14	3.141	2	4	2	754	647	58382	61303	164	116	45	2	126.4	0.009	164.9	1.065	0.858	150.7	0.765	23.54	124.79
15	0.666	2	4	2	653	719	27078	27619	28	45	40	2	14.99	0.074	27.91	1.023	1.101	31.44	1.39	-39.042	36.93
16	2.193	2	4	4	499	370	33500	32317	68	38	45	1	63.81	0.036	68.68	0.955	0.741	48.64	0.766	23.394	23.53
17	1.048	19	4	0	1043	711	22500	26500	201	121	40	1	29.74	0.025	198.1	1.176	0.682	158.8	0.757	24.281	99.55
18	0.93	19	6	0	847	1201	74333	79833	81	127	45	2	71.44	0.013	82.08	1.085	1.418	126.3	0.998	0.233	295.28
19	0.551	24	4	0	1616	480	33100	37500	62	28	55	2	6.945	0.065	59.96	1.154	0.297	20.55	1.303	-30.327	2.26
20	1.445	24	6	0	1473	458	49794	49776	202	49	40	1	108.7	0.007	203.7	1	0.311	63.31	0.762	23.802	6.07
21	2.037	24	6	0	1473	458	49600	49500	104	25	45	1	97.82	0.008	106.3	0.997	0.311	32.98	0.736	26.413	3.15
22	0.984	28	4	0	836	1319	22072	24219	72	118	45	2	14.58	0.06	69.67	1.112	1.578	122.3	0.958	4.221	353.78
23	2.897	28	4	0	1321	592	27136	27498	322	118	45	1	64.56	0.014	320.8	1.017	0.448	146.2	0.802	19.843	29.97
24	1.702	30	6	0	1448	416	54629	57413	343	52	45	2	67.19	0.016	341.8	1.06	0.287	104.1	0.495	50.51	9.5
25	1.25	31	4	0	1008	519	42438	47366	231	56	40	2	42.97	0.018	229	1.134	0.515	133.7	0.416	58.43	44.79
26	1.437	31	4	0	930	530	44524	51768	119	39	40	2	52.91	0.03	119.5	1.193	0.57	81.24	0.474	52.561	36.43

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in total number of crashes)

Table 6-4: EB analysis for Severe Crashes for All the Improvement Projects except for Resurfacing

ID	total_length	Major_Work(Code)	# of lanes	Added lanes	before_period(in days)	after_period (in days)	mean_before_sect_aadt	mean_after_sect_aadt	before_severe_frequency	after_severe_frequency	Speed limit	LandUse (1-urb, 2-suburb,3-rur)	SPF_severe	weight_severe	EB_severe	adj_adt_severe	adj_bef_aft_period	pred_Aft_severe	ind_eff_severe	percent_reduction_severe	var_pred_Aft_severe
1	1.284	2	4	2	615	552	38080	49500	1	2	55	2	2.8531	0.5828	3.219	1.3054	0.8976	3.7717	0.4775	52.254	2.16
2	1.004	2	4	2	1092	882	26349	29521	2	2	45	1	1.7135	0.3539	3.106	1.0933	0.8077	2.7431	0.5901	40.989	1.382
3	1.311	2	4	2	600	1591	41296	48213	14	7	50	2	3.1759	0.5626	9.06	1.1705	2.6517	28.12	0.2451	75.488	118.5
4	2.384	2	4	2	958	384	27725	27155	18	15	45	2	4.3193	0.372	15.52	0.9791	0.4008	6.0914	2.2323	-123.234	0.589
5	3.321	2	4	2	734	657	32274	34463	13	4	60	2	5.9658	0.1958	12.8	1.0761	0.8951	12.333	0.3045	69.552	9.202
6	2.509	2	4	2	930	528	40248	43473	13	4	65	3	5.104	0.1012	13	1.0721	0.5677	7.9131	0.4539	54.607	2.635
7	1.505	2	4	2	762	686	37000	34000	13	13	50	1	2.2623	0.43	9.441	0.9331	0.9003	7.9309	1.5292	-52.924	3.19
8	0.888	2	4	2	1189	439	37122	38693	14	1	40	1	2.3677	0.2669	12.32	1.0331	0.3692	4.6999	0.1841	81.594	0.501
9	4.557	2	4	2	533	648	52816	49413	30	21	50	2	13.61	0.1282	28.7	0.9282	1.2158	32.39	0.6314	36.865	35.96
10	1.967	2	4	2	671	747	38535	43329	6	4	45	2	4.7999	0.4322	7.22	1.1265	1.1133	9.0555	0.4157	58.434	8.088
11	1.133	2	5	1	1007	700	52579	54377	8	2	40	1	4.3609	0.1892	8.763	1.0267	0.6951	6.2542	0.2831	71.691	2.583
12	0.986	2	4	2	378	1308	45250	47437	6	15	45	1	2.5657	0.5138	4.282	1.0377	3.4603	15.377	0.9456	5.443	96.4
13	0.639	2	4	2	1130	385	34503	40844	1	2	45	2	1.5545	0.2341	1.892	1.1224	0.3407	0.7237	1.3426	-34.262	0.081
14	3.141	2	4	2	754	647	58382	61303	22	18	45	2	11.03	0.1136	22.09	1.0561	0.8581	20.018	0.8611	13.894	14.57
15	0.666	2	4	2	653	719	27078	27619	3	2	40	2	1.3495	0.3786	2.778	1.0136	1.1011	3.1008	0.5373	46.269	2.4
16	2.193	2	4	4	499	370	33500	32317	8	4	45	1	4.9643	0.3442	7.582	0.971	0.7415	5.4591	0.6541	34.586	1.856
17	1.048	19	4	0	1043	711	22500	26500	16	6	40	1	1.9305	0.3373	12.46	1.137	0.6817	9.6602	0.5812	41.876	3.846
18	0.93	19	6	0	847	1201	74333	79833	11	12	45	2	3.2835	0.1618	10.45	1.0501	1.418	15.564	0.7316	26.84	28.92
19	0.551	24	4	0	1616	480	33100	37500	10	3	55	2	1.384	0.1936	9.25	1.0892	0.297	2.9927	0.7897	21.035	0.253
20	1.445	24	6	0	1473	458	49794	49776	11	4	40	1	8.0641	0.0987	13.13	0.9997	0.3109	4.08	0.803	19.7	0.355
21	2.037	24	6	0	1473	458	49600	49500	16	2	45	1	9.7376	0.0831	17.94	0.9984	0.3109	5.5678	0.3084	69.158	0.492
22	0.984	28	4	0	836	1319	22072	24219	1	3	45	2	1.4786	0.3028	1.723	1.0656	1.5778	2.8962	0.8349	16.513	5.707
23	2.897	28	4	0	1321	592	27136	27498	21	6	45	1	5.4119	0.1539	20.78	1.0109	0.4482	9.4153	0.5847	41.528	1.635
24	1.702	30	6	0	1448	416	54629	57413	28	3	45	2	5.7596	0.2272	26.83	1.0518	0.2873	8.1073	0.3378	66.217	0.572
25	1.25	31	4	0	1008	519	42438	47366	21	5	40	2	2.6654	0.1665	18.73	1.0781	0.5149	10.396	0.4453	55.475	2.67
26	1.437	31	4	0	930	530	44524	51768	10	0	40	2	3.8244	0.408	9.896	1.1655	0.5699	6.573	0	100	1.717

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in severe of crashes)

Table 6-5: EB analysis for Rear-end Crashes for All the Improvement Projects except for Resurfacing

ID	total_length	Major_Work(Code)	# of lanes	added_lanes	before_period(in days)	after_period (in days)	mean_before_sect_aadt	mean_after_sect_aadt	Speed limit	LandUse (1-urb, 2-suburb,3-rur)	rearend_before	rearend_after	SPF_rearend	weight_rearend	eb_rearend	adj_adt_rearend	adj_bef_aft_period	pred_Aft_rearend	ind_eff_rearend	percent_reduction_rearend	var_pred_Aft_rearend
1	1.284	2	4	2	615	552	38080	49500	55	2	3	1	7.9266	0.1877	4.944	1.5575	0.8976	6.911	0.12947	87.053	10.97
2	1.004	2	4	2	1092	882	26349	29521	45	1	14	8	6.5751	0.1014	14.575	1.2093	0.8077	14.236	0.52858	47.142	12.21
3	1.311	2	4	2	600	1591	41296	48213	50	2	28	35	16.487	0.1022	27.908	1.2991	2.6517	96.136	0.3607	63.93	1024.13
4	2.384	2	4	2	958	384	27725	27155	45	2	38	34	15.716	0.0696	38.226	0.9655	0.4008	14.794	2.16226	-116.23	2.06
5	3.321	2	4	2	734	657	32274	34463	60	2	85	52	5.3912	0.1472	74.081	1.1322	0.8951	75.077	0.68484	31.516	65.76
6	2.509	2	4	2	930	528	40248	43473	65	3	57	22	22.09	0.0239	56.983	1.2102	0.5677	39.152	0.54825	45.175	18.04
7	1.505	2	4	2	762	686	37000	34000	50	1	66	60	10.111	0.1416	59.643	0.8703	0.9003	46.733	1.26074	-26.074	24.63
8	0.888	2	4	2	1189	439	37122	38693	40	1	80	30	16.572	0.0395	78.973	1.0718	0.3692	31.251	0.93134	6.866	4.7
9	4.557	2	4	2	533	648	52816	49413	50	2	185	161	90.903	0.0139	184.27	0.8816	1.2158	197.5	0.81115	18.885	223.71
10	1.967	2	4	2	671	747	38535	43329	45	2	42	43	23.03	0.068	42.023	1.2191	1.1133	57.031	0.74185	25.815	97.91
11	1.133	2	5	1	1007	700	52579	54377	40	1	46	16	36.253	0.0217	47.172	1.0578	0.6951	34.688	0.4486	55.14	18.35
12	0.986	2	4	2	378	1308	45250	47437	45	1	31	132	16.001	0.1181	29.296	1.0821	3.4603	109.7	1.19369	-19.369	1356.51
13	0.639	2	4	2	1130	385	34503	40844	45	2	19	4	6.0797	0.0628	18.989	1.3115	0.3407	8.485	0.42453	57.547	1.59
14	3.141	2	4	2	754	647	58382	61303	45	2	65	39	96.052	0.0094	66.247	1.0968	0.8581	62.348	0.61574	38.426	54.71
15	0.666	2	4	2	653	719	27078	27619	40	2	13	11	4.2389	0.1425	12.228	1.0323	1.1011	13.899	0.74543	25.457	15.4
16	2.193	2	4	4	499	370	33500	32317	45	1	22	15	23.286	0.0986	22.97	0.9427	0.7415	16.055	0.88462	11.538	7.07
17	1.048	19	4	0	1043	711	22500	26500	40	1	65	31	8.2235	0.0863	61.42	1.3147	0.6817	55.045	0.55398	44.602	40.4
18	0.93	19	6	0	847	1201	74333	79833	45	2	29	47	27.111	0.0196	29.666	1.1216	1.418	47.179	0.97594	2.406	116.98
19	0.551	24	4	0	1616	480	33100	37500	55	2	8	9	5.1298	0.0526	8.773	1.2221	0.297	3.185	2.17799	-117.8	0.4
20	1.445	24	6	0	1473	458	49794	49776	40	1	83	14	38.735	0.0218	84.598	0.9994	0.3109	26.288	0.51345	48.655	2.48
21	2.037	24	6	0	1473	458	49600	49500	45	1	42	9	40.676	0.0208	44.537	0.9967	0.3109	13.802	0.60887	39.113	1.3
22	0.984	28	4	0	836	1319	22072	24219	45	2	26	43	4.0053	0.1208	23.968	1.1609	1.5778	43.899	0.9603	3.97	129.48
23	2.897	28	4	0	1321	592	27136	27498	45	1	102	39	22.849	0.0404	101.22	1.022	0.4482	46.36	0.82418	17.582	9.33
24	1.702	30	6	0	1448	416	54629	57413	45	2	161	29	36.432	0.0209	160.66	1.0876	0.2873	50.198	0.56666	43.334	4.8
25	1.25	31	4	0	1008	519	42438	47366	40	2	80	21	13.531	0.0326	78.609	1.1931	0.5149	48.291	0.42633	57.367	17.63
26	1.437	31	4	0	930	530	44524	51768	40	2	26	4	21.816	0.0526	27.556	1.29	0.5699	20.259	0.18863	81.137	10.37

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in rear-end of crashes)

Table 6-6: Overall Index of Effectiveness for Total Crashes

Type of Improvement	Number of Projects	overall index of effectiveness for total crashes(Naïve Before-After)	Percentage Reduction in Total Crashes(Naïve Before-After)	overall index of effectiveness for total crashes(EB)	Percentage Reduction in Total Crashes(EB)	Standard Deviation(Index of effectiveness for total crashes) (EB)
Add Lanes & Reconstruct	16	0.987011786	1.298821378	0.8945	10.55	0.04372
Rigid Pavement Rehabilitation	2	0.966025936	3.397406384	0.86556	13.444	0.08141
Construct/reconstruct Median	3	0.893542175	10.64578254	0.87222	12.778	0.08995
Skid Hazard Overlay	2	0.875437067	12.45629334	0.87435	12.565	0.08527
Bike Path/trail	1	0.527694567	47.23054325	0.49914	50.086	0.07075
Flexible Pavement Reconstruct.	2	0.508177982	49.18220176	0.44114	55.886	0.04885

Table 6-7: Overall Index of Effectiveness for Severe Crashes

Type of Improvement	Number of Projects	overall index of effectiveness for severe crashes(Naïve Before-After)	Percentage Reduction in Severe Crashes(Naïve Before-After)	overall index of effectiveness for severe crashes	Percentage Reduction in Severe Crashes(EB)	Standard Deviation(Index of effectiveness for severe crashes)(EB)
Add Lanes & Reconstruct	16	0.744121253	25.58787474	0.69134	30.866	0.09605
Rigid Pavement Rehabilitation	2	0.650870406	34.91295938	0.67865	32.135	0.21654
Construct/reconstruct Median	3	0.788826816	21.11731844	0.70713	29.287	0.24207
Skid Hazard Overlay	2	0.725961538	27.40384615	0.69725	30.275	0.272
Bike Path/trail	1	0.372521246	62.74787535	0.36684	63.316	0.21362
Flexible Pavement Reconstruct.	2	0.305290546	69.47094536	0.29023	70.977	0.13363

Table 6-8: Overall Index of Effectiveness for Rear-end Crashes

Type of Improvement	Number of Projects	overall index of effectiveness for rear-end crashes(Naïve Before-After)	Percentage Reduction in Rear-end Crashes(Naïve Before-After)	overall index of effectiveness for rear-end crashes	Percentage Reduction in Rear-end Crashes(EB)	Standard Deviation(Index of effectiveness for rear-end crashes)(EB)
Add Lanes & Reconstruct	16	0.837553199	16.24468008	0.80115	19.885	0.06107
Rigid Pavement Rehabilitation	2	0.856980704	14.30192963	0.75171	24.829	0.12458
Construct/reconstruct Median	3	0.767846248	23.21537523	0.73781	26.219	0.13485
Skid Hazard Overlay	2	0.909182899	9.081710094	0.89328	10.672	0.15145
Bike Path/trail	1	0.626909808	37.30901922	0.57662	42.338	0.10989
Flexible Pavement Reconstruct.	2	0.447281082	55.27189175	0.36254	63.746	0.07749

6.1.2 Improvement Projects with Major Work as Resurfacing

Applying the same approach explained in previous section, the EB method was applied for all the 136 resurfacing projects under consideration. From Equation 4-10 three overall indices of effectiveness (corresponding to total, rear-end and severe crashes) were estimated. Table 6-9 shows the indices of effectiveness estimated by both EB method and naïve before-after comparison.

Table 6-9: Overall Indices of Effectiveness for Resurfacing Projects by Crash Type

Total Number of Projects =136					
	Overall index of effectiveness (Naïve Before-After)	Percentage Reduction (Naïve Before-After)	Overall Index of Effectiveness(EB)	Percentage Reduction(EB)	Standard Deviation of Index of effectiveness(EB)
Total Crashes	1.02841	-2.841	1.00625	-0.625	0.01627
Severe Crashes	0.9392	6.077	0.95367	4.633	0.045801
Rear-end Crashes	1.0319	-3.1881	0.9917	0.83	0.026491

The results showed an estimated increase of 0.62% in total number of crashes at the treatment sites. Rear-end crashes were reduced by an estimate of 0.83 % and severe crashes were reduced by an estimate of 4.63%. It is important to note that while there was a significant reduction in severe as well as rear-end crashes; the estimates from individual projects varied widely. It can be seen from the table that the results from the naïve before-after and EB method differed, naïve before-after comparison either over-estimated or under-estimated the percentage reduction of crashes for each crash type. Had the EB method not been used, the safety effectiveness of resurfacing would have been wrongly estimated.

It was observed that most of the resurfacing projects involved some of the additional improvements listed in Chapter 3; it became of interest to study these resurfacing projects and analyze the impact of additional improvements included along with resurfacing on the safety of the site treated. Table 6-10 shows the percentage of 136 resurfacing projects involving each of the additional improvements. With percentage reduction in crashes for each site (for each crash type), the worst 25% and best 25% projects in terms of their performance in the crash reduction are selected and analyzed for different type of additional treatments involved in the projects. Based on the analysis conclusions will be drawn on which additional improvements are better in terms of improving safety.

Table 6-10: Percentage of Projects Involving Each of the Additional Improvements

Type of Improvement	% of projects
Add lane	0.7
median widening	3.7
Add shoulder	4.4
Signal Installation	5.1
Access Improvement	5.1
Guardrail Installation	6.6
Add Right turn lane	8.8
Add left turn lane	10.3
Guardrail Improvement	13.2
Lighting Improvement	14.7
Pave Shoulder	16.9
Sidewalk	23.5
Widening	31.6
Drainage Improvement	40.4
Signal Update	43.4

The next step was to examine the results for individual projects. Table 6-11 shows a sample of results (for 14 (~10%) out of the total 136 projects) based on total crashes. Appendix B provides EB results for all the projects. Tabulated information includes length of the section resurfaced, binary variables indicating presence of additional treatments, observed number of total crashes in the after period, EB estimate of total crashes in the after period (had no treatment been applied) along with index of effectiveness and estimated percentage reduction in total crashes.

Table 6-11: Sample Results from EB Method for Total Crashes

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	After crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
1	5.45	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	158	117.2	1.34	-33.7
2	0.93	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	61	44.9	1.33	-32.9
3	0.66	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	5	2.9	1.32	-31.6
4	3.87	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	457	348.1	1.31	-30.9
5	2.47	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	46	34.5	1.30	-29.9
6	4.44	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	89	68.9	1.27	-27.4
7	2.07	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	10	17.7	0.54	46.2
8	1.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	39	72.5	0.53	46.8
9	1.23	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	79	185.1	0.42	57.5
10	1.25	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	9	21.0	0.41	58.9
11	1.63	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	35	86.0	0.40	59.8
12	2.89	0	0	0	1	0	1	0	1	1	1	0	0	0	0	0	4	11.2	0.33	66.9
13	0.77	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	1	2.3	0.31	69.3
14	0.94	1	0	0	0	0	0	0	1	1	1	0	1	0	0	0	7	28.6	0.24	76.3

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in total number of crashes)

Of the 136 projects under consideration, 57.35% of them had a reduction in the total number of crashes, 71.32 % of them had a reduction in the number of severe crashes, and 59.56 % had a reduction in number of rear-end crashes. Figure 6-1 shows the scatter plot of percentage reduction in total crashes for each project plotted against their respective section lengths. It can be seen from the plot the there is no correlation between the percentage reduction and the section length. It was also found that the reductions in severe and rear-end crashes were also not correlated with the lengths of the segment resurfaced.

The percentage reductions in the number of crashes were used to identify the best and worst 25% projects based on each crash type. Note that some of the project sites in the bottom quartile (i.e., worst 25% projects) actually observed higher crashes after improvement (based on actual 'after' crash frequency); compared to the estimated number that would have occurred had the resurfacing not been carried out. To examine the effects of the additional improvements (listed in Table 6-10), proportions of projects with a particular improvement were calculated among best 25% and worst 25% projects. These two proportions were then compared with proportion of projects with that particular improvement in all (i.e., 136) projects.

Bar charts were created to display comparisons among these three proportions. Figures 6-2, 6-3 and 6-4 correspond to total, severe, and rear-end crashes, respectively. If the proportion of projects involving a particular improvement in best 25% is more than the proportion of projects involving the same treatment in worst 25% as well as all projects (i.e., 136 total project being evaluated); then the improvement/treatment can be considered to be a good practice to go along with resurfacing. For example, in terms of total crashes (Figure 6-2) the proportions of resurfacing projects with lighting improvements in the best and worst quartiles are 33% and 6%, respectively. It implies that resurfacing projects with accompanying lighting improvements are more likely to lead to reduction in overall crashes. Using this logic it can be inferred that signal installation, guardrail improvement, drainage improvement, adding turn lanes (left and/or right), and access improvement are good practices, which when executed along with resurfacing are likely to lead to reduction in total crashes. Note that for all these improvements the bar corresponding to (best 25%) is higher in Figure 6-2 compared to the bar corresponding to (worst 25%). Similarly, for severe crashes guardrail improvement and lighting improvement appear to be good candidates for additional improvements to be carried out with resurfacing (see Figure 6-3). For rear-end crashes, guardrail improvement, shoulder paving, drainage improvement, adding right or left turn lane, lighting improvement, and access improvement may be considered good practices (see Figure 6-4).

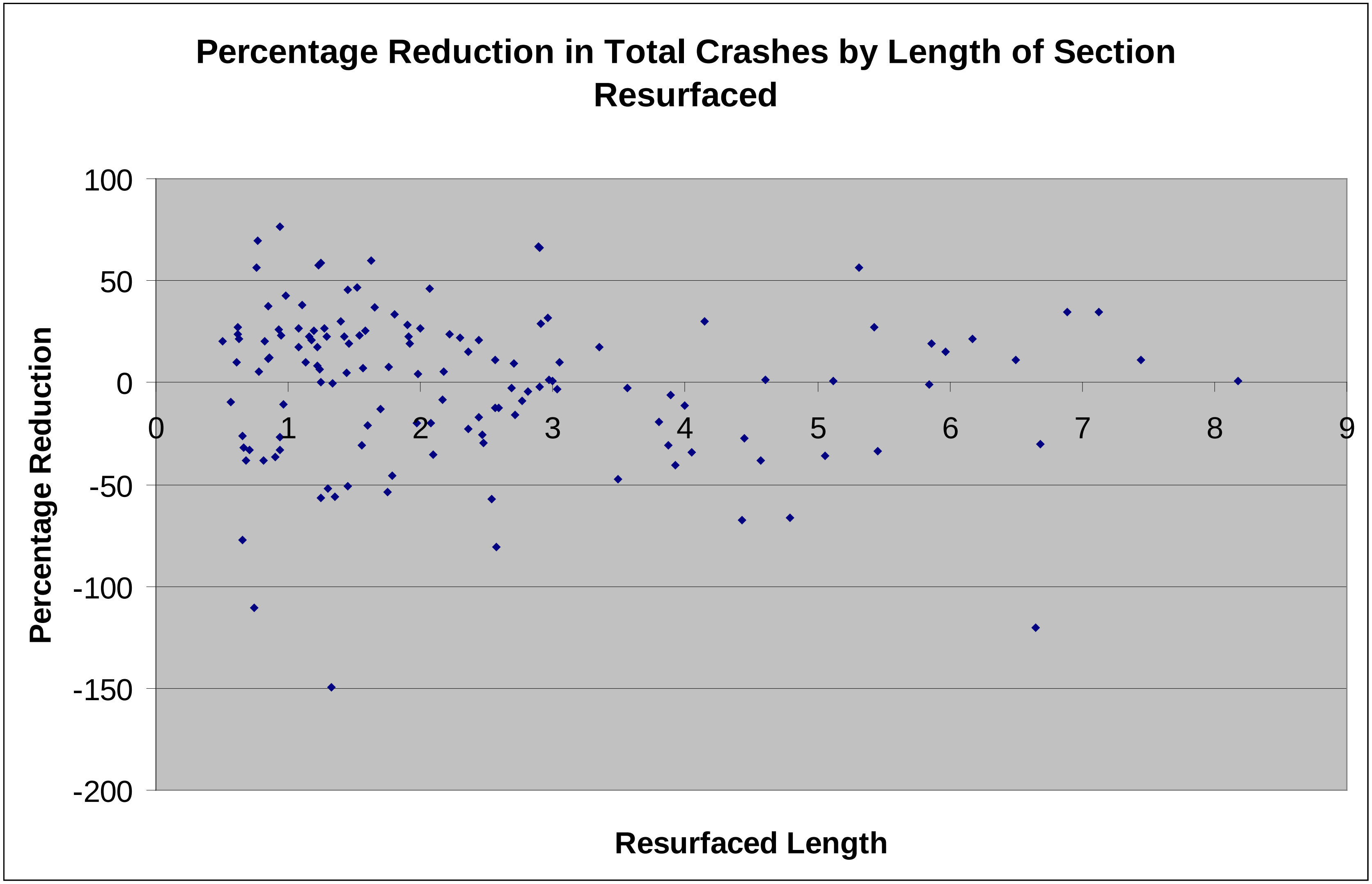


Figure 6-1: Percentage Reduction in Total Crashes by Length of the Section Resurfaced

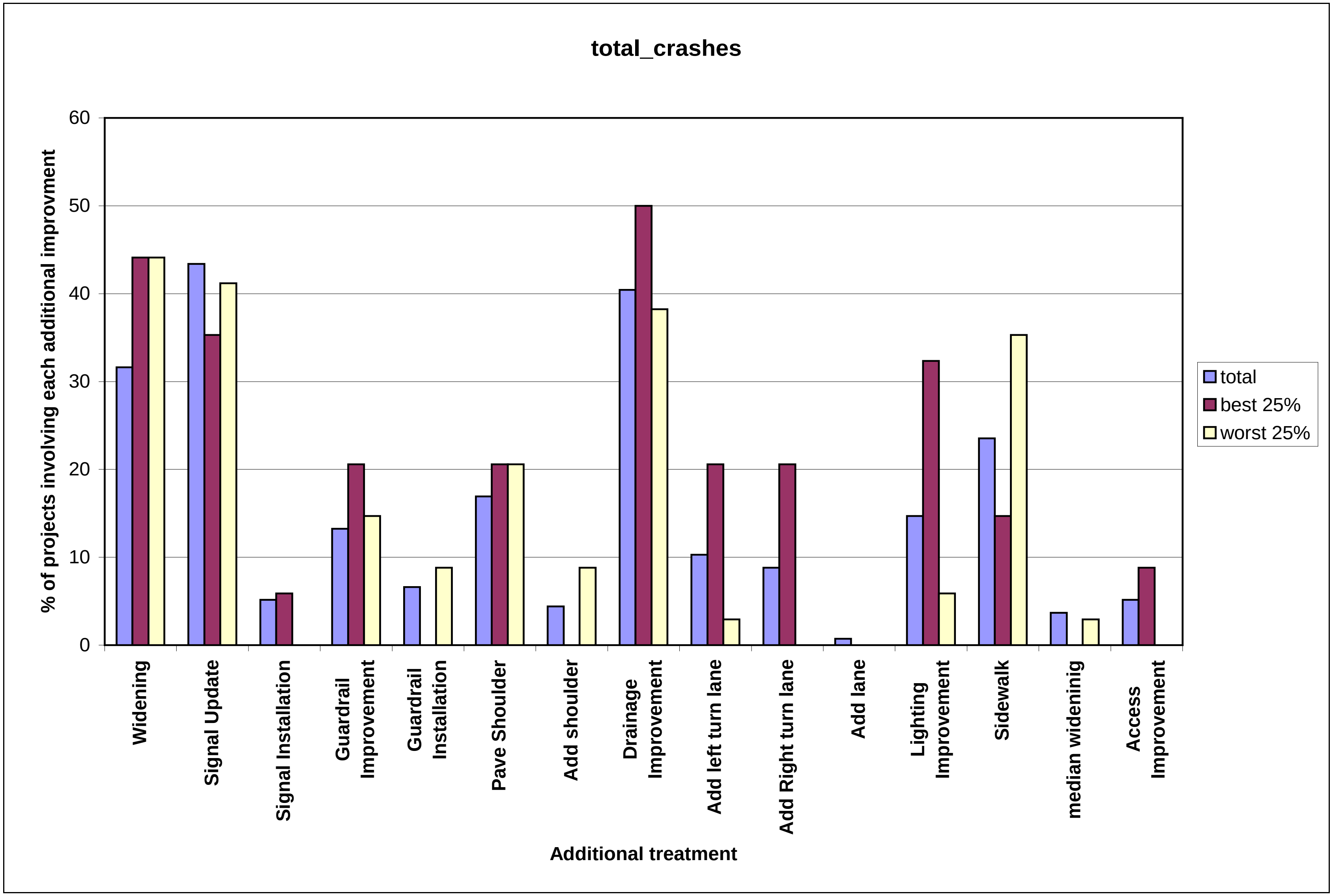


Figure 6-2: Comparison of Proportions (of project with each additional improvement) in Best 25%, Worst 25%, and All (100%; 136) Projects in Terms of Changes in Total Crashes

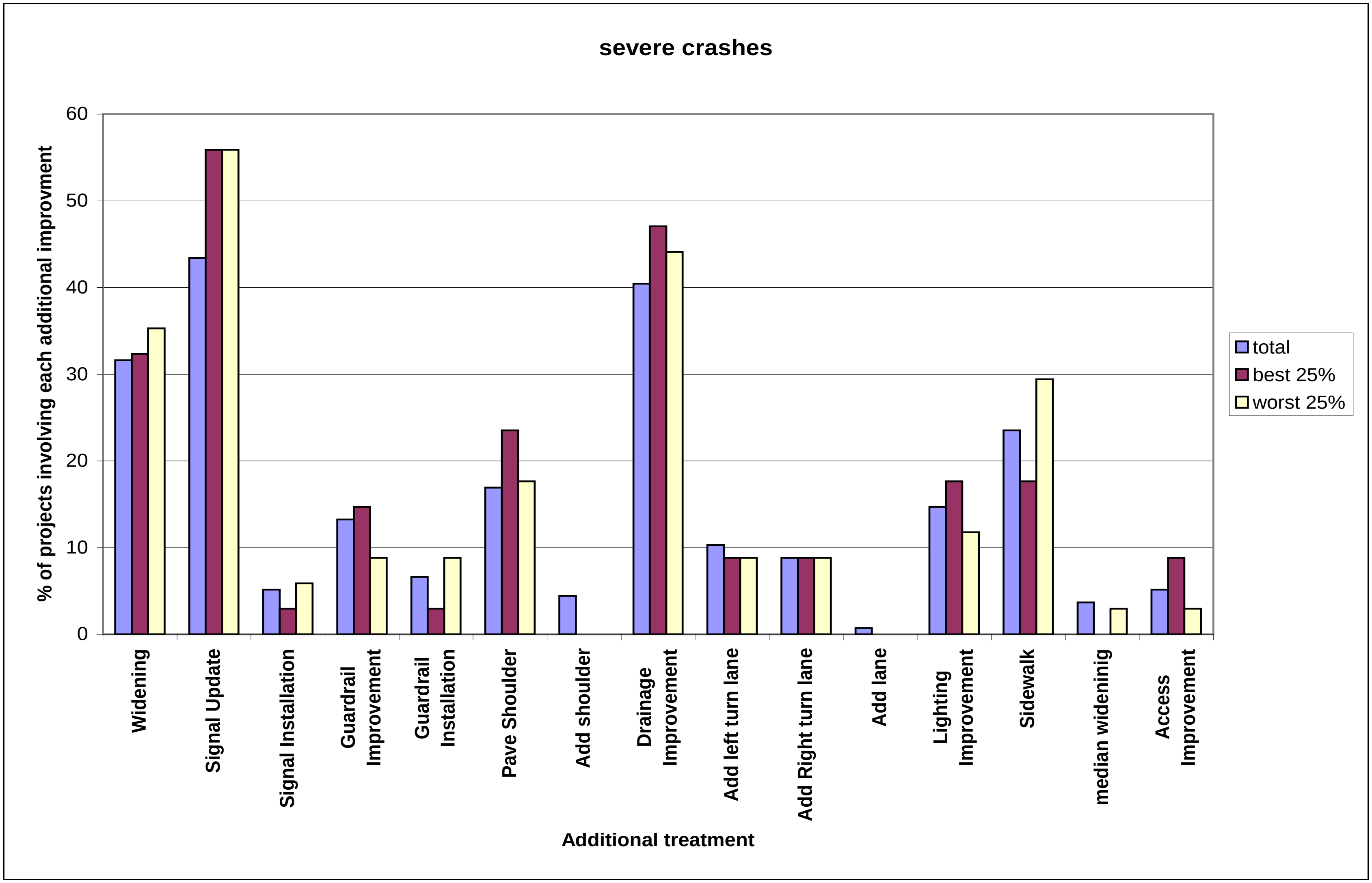


Figure 6-3: Comparison of Proportions (of project with each additional improvement) in Best 25%, Worst 25%, and Overall (100%; 136) Projects in Terms of Changes in Severe Crashes

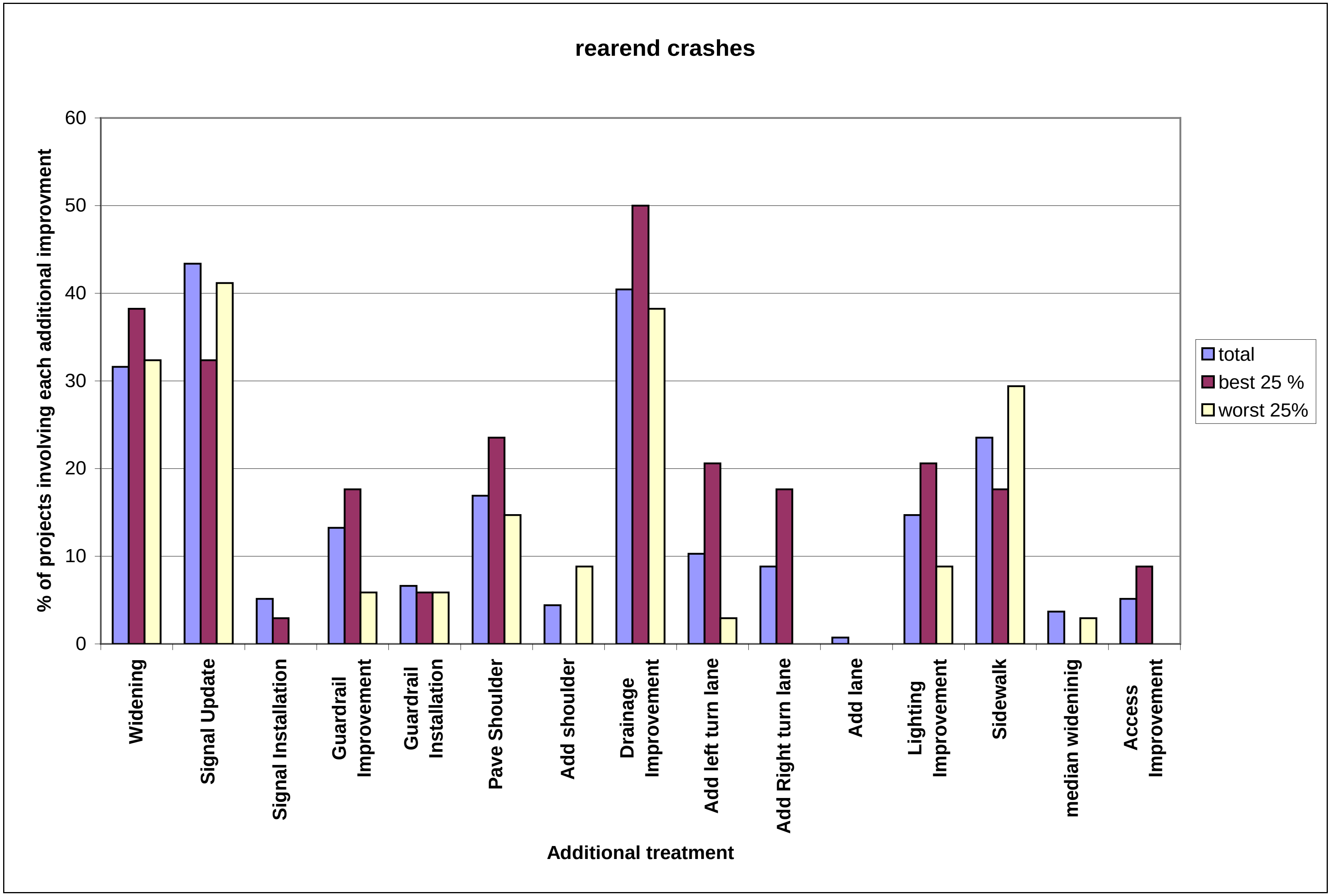


Figure 6-4: Comparison of Proportions (of project with each additional improvement) in Best 25%, Worst 25%, and Overall (100%; 136) Projects in Terms of Changes in Rear-end Crashes

It is worth noting that the results shown in the Figures 6-2 to 6-4 are for better visual understanding with no statistical significance attached to them. Therefore, these preliminary comparisons between additional improvements were followed up with statistical tests to see if certain improvements are indeed associated with increased likelihood of a project being part of best or worst 25% groups. The Fisher's exact test is based on the frequency of cells in (2 X 2) contingency tables. One-sided Fisher's test (carried out separately for each of the additional improvement) evaluates whether the presence of a particular improvement in a project increases the likelihood of that project falling in the best 25%. Similar tests are also done for worst 25%. The null hypothesis for this test is that there is no association between presence of an improvement with the project falling in best 25 % or worst 25%. The low p-values indicate sufficient evidence for rejection of the null hypothesis.

Table 6-12 show the results of the Fisher's exact test. If an improvement has a low p-value corresponding to best 25% and high p-value corresponding to worst 25% then it may be considered a good improvement in terms of that corresponding crash group. If both p-values are either low or if both of them are high then no inference can be made. Additional improvements with low p-value (i.e., <=0.15) corresponding to best 25% and high p-value (>0.15) corresponding to worst 25% have been highlighted in light shade indicating improvements with a positive impact on safety. Similarly, improvements with low p-value (i.e., <=0.15) corresponding to worst 25% and high p-value (>0.15) corresponding to best 25% have been highlighted in dark shade indicating improvements that have a deteriorating impact on safety. Also, note that p-value of 1 in the table indicates that there were exactly zero projects involving corresponding improvement in the corresponding category (i.e., best25% or worst25%).

The results indicate that sidewalk is the only improvement that is associated with a project lying in the worst 25% (p-value 0.05) and not significantly associated with the project lying in the best 25% (p-value .95). It seems that none of the additional improvements carried out along with resurfacing have a significant impact on severe crashes. Paving shoulder and adding turn lanes (left and/or right) seem to be positively associated with projects being in best 25% in terms of rear-end crashes. Similarly guard rail improvements, drainage improvement, adding turn lanes (left and/or right), and lighting improvement are good practices in terms of all crashes.

Table 6-12: Fisher's Exact Test for Identifying the Best Practices with Resurfacing

Additional improvement	Total Crashes		Severe Crashes		Rear End Crashes	
	Fishers exact test		Fishers exact test		Fishers exact test	
	p-value best25%	p-value worst25%	p-value best25%	p-value worst25%	p-value best25%	p-value worst25%
Widening	0.06	0.06	0.54	0.32	0.19	0.54
Signal Update	0.90	0.69	0.07	0.10	0.94	0.69
Signal Installation	0.56	1.00	0.87	0.54	0.86	1.00
Guardrail Improvement	0.12	0.49	0.49	0.87	0.25	0.97
Guardrail Installation	1.00	0.40	0.93	0.38	0.69	0.71
Pave Shoulder	0.34	0.34	0.18	0.50	0.15	0.74
Add shoulder	1.00	0.16	1.00	1.00	1.00	0.16
Drainage Improvement	0.13	0.69	0.24	0.32	0.19	0.69
Add left turn lane	0.03	0.99	0.73	0.71	0.03	0.99
Add Right turn lane	0.01	1.00	0.62	0.59	0.04	1.00
Add lane	1.00	1.00	1.00	1.00	1.00	1.00
Lighting Improvement	0.00	0.98	0.38	0.91	0.17	0.93
Sidewalk	0.95	0.05	0.88	0.20	0.86	0.24
Median widening	1.00	0.77	1.00	0.76	1.00	0.77
Access Improvement	0.24	1.00	0.24	0.86	0.22	1.00

It is interesting to note that none of the additional improvements, other than sidewalk improvements, increases the likelihood of a project lying in the worst 25% projects. Consequently, it may be inferred that getting additional improvements done when roadway surface are being repaved may be a good approach especially if it is found to be cost-effective.

6.2 Intersection Improvements

Similar to the EB analysis of the corridor projects, SPFs were used first to estimate the number of crashes at the reference sites in the before period and then using Equation 4.1 and 4.2 crashes were estimated at the treated sites. The crash numbers thus estimated were adjusted for *aadt* and period difference between before and after periods to get the after period crashes at the treated sites had the treatment not been implemented. The values obtained from EB were then compared to the observed values using Equation 4.8 to obtain index of effectiveness of each treatment. Tables 6-13, 6-14, 6-15, and 6-16 show the results of EB analysis and the percentage reduction resulting from the treatments for four crash types: total, severe, rear-end, and angle. Tabulated information include major work involved, number of lanes on major road, added lanes (if any), number of lanes on minor road, number of days in the period, number days in after period, mean *adt* in before period, mean *adt* in after period, speed limit and land-use (1=urban, 2-suburban, and 3-rural). The tabulated information also include crash frequency in before period, crash frequency in after period, number of crashes in the before period estimated from SPF, weights used in EB estimation (Equation 4.2), EB estimate of crashes (Equation 4.1), adjustment factor for ADT (Equation 4.5), adjustment factor for difference in period (Equation 4.6), EB estimates of number of crashes in after period (Equation 4.7), index of effectiveness of the treatment (Equation 4.8), percentage reduction in number of crashes (Equation 4.9), and variance of the estimated number of crashes obtained from EB. It can be seen from the tables that the percentage reductions resulting from the treatment varied among the different treatment and also within the projects involving the same treatment. In most of the projects the percentage reduction is positive implying that the safety of the treated sites improved after the treatment. Only in few cases the safety deteriorated, 4 of 20 projects had an increase in total crashes, 5 projects had an increase in severe crashes, 4 projects had an increase in rear-end crashes, and 4 projects had an increase in angle crashes.

Four overall indices of effectiveness (corresponding to total, severe, rear-end and angle crashes) were estimated by equation (4-10). Based on these indices and the overall percentage reduction in the numbers of crashes were also calculated along with corresponding standard deviations. Tables 6-17, 6-18, 6-19, and 6-20 show the overall indices of effectiveness obtained by EB method and also by naïve before after comparison for total, severe, rear-end, and angle crashes, respectively. Although some of the projects did not have a reduction in the crashes, the overall percentage reductions in the number of total and rear-end crashes for each type of improvement is positive, implying that the improvements are effective in reducing the number crashes (total and rear-end). It was found that all the improvements except for added turn lanes and added right turn lane were effective in reducing severe crashes at the intersections. In the case of added right turn lanes and drainage improvements no generalized conclusions can be made as there is only one project involving these improvements hence the percentage reductions obtained are only site specific.

Overall the intersection improvement projects were effective in improving the safety at the intersections except for the added turn lanes where the severe crashes increased following the treatment. The design guidelines of this specific improvement have to be revisited and necessary changes have to be made while implementing this type of improvement in order to improve the safety at the intersections in terms of reducing severe crashes.

Table 6-13: EB Analysis for Total Crashes for All the Intersection Improvement Projects

Int ID	Major_Work (Code)	no_of_lanes_major	added_lanes	no_of_lanes_minor	before_period	after_period	mean_before_sect_aadt	mean_after_sect_aadt	Speed limit	ursubrur_num	freq_of_crashes_before	freq_of_crashes_after	SPF_total	weight_total	EB_total	adj_adt_total	adj_bef_aft_period	pred_Aft_total	ind_eff_total	percent_reduction_total	var_pred_aft_total
1	6	6	0	4	1146	941	51468	51367	45	1	73	45	15.848	0.0452	71.95	0.9987	0.8211	59.002	0.7505	24.9465	37.885
2	6	4	0	3	1525	408	30712	32153	45	2	100	24	11.301	0.0475	97.493	1.0307	0.2675	26.885	0.8621	13.7861	1.947
3	6	6	0	3	1289	609	28550	32500	40	1	60	18	13.404	0.0474	59.4	1.0893	0.4725	30.57	0.571	42.8987	7.713
4	6	4	0	2	1514	530	34800	33500	35	1	27	8	9.882	0.0543	27.76	0.9752	0.3501	9.477	0.7676	23.2413	1.044
5	10	4	0	6	1098	1025	37875	42500	45	2	56	23	13.85	0.0535	55.233	1.079	0.9335	55.636	0.4065	59.351	53.43
6	10	6	0	3	1385	679	63420	63041	45	1	69	32	18.239	0.0329	69.007	0.9961	0.4903	33.697	0.9231	7.6865	7.771
7	10	4	0	4	1294	809	37875	35000	40	1	34	21	16.109	0.0396	34.915	0.9492	0.6252	20.72	0.9686	3.1392	7.008
8	10	4	0	2	1655	502	29153	31489	45	1	16	5	7.0641	0.0685	17.097	1.0522	0.3033	5.457	0.7827	21.733	0.518
9	10	6	0	4	980	1034	43412	47068	40	1	57	46	17.628	0.0474	56.542	1.0548	1.0551	62.928	0.7201	27.991	74.254
10	10	6	0	4	980	1034	43333	41000	40	1	39	45	17.607	0.0474	39.392	0.9641	1.0551	40.072	1.0969	-9.6908	39.499
11	15	4	0	2	1035	1096	42500	49667	45	1	13	2	9.0599	0.0839	14.065	1.1083	1.0589	16.508	0.1148	88.5215	20.831
12	20	6	0	6	1658	365	65578	77482	45	3	121	34	19.899	0.0254	120.22	1.1164	0.2201	29.547	1.114	-11.3962	1.739
13	20	4	0	2	1651	507	26100	22000	35	1	97	18	8.1728	0.0599	93.406	0.8933	0.3071	25.624	0.6776	32.2392	1.813
14	20	4	0	4	1346	615	27875	30000	35	1	4	2	13.158	0.0463	6.06	1.0497	0.4569	2.906	0.5181	48.1894	0.638
15	20	4	0	2	482	1270	17750	17567	45	2	4	9	5.0912	0.2593	4.706	0.9932	2.6349	12.315	0.6893	31.067	62.465
16	23	4	0	2	944	1109	40000	45500	45	1	94	96	8.7045	0.0947	87.232	1.0888	1.1748	111.58	0.8535	14.6526	165.26
17	1	6	0	2	1140	878	61500	62500	45	1	4	1	11.563	0.0612	5.965	1.0107	0.7702	4.643	0.1791	82.086	2.641
18	1	7	0	4	643	823	13470	12986	45	2	14	9	6.5414	0.1696	13.58	0.9762	1.2799	16.967	0.5057	49.4308	21.993
19	1	7	0	4	643	823	15895	16105	45	2	31	20	7.2968	0.1548	28.191	1.0087	1.2799	36.397	0.537	46.298	51.28
20	1	4	0	4	1182	755	15425	15000	25	1	3	2	8.9034	0.0755	4.95	0.9817	0.6388	3.104	0.4965	50.3535	1.128

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in total number of crashes)(Refer Table6-2 for work codes)

Table 6-14: EB Analysis for Severe Crashes for All the Intersection Improvement Projects

Int ID	Major_Work (Code)	no_of_lanes_major	added_lanes	no_of_lanes_minor	before_period	after_period	mean_before_sect_aadt	mean_after_sect_aadt	Speed limit	ursubrur_num	freq_of_sev_crashes_before	freq_of_sev_crashes_after	SPF_severe	weight_severe	EB_severe	adj_adt_severe	adj_bef_aft_period	pred_Aft_severe	ind_eff_severe	percent_reduction_severe	var_pred_aft_severe
1	6	6	0	4	1146	941	51468	51367	45	1	3	2	1.2274	0.6164	3.5261	0.9992	0.8211	2.8929	0.6104	38.96	0.747
2	6	4	0	3	1525	408	30712	32153	45	2	17	7	1.2993	0.5329	10.834	1.0196	0.2675	2.9554	2.0453	-104.53	0.1027
3	6	6	0	3	1289	609	28550	32500	40	1	9	1	0.9137	0.6574	5.2045	1.0564	0.4725	2.5975	0.3401	65.988	0.2217
4	6	4	0	2	1514	530	34800	33500	35	1	2	1	0.5115	0.7448	2.0905	0.984	0.3501	0.7201	1.0253	-2.533	0.0218
5	10	4	0	6	1098	1025	37875	42500	45	2	1	0	0.612	0.7708	1.6484	1.05	0.9335	1.6157	0	100	0.3558
6	10	6	0	3	1385	679	63420	63041	45	1	4	1	1.7661	0.4803	5.2973	0.9975	0.4903	2.5905	0.3215	67.848	0.322
7	10	4	0	4	1294	809	37875	35000	40	1	1	2	0.7818	0.6908	2.2238	0.9671	0.6252	1.3446	1.2093	-20.93	0.152
8	10	4	0	2	1655	502	29153	31489	45	1	1	0	0.6543	0.6761	2.3296	1.0332	0.3033	0.7301	0	100	0.0232
9	10	6	0	4	980	1034	43412	47068	40	1	5	3	0.8283	0.7358	2.9575	1.0348	1.0551	3.2291	0.8588	14.123	1.0172
10	10	6	0	4	980	1034	43333	41000	40	1	2	1	0.8277	0.7359	2.1635	0.9768	1.0551	2.2299	0.401	59.903	0.6256
11	15	4	0	2	1035	1096	42500	49667	45	1	0	0	0.7675	0.7399	1.6103	1.0682	1.0589	1.8214	0	100	0.6061
12	20	6	0	6	1658	365	65578	77482	45	3	6	0	0.7722	0.6384	4.4088	1.0732	0.2201	1.0416	0	100	0.021
13	20	4	0	2	1651	507	26100	22000	35	1	4	1	0.4528	0.7514	2.5334	0.9302	0.3071	0.7237	1.0286	-2.856	0.0147
14	20	4	0	4	1346	615	27875	30000	35	1	1	0	0.6867	0.7098	2.0875	1.0316	0.4569	0.9839	0	100	0.0634
15	20	4	0	2	482	1270	17750	17567	45	2	1	1	0.5303	0.8984	0.7308	0.9956	2.6349	1.917	0.4954	50.461	1.3405
16	23	4	0	2	944	1109	40000	45500	45	1	5	4	0.748	0.7619	2.6643	1.0561	1.1748	3.3054	1.1288	-12.883	1.2112
17	1	6	0	2	1140	878	61500	62500	45	1	0	0	0.8974	0.6884	1.9294	1.0069	0.7702	1.4962	0	100	0.2804
18	1	7	0	4	643	823	13470	12986	45	2	0	0	0.6959	0.8347	1.0233	0.9846	1.2799	1.2896	0	100	0.3385
19	1	7	0	4	643	823	15895	16105	45	2	2	0	0.7464	0.8248	1.4349	1.0056	1.2799	1.8468	0	100	0.5359
20	1	4	0	4	1182	755	15425	15000	25	1	0	0	0.5345	0.7815	1.3528	0.9882	0.6388	0.8539	0	100	0.0743

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in total number of crashes)

Table 6-15: EB analysis for Rear-end Crashes for All the Intersection Improvement Projects

Int ID	Major_Work (Code)	no_of_lanes_major	added_lanes	no_of_lanes_minor	before_period	after_period	mean_before_sect_aadt	mean_after_sect_aadt	Speed limit	ursubrur_num	freq_of_re_crashes_before	freq_of_re_crashes_after	SPF_rear-end	weight_ rear-end	EB_ rear-end	adj_adt_ rear-end	adj_bef_aft_period	pred_Aft_ rear-end	ind_eff_ rear-end	percent_reduction_ rear-end	var_pred_aft_ rear-end
1	6	6	0	4	1146	941	51468	51367	45	1	22	12	7.604	0.0951	22.178	0.9981	0.8211	18.177	0.6289	37.113	11.049
2	6	4	0	3	1525	408	30712	32153	45	2	39	11	4.471	0.1184	36.595	1.0444	0.2675	10.225	0.9904	0.961	0.7038
3	6	6	0	3	1289	609	28550	32500	40	1	18	6	3.5652	0.1661	17.101	1.1305	0.4725	9.1344	0.6019	39.809	2.1731
4	6	4	0	2	1514	530	34800	33500	35	1	15	3	2.813	0.1769	14.411	0.9646	0.3501	4.866	0.5273	47.268	0.4567
5	10	4	0	6	1098	1025	37875	42500	45	2	36	13	6.1485	0.1194	33.91	1.1153	0.9335	35.304	0.3593	64.073	33.697
6	10	6	0	3	1385	679	63420	63041	45	1	43	19	8.8832	0.0693	42.357	0.9944	0.4903	20.648	0.8805	11.95	4.5669
7	10	4	0	4	1294	809	37875	35000	40	1	12	4	4.8599	0.1271	12.665	0.928	0.6252	7.3475	0.4866	51.341	2.1589
8	10	4	0	2	1655	502	29153	31489	45	1	4	1	2.784	0.1658	5.4294	1.0757	0.3033	1.7716	0.3838	61.624	0.1574
9	10	6	0	4	980	1034	43412	47068	40	1	15	15	5.53	0.1445	14.978	1.0796	1.0551	17.061	0.8372	16.277	18.937
10	10	6	0	4	980	1034	43333	41000	40	1	15	21	5.5206	0.1447	14.974	0.9489	1.0551	14.993	1.3251	-32.509	12.855
11	15	4	0	2	1035	1096	42500	49667	45	1	6	2	3.9781	0.1819	6.9605	1.159	1.0589	8.5425	0.2137	78.634	10.527
12	20	6	0	6	1658	365	65578	77482	45	3	69	16	10.339	0.0507	67.883	1.1711	0.2201	17.501	0.8672	13.279	1.1042
13	20	4	0	2	1651	507	26100	22000	35	1	14	5	2.1423	0.2056	13.114	0.8506	0.3071	3.4255	1.1849	-18.487	0.1857
14	20	4	0	4	1346	615	27875	30000	35	1	0	0	3.6355	0.1576	2.1129	1.072	0.4569	1.0349	0	100	0.2092
15	20	4	0	2	482	1270	17750	17567	45	2	2	3	1.7404	0.5218	2.1557	0.9902	2.6349	5.6243	0.4916	50.84	18.307
16	23	4	0	2	944	1109	40000	45500	45	1	42	45	3.7561	0.2052	35.375	1.1297	1.1748	46.949	0.9425	5.748	65.728
17	1	6	0	2	1140	878	61500	62500	45	1	3	1	5.6444	0.1246	4.8221	1.0154	0.7702	3.771	0.2152	78.478	2.019
18	1	7	0	4	643	823	13470	12986	45	2	7	4	2.1371	0.3998	5.7065	0.966	1.2799	7.0554	0.5225	47.751	6.473
19	1	7	0	4	643	823	15895	16105	45	2	9	11	2.4998	0.3629	7.3321	1.0125	1.2799	9.5021	1.0849	-8.49	10.168
20	1	4	0	4	1182	755	15425	15000	25	1	0	2	2.0761	0.2717	1.8267	0.9739	0.6388	1.1363	1.0726	-7.26	0.3203

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in total number of crashes)

Table 6-16: EB Analysis for Angle Crashes for All the Intersection Improvement Projects

Int ID	Major_Work (Code)	no_of_lanes_major	added_lanes	no_of_lanes_minor	before_period	after_period	mean_before_sect_aadt	mean_after_sect_aadt	Speed limit	ursubrur_num	freq_of_angle_crashes_before	freq_of_angle_crashes_after	SPF_angle	weight_angle	EB_angle	adj_adt_angle	adj_bef_aft_period	pred_Aft_angle	ind_eff_angle	percent_reduction_angle	var_pred_aft_angle
1	6	6	0	4	1146	941	51468	51367	45	1	8	8	2.7975	0.168	8.1316	0.999	0.8211	6.6704	1.0663	-6.633	3.7343
2	6	4	0	3	1525	408	30712	32153	45	2	22	9	2.6378	0.1387	20.478	1.0233	0.2675	5.6063	1.3915	-39.154	0.3619
3	6	6	0	3	1289	609	28550	32500	40	1	9	1	3.3161	0.1316	9.3566	1.0672	0.4725	4.7179	0.179	82.099	1.0417
4	6	4	0	2	1514	530	34800	33500	35	1	0	1	2.0612	0.1718	1.4692	0.9811	0.3501	0.5046	0.7503	24.966	0.0493
5	10	4	0	6	1098	1025	37875	42500	45	2	5	3	2.2087	0.2107	5.3465	1.0596	0.9335	5.2883	0.4936	50.639	4.0836
6	10	6	0	3	1385	679	63420	63041	45	1	12	1	3.7965	0.1096	12.264	0.997	0.4903	5.9943	0.1453	85.475	1.2751
7	10	4	0	4	1294	809	37875	35000	40	1	2	4	3.1274	0.1379	3.2534	0.9611	0.6252	1.955	1.4199	-41.993	0.6085
8	10	4	0	2	1655	502	29153	31489	45	1	5	1	1.4461	0.2129	5.3315	1.0395	0.3033	1.681	0.4052	59.483	0.1315
9	10	6	0	4	980	1034	43412	47068	40	1	7	6	3.3493	0.1648	7.3283	1.0415	1.0551	8.0526	0.6751	32.492	8.1209
10	10	6	0	4	980	1034	43333	41000	40	1	5	7	3.3462	0.1649	5.657	0.9726	1.0551	5.8051	1.0542	-5.419	5.105
11	15	4	0	2	1035	1096	42500	49667	45	1	0	0	1.7475	0.2636	1.3063	1.0814	1.0589	1.4959	0	100	1.4445
12	20	6	0	6	1658	365	65578	77482	45	3	17	4	2.9098	0.1183	16.553	1.0874	0.2201	3.9623	0.8258	17.424	0.2002
13	20	4	0	2	1651	507	26100	22000	35	1	24	5	1.7839	0.1802	21.129	0.9178	0.3071	5.9548	0.7381	26.194	0.3877
14	20	4	0	4	1346	615	27875	30000	35	1	2	1	2.6812	0.1521	3.1999	1.0376	0.4569	1.517	0.4229	57.714	0.2891
15	20	4	0	2	482	1270	17750	17567	45	2	1	1	1.1272	0.5438	1.2656	0.9948	2.6349	3.3173	0.265	73.5	10.398
16	23	4	0	2	944	1109	40000	45500	45	1	15	11	1.6951	0.2881	11.942	1.0668	1.1748	14.967	0.7016	29.841	16.737
17	1	6	0	2	1140	878	61500	62500	45	1	0	0	2.1038	0.2126	1.3969	1.0081	0.7702	1.0846	0	100	0.5149
18	1	7	0	4	643	823	13470	12986	45	2	3	0	1.4269	0.4137	2.7988	0.9818	1.2799	3.5171	0	100	3.2562
19	1	7	0	4	643	823	15895	16105	45	2	10	3	1.5506	0.3937	7.1382	1.0066	1.2799	9.197	0.306	69.398	9.2559
20	1	4	0	4	1182	755	15425	15000	25	1	0	0	1.9919	0.2157	1.3913	0.9861	0.6388	0.8763	0	100	0.2727

(Positive values indicate that the safety improved and negative values indicate that the safety deteriorated in terms of reduction in total number of crashes)

Table 6-17: Overall Index of Effectiveness for Total Crashes for Intersection Improvements

Type of Improvement	Number of Projects	overall index of effectiveness for total crashes(Naïve Before-After)	Percentage Reduction in Total Crashes(Naïve Before-After)	overall index of effectiveness for total crashes(EB)	Percentage Reduction in Total Crashes(EB)	Standard Deviation(Index of effectiveness for total crashes) (EB)
Add Turn Lane(s)	4	0.781267685	21.87323147	0.75206	24.794	0.08754
Add Left Turn Lane(s)	6	0.824325902	17.56740983	0.78415	21.585	0.07683
Drainage Improvements	1	0.14628821	85.37117904	0.11255	88.745	0.08236
Traffic Signals	4	0.972025292	2.79747078	0.8831	11.69	0.15022
Add Right Turn Lane(s)	1	0.869335534	13.06644655	0.84913	15.087	0.12984
Resurfacing	4	0.513153153	48.68468468	0.51305	48.695	0.11567

Table 6-18: Overall Index of Effectiveness for Severe Crashes for Intersection Improvements

Type of Improvement	Number of Projects	overall index of effectiveness for severe crashes(Naïve Before-After)	Percentage Reduction in Severe Crashes(Naïve Before-After)	overall index of effectiveness for severe crashes	Percentage Reduction in Severe Crashes(EB)	Standard Deviation(Index of effectiveness for severe crashes)(EB)
Add Turn Lane(s)	4	1.033649185	-3.364918502	1.18467	-18.467	0.37944
Add Left Turn Lane(s)	6	0.634271688	36.5728312	0.58566	41.434	0.23287
Drainage Improvements	1	0	100	0	100	0
Traffic Signals	4	0.311515833	68.8484167	0.40203	59.797	0.29296
Add Right Turn Lane(s)	1	0.68097385	31.90261497	1.08937	-8.937	0.62088
Resurfacing	4	0	100	0	100	0

Table 6-19: Overall Index of Effectiveness for Rear-end Crashes for Intersection Improvements

Type of Improvement	Number of Projects	overall index of effectiveness for rear-end crashes(Naïve Before-After)	Percentage Reduction in Rear-end Crashes(Naïve Before-After)	overall index of effectiveness for rear-end crashes	Percentage Reduction in Rear-end Crashes(EB)	Standard Deviation(Index of effectiveness for rear-end crashes)(EB)
Add Turn Lane(s)	4	0.804538165	19.54618351	0.74869	25.131	0.14774
Add Left Turn Lane(s)	6	0.776527113	22.34728869	0.74589	25.411	0.10862
Drainage Improvements	1	0.314781022	68.52189781	0.20461	79.539	0.15353
Traffic Signals	4	1.033445395	-3.344539539	0.84795	15.205	0.21781
Add Right Turn Lane(s)	1	0.91201855	8.798145047	0.93073	6.927	0.20923
Resurfacing	4	0.800073075	19.99269249	0.8054	19.46	0.24551

Table 6-20: Overall Index of Effectiveness for Angle Crashes for Intersection Improvements

Type of Improvement	Number of Projects	overall index of effectiveness for angle crashes(Naïve Before-After)	Percentage Reduction in angle Crashes(Naïve Before-After)	overall index of effectiveness for angle crashes	Percentage Reduction in angle Crashes(EB)	Standard Deviation(Index of effectiveness for angle crashes)(EB)
Add Turn Lane(s)	4	1.200782669	-20.07826692	1.06768	-6.768	0.27926
Add Left Turn Lane(s)	6	0.796164348	20.38356516	0.74708	25.292	0.1937
Drainage Improvements	1	0	100	0	100	0
Traffic Signals	4	0.819534983	18.04650174	0.70895	29.105	0.26116
Add Right Turn Lane(s)	1	0.624226029	37.57739705	0.68387	31.613	0.26847
Resurfacing	4	0.180297224	81.9702776	0.19254	80.746	0.11745

CHAPTER 7. SUMMARY AND CONCLUSIONS

This study assessed the safety impact of general improvements made on multi-lane arterials in the state of Florida. Multi-lane roads which were improved or modified between the years 2003 and 2006 were considered for analysis. A total of 182 such projects were identified of which 162 were corridor level and 26 were intersection improvement projects. The information on improvements involved in each of these projects were collected from various sources such as financial project search database, project plans, contract documents, and video log application which can be accessed through FDOT's intranet. The crash data was obtained from the CAR database and the roadway characteristics were obtained from combining the information from three sources: RCI, video log application, and Google Earth application.

For analyzing the improvements for their safety impact various available before and after methodologies were studied, and EB approach was considered as the best among the others as it takes care of the *Rtm* bias, volume changes resulting from the improvements, and time trends. The EB method requires a comparison group (a group of sites which are similar to the sites being treated) to estimate the crash frequencies at the treatment site. Hence separate comparison groups for corridor level projects and intersection projects were obtained. Crash data and roadway characteristics data for the comparison group was extracted from CAR and RCI databases. SPFs for total, severe, and rear-end crashes were developed for corridor level improvement projects for different section length ranges and land-use categories using the data from their respective comparison groups. And similarly SPFs for total, severe, angle, and rear-end crashes were developed for intersection improvement projects using the comparison group of intersections. The SPFs estimated for segments included *adt*, section length, number of lanes, and speed limit as the explanatory variables. The SPFs for intersections included *adt* on major road, number of lanes on major road, speed limit on the major road, and number of lanes on minor road.

The EB estimates for changes in safety (in terms of reduction in number of crashes of each type) for all the projects were calculated. All of the improvements implemented at the corridor level had a positive effect on safety, i.e. the number of crashes reduced following the improvement. Table 7-1 shows the percentage reductions estimated by EB method for total, severe, and rear-end crashes for each type of corridor level improvement.

Table 7-1: Percentage Reduction for Each Type by Type of Improvement for Corridor Level Improvement Projects

Type of Improvement	Percentage Reduction in Total Crashes(EB)	Percentage Reduction in Severe Crashes(EB)	Percentage Reduction in Rear-end Crashes(EB)
Add Lanes & Reconstruct	10.55	30.866	19.885
Rigid Pavement Rehabilitation	13.444	32.135	24.829
Construct/reconstruct Median	12.778	29.287	26.219
Skid Hazard Overlay	12.565	30.275	10.672
Bike Path/trail	50.086	63.316	42.338
Flexible Pavement Reconstruct.	55.886	70.977	63.746

The EB estimates of safety following the resurfacing projects showed that the improvement in safety was not correlated with lengths of the section resurfaced. For projects involving resurfacing as the major work the estimates of change in safety varied widely from project to project and even for the three crash groups. Based on the overall indices of effectiveness of resurfacing, it can be said that there is a slight increase of 0.62% in the total number of crashes, slight decrease of 0.83 % in rear-end crashes, and decrease of 4.63% in severe crashes following the improvement. Looking at the additional improvements involved in the projects along with resurfacing, projects involving additional improvements such as: adding turn lanes (left and/or right), guard rail improvement, drainage Improvement, and lighting improvement are more likely to result in reduction in the total number of crashes. However, in terms of rear-end crashes resurfacing projects are likely to result in relatively higher improvement if paving shoulder and adding turning lanes are also part of the project. Also, none of the additional improvements carried out along with resurfacing have a significant impact on severe crashes.

Table 7-2 shows the percentage reduction estimated for each crash type by the type of intersection improvements. Except for adding turn lane(s) and adding right turn lane(s) all other improvements showed a positive impact on safety in terms of reducing the number of crashes for all the crash types considered. The percentage reductions obtained in case of added right turn lanes and drainage improvements cannot be generalized as the sample size for these types of intersection improvements is very small hence the percentage reductions obtained are only site specific. In all it can be concluded that FDOT is doing a good job in selecting the sites for treatment and it is very successful in improving the safety of the sections being treated.

Table 7-2: Percentage Reduction for Each Type by Type of Improvement for Intersection Improvement Projects

Type of Improvement	Percentage Reduction in Total Crashes(EB)	Percentage Reduction in Severe Crashes(EB)	Percentage Reduction in Rear-end Crashes(EB)	Percentage Reduction in angle Crashes(EB)
Add Turn Lane(s)	24.794	-18.467	25.131	-6.768
Add Left Turn Lane(s)	21.585	41.434	25.411	25.292
Drainage Improvements	88.745	100	79.539	100
Traffic Signals	11.69	59.797	15.205	29.105
Add Right Turn Lane(s)	15.087	-8.937	6.927	31.613
Resurfacing	48.695	100	19.46	80.746

7.1 Recommendations for Further Research

In the future, the analysis may be extended to other improvements which are not considered in this report due to unavailability of data for those improvements. For each of the intersection improvements and corridor level improvements, the best practices for carrying out additional improvements can be identified as it was done for resurfacing projects. One interesting area of examination could be to assess associations between the characteristics of the resurfaced sections with the improvements that they achieve. Geographical Information System (GIS) based analysis may also be employed to examine if certain regions of a jurisdiction (state/county) are associated with the estimated improvements in safety.

For modeling the SPFs extra variables can be included and therefore increasing the accuracy of the crash prediction models. Although the Empirical Bayes approach has now gained wide acceptance among researchers as the much preferred one for the before-after evaluation of road safety treatments, during the recent years a Full Bayesian (FB) approach has been suggested as a useful, though complex alternative to the Empirical Bayes approach in that it is believed to require less data for untreated reference sites, it better accounts for uncertainty in data used, and it provides more detailed causal inferences and more flexibility in selecting crash count distributions.

APPENDIX A:

A.1 SPFs for Corridors

A.1.1 Total Crashes

A.1.1.1 Sub-Urban Multi-Lane Roads

A.1.1.1.1. Section Lengths Ranging from (0.5, 1.25] Miles

Table A 1: SPF for Total Crashes on Sub-Urban Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	229	266.5315	1.1639
Scaled Deviance	229	266.5315	1.1639
Pearson Chi-Square	229	230.9515	1.0085
Scaled Pearson X2	229	230.9515	1.0085
Log Likelihood		7723.7439	

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-8.6418	1.0254	-10.6516	-6.6319	71.02	<.0001
Log(ADT)		1	1.146	0.0988	0.9524	1.3397	134.5	<.0001
Log(length)		1	0.8547	0.1983	0.466	1.2434	18.58	<.0001
Speed limit	65	1	0.2075	0.5772	-0.9237	1.3388	0.13	0.7192
Speed limit	60	1	-1.8861	1.0045	-3.855	0.0827	3.53	0.0604

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Speed limit	55	1	-0.8375	0.2052	-1.2396	-0.4354	16.66	<.0001
Speed limit	50	1	-0.3248	0.2197	-0.7554	0.1058	2.19	0.1393
Speed limit	45	1	-0.1269	0.1991	-0.5171	0.2634	0.41	0.524
Speed limit	40	0	0	0	0	0	.	.
# of lanes	6	1	0.2457	0.1443	-0.0371	0.5286	2.9	0.0886
# of lanes	5	1	0.1109	0.3351	-0.5459	0.7678	0.11	0.7407
# of lanes	4	0	0	0	0	0	.	.
Dispersion		1	0.4665	0.0526	0.3635	0.5695		

A.1.1.1.2 Section Lengths Ranging from (1.25, 3.0] Miles

Table A 2: SPF for Total Crashes on Sub-Urban Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	204	225.5815	1.1058
Scaled Deviance	204	225.5815	1.1058
Pearson Chi-Square	204	191.5587	0.939
Scaled Pearson X2	204	191.5587	0.939
Log Likelihood		21577.8212	

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-8.9097	0.9267	-10.7259	-7.0934	92.44	<.0001
Log(ADT)		1	1.1715	0.087	1.0011	1.342	181.51	<.0001
Log(length)		1	0.9345	0.1551	0.6305	1.2385	36.29	<.0001
Speed limit	65	1	-1.0132	0.3242	-1.6485	-0.3778	9.77	0.0018
Speed limit	60	1	-1.3703	0.3322	-2.0214	-0.7193	17.02	<.0001

Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Speed limit	55	1	-0.6908	0.1618	-1.008	-0.3737	18.23	<.0001
Speed limit	50	1	-0.1875	0.1727	-0.526	0.1509	1.18	0.2775
Speed limit	45	1	-0.1588	0.1591	-0.4707	0.1531	1	0.3184
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.2378	0.027	0.1849	0.2908		

A.1.1.1.3 Section Lengths Ranging from (3.0, 9.0] Miles

Table A 3: SPF for Total Crashes on Sub-Urban Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	101	122.0889	1.2088
Scaled Deviance	101	122.0889	1.2088
Pearson Chi-Square	101	94.2441	0.9331
Scaled Pearson X2	101	94.2441	0.9331
Log Likelihood		31319.3303	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-10.3177	1.7191	-13.6871	-6.9482	36.02	<.0001
Log(ADT)		1	1.2953	0.1612	0.9793	1.6112	64.57	<.0001
Log(length)		1	0.9156	0.2264	0.4719	1.3594	16.35	<.0001
Speed limit	65	1	-0.4509	0.4345	-1.3024	0.4007	1.08	0.2994
Speed limit	60	1	-1.1221	0.4476	-1.9994	-0.2447	6.28	0.0122
Speed limit	55	1	-0.6174	0.3427	-1.289	0.0542	3.25	0.0716
Speed limit	50	1	-0.0226	0.3813	-0.7699	0.7246	0	0.9527
Speed limit	45	1	0.1065	0.3501	-0.5798	0.7927	0.09	0.761
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.4165	0.0591	0.3006	0.5323		

A.1.1.2 Rural Multi-Lane Roads

A.1.1.2.1 Section Lengths Ranging from (0.5, 1.25] Miles

Table A 4: SPF for Total Crashes on Rural Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	72	87.3311	1.2129
Scaled Deviance	72	87.3311	1.2129
Pearson Chi-Square	72	73.1754	1.0163
Scaled Pearson X2	72	73.1754	1.0163
Log Likelihood		671.4611	

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-4.1184	2.101	-8.2364	-0.0004	3.84	0.05
Log(ADT)		1	0.6805	0.2144	0.2603	1.1008	10.07	0.0015
Log(length)		1	1.1389	0.4253	0.3054	1.9725	7.17	0.0074
Speed limit	65	1	-1.7909	0.4828	-2.7371	-0.8447	13.76	0.0002
Speed limit	60	1	-0.8296	0.6378	-2.0797	0.4205	1.69	0.1934
Speed limit	55	1	-0.729	0.2659	-1.2501	-0.2079	7.52	0.0061
Speed limit	50	1	0.3374	0.3534	-0.3553	1.0302	0.91	0.3397
Speed limit	45	0	0	0	0	0	.	.
No of lanes	6	1	-0.0924	0.4599	-0.9938	0.809	0.04	0.8407
No of lanes	4	0	0	0	0	0	.	.
Dispersion		1	0.6503	0.1418	0.3723	0.9282		

A.1.1.2.2 Section Lengths Ranging from (1.25, 3.0] Miles

Table A 5: SPF for Total Crashes on Rural Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	62	77.2952	1.2467
Scaled Deviance	62	77.2952	1.2467
Pearson Chi-Square	62	68.7013	1.1081
Scaled Pearson X2	62	68.7013	1.1081
Log Likelihood		1209.7148	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-15.0887	2.0393	-19.0856	-11.0917	54.74	<.0001
Log(ADT)		1	1.3928	0.1907	1.0191	1.7665	53.36	<.0001
Log(length)		1	1.2822	0.3909	0.516	2.0485	10.76	0.001
Speed limit	65	1	2.5749	0.8343	0.9396	4.2102	9.52	0.002
Speed limit	60	1	3.0056	0.848	1.3435	4.6677	12.56	0.0004
Speed limit	55	1	2.67	0.8113	1.0799	4.26	10.83	0.001
Speed limit	50	1	2.8183	0.8578	1.1371	4.4995	10.8	0.001
Speed limit	45	1	3.5205	0.8339	1.886	5.1549	17.82	<.0001
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.4195	0.1046	0.2146	0.6245		

A.1.1.2.3 Section Lengths Ranging from (3.0, 9.0] Miles

Table A 6: SPF for Total Crashes on Rural Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	72	80.7654	1.1217
Scaled Deviance	72	80.7654	1.1217
Pearson Chi-Square	72	84.5773	1.1747
Scaled Pearson X2	72	84.5773	1.1747
Log Likelihood		2507.4877	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-7.3089	1.4875	-10.2242	-4.3935	24.14	<.0001
Log(ADT)		1	0.9745	0.1343	0.7113	1.2377	52.67	<.0001
Log(length)		1	0.8067	0.2283	0.3593	1.2541	12.49	0.0004
Speed limit	65	1	-0.6505	0.5426	-1.7141	0.413	1.44	0.0230
Speed limit	60	1	-0.8729	0.5538	-1.9583	0.2125	2.48	0.115
Speed limit	55	1	-0.5427	0.5303	-1.582	0.4966	1.05	0.0306
Speed limit	50	1	-0.9876	0.7619	-2.4808	0.5056	1.68	0.1949
Speed limit	45	0	0	0	0	0	.	.
Dispersion		1	0.2323	0.049	0.1362	0.3283		

A.1.2 Severe Crashes

A.1.2.1 Sub-Urban Multi-Lane Roads

A.1.2.1.1 Section Lengths Ranging from (0.5, 1.25] Miles

Table A 7: SPF for Severe Crashes on Sub-Urban and Rural Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	316	335.1732	1.0607
Scaled Deviance	316	335.1732	1.0607
Pearson Chi-Square	316	337.2717	1.0673
Scaled Pearson X2	316	337.2717	1.0673
Log Likelihood		-203.1429	

Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	-6.4468	1.1345	-8.6703	-4.2233	32.29	<.0001
Log(ADT)	1	0.6846	0.1113	0.4664	0.9027	37.83	<.0001
Log(length)	1	0.5924	0.2574	0.088	1.0968	5.3	0.0213
Dispersion	1	0.6799	0.129	0.4271	0.9327		

A.1.2.1.2 Section Lengths Ranging from (1.25, 3.00] Miles

Table A 8: SPF for Severe Crashes on Sub-Urban Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	209	242.0904	1.1583
Scaled Deviance	209	242.0904	1.1583
Pearson Chi-Square	209	210.3046	1.0062
Scaled Pearson X2	209	210.3046	1.0062
Log Likelihood		429.3227	

Analysis Of Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1	-9.9677	1.1942	-12.3084	-7.6271	69.67	<.0001
Log(ADT)	1	1.0162	0.1127	0.7953	1.237	81.33	<.0001
Log(length)	1	1.1913	0.1907	0.8176	1.565	39.04	<.0001
Dispersion	1	0.1489	0.0427	0.0653	0.2325		

A.1.2.1.3 Section Lengths Ranging from (3.0, 9.0] miles

Table A 9: SPF for Severe Crashes on Sub-Urban Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	106	122.0015	1.151
Scaled Deviance	106	122.0015	1.151
Pearson Chi-Square	106	115.1298	1.0861
Scaled Pearson X2	106	115.1298	1.0861
Log Likelihood		1111.8317	

Analysis Of Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1	-10.8623	1.6763	-14.1478	-7.5768	41.99	<.0001
Log(ADT)	1	1.1182	0.1578	0.8088	1.4276	50.18	<.0001
Log(length)	1	0.8658	0.2387	0.398	1.3335	13.16	0.0003
Dispersion	1	0.3423	0.0703	0.2045	0.4802		

A.1.2.2 Rural Multi-Lane Roads

A.1.2.2.1 Section Lengths Ranging from (0.5, 1.25] Miles

Refer Table A7

A.1.2.2.2 Section Lengths Ranging from (1.25, 3.00] Miles

Table A 10: SPF for Severe Crashes on Rural Sections with Sections Lengths ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	67	75.1144	1.1211
Scaled Deviance	67	75.1144	1.1211
Pearson Chi-Square	67	64.0208	0.9555
Scaled Pearson X2	67	64.0208	0.9555
Log Likelihood		-16.8516	

Analysis Of Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1	-8.7639	2.5795	-13.8195	-3.7082	11.54	0.0007
Log(ADT)	1	0.9033	0.2619	0.39	1.4166	11.9	0.0006
Log(length)	1	0.8875	0.4971	-0.0869	1.8618	3.19	0.0742
Dispersion	1	0.6833	0.2417	0.2095	1.157		

A.1.2.2.3 Section Lengths Ranging from (3.0, 9.0] Miles

Table A 11: SPF for Severe Crashes on Rural Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	76	90.1236	1.1858
Scaled Deviance	76	90.1236	1.1858
Pearson Chi-Square	76	83.4197	1.0976
Scaled Pearson X2	76	83.4197	1.0976
Log Likelihood		113.3746	

Analysis Of Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1	-9.018	1.6368	-12.2261	-5.8098	30.35	<.0001
Log(ADT)	1	1.0174	0.1618	0.7004	1.3344	39.56	<.0001
Log(length)	1	0.3016	0.2527	-0.1937	0.7968	1.42	0.2327
Dispersion	1	0.1499	0.0749	0.0032	0.2967		

A.1.3 Rear-end Crashes

A.1.3.1 Urban Multi-Lane Roads

A.1.3.1.1 Section Lengths Ranging from (0.5, 1.25] Miles

Table A 12: SPF for Rear-end Crashes on Urban Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	365	414.5155	1.1357
Scaled Deviance	365	414.5155	1.1357
Pearson Chi-Square	365	432.1373	1.1839
Scaled Pearson X2	365	432.1373	1.1839
Log Likelihood		5455.3215	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-14.6882	0.9099	-16.4716	-12.9048	260.58	<.0001
Log(ADT)		1	1.6721	0.0894	1.497	1.8473	350.19	<.0001
Log(length)		1	0.824	0.161	0.5085	1.1394	26.2	<.0001
Speed limit	55	1	-2.0093	0.4848	-2.9594	-1.0592	17.18	<.0001
Speed limit	50	1	-1.2298	0.2258	-1.6724	-0.7871	29.65	<.0001
Speed limit	45	1	-0.4524	0.0922	-0.6331	-0.2716	24.06	<.0001
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.4507	0.0475	0.3576	0.5438		

A.1.3.1.2 Section Lengths Ranging from (1.25, 3.00] Miles

Table A 13: SPF for Rear-end Crashes on Urban Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	335	370.0954	1.1048
Scaled Deviance	335	370.0954	1.1048
Pearson Chi-Square	335	347.557	1.0375
Scaled Pearson X2	335	347.557	1.0375
Log Likelihood		22594.7449	

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-14.5383	0.8068	-16.1197	-12.9569	324.68	<.0001
Log(ADT)		1	1.6423	0.0783	1.4887	1.7958	439.46	<.0001
Log(length)		1	1.1749	0.1335	0.9134	1.4365	77.51	<.0001
Speed limit	60	1	-1.6029	0.5941	-2.7672	-0.4385	7.28	0.007
Speed limit	55	1	-1.065	0.2347	-1.5251	-0.6049	20.58	<.0001
Speed limit	50	1	-0.9032	0.1297	-1.1575	-0.6489	48.46	<.0001
Speed limit	45	1	-0.3481	0.0687	-0.4828	-0.2135	25.67	<.0001
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.2872	0.0273	0.2337	0.3407		

A.1.3.1.3 Section Lengths Ranging from (3.0, 9.0] Miles

Table A 14: SPF for Rear-end Crashes on Urban Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	150	161.7865	1.0786
Criterion	**DF**	**Value**	**Value/DF**
Scaled Deviance	150	161.7865	1.0786
Pearson Chi-Square	150	174.9302	1.1662
Scaled Pearson X2	150	174.9302	1.1662
Log Likelihood		32954.1114	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-12.2038	1.0657	-14.2926	-10.1151	131.14	<.0001
Log(ADT)		1	1.4072	0.1016	1.208	1.6063	191.8	<.0001
Log(length)		1	1.1979	0.1697	0.8652	1.5306	49.8	<.0001
Speed limit	55	1	-0.7421	0.3706	-1.4686	-0.0157	4.01	0.0453
Speed limit	50	1	-0.7616	0.1849	-1.124	-0.3993	16.97	<.0001
Speed limit	45	1	-0.3627	0.0883	-0.5359	-0.1896	16.87	<.0001
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.2318	0.0284	0.176	0.2875		

A.1.3.2 Sub-Urban Multi-Lane Roads

A.1.3.2.1 Section Lengths Ranging from (0.5, 1.25] Miles

Table A 15: SPF for Rear-end Crashes on Sub- urban Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	73	73.9079	1.0124
Scaled Deviance	73	73.9079	1.0124
Pearson Chi-Square	73	94.2624	1.2913
Scaled Pearson X2	73	94.2624	1.2913
Log Likelihood		100.2882	

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-13.2148	3.4514	-19.9794	-6.4501	14.66	0.0001
Log(ADT)		1	1.4687	0.3439	0.7946	2.1428	18.24	<.0001
Log(length)		1	0.8516	0.6939	-0.5084	2.2116	1.51	0.2197
Speed limit	65	1	-2.7611	1.1876	-5.0887	-0.4335	5.41	0.0201
Speed limit	60	1	-0.8406	1.0591	-2.9164	1.2351	0.63	0.4273
Speed limit	55	1	-0.7331	0.4208	-1.5579	0.0917	3.03	0.0815
Speed limit	50	1	0.4235	0.5339	-0.6229	1.4699	0.63	0.4276
Speed limit	45	0	0	0	0	0	.	.
Dispersion		1	1.2322	0.4076	0.4333	2.0311		

A.1.3.2.2 Section Lengths Ranging from (1.25, 3.00] Miles

Table A 16: SPF for Rear-end Crashes on Sub-urban Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	204	227.3066	1.1142
Scaled Deviance	204	227.3066	1.1142
Pearson Chi-Square	204	200.5677	0.9832
Scaled Pearson X2	204	200.5677	0.9832
Log Likelihood		6498.1667	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-15.3285	1.2851	-17.8472	-12.8098	142.28	<.0001
Log(ADT)		1	1.6894	0.1203	1.4536	1.9252	197.17	<.0001
Log(length)		1	0.9051	0.1996	0.5139	1.2963	20.56	<.0001
Speed limit	65	1	-1.2823	0.4601	-2.1841	-0.3804	7.77	0.0053
Speed limit	60	1	-2.396	0.5726	-3.5182	-1.2738	17.51	<.0001
Speed limit	55	1	-0.6464	0.2001	-1.0386	-0.2541	10.43	0.0012
Speed limit	50	1	-0.0698	0.2126	-0.4865	0.347	0.11	0.7428
Speed limit	45	1	0.0141	0.1954	-0.3689	0.3971	0.01	0.9424
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.324	0.0423	0.2411	0.407		

A.1.3.2.3 Section Lengths Ranging from (3.0, 9.0] Miles

Table A 17: SPF for Rear-end Crashes on Sub-Urban Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	101	123.4743	1.2225
Scaled Deviance	101	123.4743	1.2225
Pearson Chi-Square	101	99.64	0.9865
Scaled Pearson X2	101	99.64	0.9865
Log Likelihood		11509.1157	

Analysis Of Parameter Estimates								
Parameter		DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept		1	-17.5753	2.1606	-21.8099	-13.3407	66.17	<.0001
Log(ADT)		1	1.8924	0.203	1.4945	2.2902	86.91	<.0001
Log(length)		1	0.8457	0.2665	0.3234	1.3681	10.07	0.0015
Speed limit	65	1	-0.6028	0.5211	-1.6242	0.4186	1.34	0.2474
Speed limit	60	1	-1.4039	0.5681	-2.5173	-0.2904	6.11	0.0135
Speed limit	55	1	-0.3999	0.3993	-1.1826	0.3828	1	0.3167
Speed limit	50	1	0.2214	0.4419	-0.6447	1.0875	0.25	0.6163
Speed limit	45	1	0.4016	0.4068	-0.3957	1.1989	0.97	0.3235
Speed limit	40	0	0	0	0	0	.	.
Dispersion		1	0.5342	0.0836	0.3704	0.698		

A.1.3.3 Rural Multi-Lane Roads

A.1.3.3.1 Section Lengths Ranging from (0.5, 1.25] Miles

Table A 18: SPF for Rear-end Crashes on Rural Sections with Sections Lengths Ranging from (0.5, 1.25] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	236	275.1933	1.1661
Scaled Deviance	236	275.1933	1.1661
Pearson Chi-Square	236	377.6112	1.6
Scaled Pearson X2	236	377.6112	1.6
Log Likelihood		2191.6482	

Analysis Of Parameter Estimates							
Parameter	**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept	1	-14.6775	1.3408	-17.3054	-12.0496	119.83	<.0001
Log(ADT)	1	1.6073	0.1299	1.3527	1.8619	153.13	<.0001
Log(length)	1	0.6964	0.2551	0.1964	1.1965	7.45	0.0063
Dispersion	1	0.7936	0.1058	0.5864	1.0009		

A.1.3.3.2 Section Lengths Ranging from (1.25, 3.00] Miles

Table A 19: SPF for Rear-end Crashes on Rural Sections with Sections Lengths Ranging from (1.25, 3.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	DF	Value	Value/DF
Deviance	67	68.6348	1.0244
Scaled Deviance	67	68.6348	1.0244
Pearson Chi-Square	67	76.3487	1.1395
Scaled Pearson X2	67	76.3487	1.1395
Log Likelihood		197.6562	

Analysis Of Parameter Estimates							
Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	-23.9347	3.3786	-30.5566	-17.3128	50.19	<.0001
Log(ADT)	1	2.4751	0.333	1.8225	3.1278	55.25	<.0001
Log(length)	1	0.8553	0.5125	-0.1491	1.8597	2.79	0.0951
Dispersion	1	0.726	0.2269	0.2813	1.1707		

A.1.3.3.2 Section Lengths Ranging from (3.0, 9.0] Miles

Table A 20: SPF for Rear-end Crashes on Rural Sections with Sections Lengths Ranging from (3.00, 9.00] Miles

Criteria For Assessing Goodness Of Fit			
Criterion	**DF**	**Value**	**Value/DF**
Deviance	72	87.9316	1.2213
Scaled Deviance	72	87.9316	1.2213
Pearson Chi-Square	72	95.2628	1.3231
Scaled Pearson X2	72	95.2628	1.3231
Criterion	**DF**	**Value**	**Value/DF**
Log Likelihood		246.3444	

Analysis Of Parameter Estimates								
Parameter		**DF**	**Estimate**	**Standard Error**	**Wald 95% Confidence Limits**		**Chi-Square**	**Pr > ChiSq**
Intercept		1	-14.8165	2.3692	-19.46	-10.1729	39.11	<.0001
Log(ADT)		1	1.6366	0.2218	1.2019	2.0713	54.45	<.0001
Log(length)		1	0.829	0.3287	0.1849	1.4732	6.36	0.0117
Speed limit	65	1	-1.079	0.6534	-2.3597	0.2016	2.73	0.0987
Speed limit	60	1	-1.539	0.6758	-2.8636	-0.2144	5.19	0.0228
Speed limit	55	1	-1.0541	0.6325	-2.2938	0.1856	2.78	0.0956
Speed limit	50	1	-1.1227	0.9498	-2.9843	0.739	1.4	0.2372
Speed limit	45	0	0	0	0	0	.	.
Dispersion		1	0.2999	0.1044	0.0954	0.5045		

APPENDIX B

Table B 1: Results from EB Method for Total Crashes (Resurfacing Projects)

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	before crash frequency	after crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
1	6.65	0	0	0	1	0	1	0	1	0	0	0	0	0	0	0	32	19	7.151	2.4612	-146.12
2	1.32	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	18	56	24.381	2.2234	-122.342
3	0.74	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	61	30.517	1.9402	-94.019
4	4.43	1	1	0	0	0	0	0	1	0	0	0	0	1	0	0	53	139	82.158	1.6733	-67.332
5	4.79	1	1	0	1	0	1	0	1	0	0	0	0	1	0	0	4	31	18.315	1.6445	-64.451
6	1.35	1	0	0	1	0	0	0	0	0	0	0	0	1	0	0	25	86	52.647	1.6117	-61.173
7	1.3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	51	22	13.045	1.5959	-59.591
8	2.57	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	11	9	4.966	1.5863	-58.625
9	0.65	1	1	0	0	1	0	0	1	0	0	0	0	1	0	0	3	29	17.846	1.5439	-54.386
10	2.53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	176	320	206.64	1.5413	-54.128
11	1.45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	76	237	154.42	1.5259	-52.587
12	1.25	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	54	25	15.628	1.5115	-51.145
13	1.75	0	1	0	0	0	1	0	0	0	0	0	0	1	1	0	44	49	31.7	1.5065	-50.652
14	3.49	1	1	0	0	1	0	0	1	0	0	0	0	1	0	0	123	512	346.24	1.4746	-47.464
15	1.78	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	301	288	195.8	1.4637	-46.369
16	6.69	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	90	33	22.217	1.4382	-43.824
17	0.71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	138	74	51.1	1.4242	-42.424
18	3.92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	856	487	344.14	1.4111	-41.109

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	before crash frequency	after crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
19	5.06	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	266	139	100.48	1.3702	-37.024
20	2.09	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	363	352	257.02	1.3645	-36.445
21	0.9	0	1	0	0	0	0	0	1	0	0	0	1	1	0	0	89	134	98.391	1.3488	-34.88
22	4.57	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	145	57	41.53	1.341	-34.098
23	4.05	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	159	276	205.41	1.3374	-33.738
24	5.45	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	423	158	117.23	1.3366	-33.661
25	3.87	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	101	457	344.2	1.3243	-32.429
26	0.93	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	72	61	45.32	1.3189	-31.89
27	1.55	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	85	276	211.05	1.3019	-30.185
28	0.81	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	57	42.993	1.2976	-29.757
29	2.46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	131	92	70.459	1.2899	-28.994
30	0.68	1	1	0	0	1	0	0	1	0	0	0	0	1	0	0	8	39	29.334	1.2879	-28.788
31	2.47	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	46	46	35.028	1.2824	-28.243
32	0.65	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	266	78	60.108	1.2775	-27.75
33	3.8	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	88	127	99.543	1.2656	-26.559
34	0.94	1	0	0	0	0	0	0	0	0	0	0	1	1	0	0	29	43	33.13	1.2653	-26.534
35	2.36	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	180	60	47.571	1.2374	-23.741
36	4.44	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	50	89	71.808	1.2231	-22.31
37	2.08	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	171	289	240.02	1.1993	-19.928
38	3.03	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	83	38	31.262	1.1897	-18.968
39	1.97	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	215	82	68.059	1.1881	-18.806
40	1.6	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	74	123	103.46	1.1779	-17.792

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	before crash frequency	after crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
41	2.71	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1167	469	401.94	1.164	-16.398
42	2.59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	79	109	94.485	1.1433	-14.331
43	0.97	0	1	0	0	0	0	0	1	0	0	0	0	1	0	0	104	86	74.424	1.1417	-14.171
44	1.69	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	220	72	63.38	1.1192	-11.918
45	0.57	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	200	117	104.17	1.1132	-11.316
46	3.99	0	1	0	1	0	0	0	1	0	0	0	0	0	0	0	216	176	158.27	1.1052	-10.52
47	2.17	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	332	193	174.55	1.0997	-9.971
48	2.56	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	120	164	148.25	1.099	-9.896
49	3.89	0	0	0	1	0	0	0	1	0	0	0	0	1	0	0	105	43	38.388	1.0968	-9.683
50	2.77	0	1	0	0	1	0	0	0	1	1	0	0	1	0	0	382	207	189.75	1.0853	-8.53
51	8.18	0	0	0	0	0	0	1	1	1	1	0	0	0	0	0	96	61	56.598	1.063	-6.296
52	2.82	0	1	0	1	0	0	0	1	0	0	0	0	0	1	0	339	100	93.305	1.0612	-6.117
53	2.44	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	26	27	25.313	1.0329	-3.294
54	2.69	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	310	218	211.39	1.0266	-2.658
55	1.34	0	0	1	0	0	0	0	1	0	0	0	0	1	0	0	293	151	147.76	1.0154	-1.541
56	5.84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	416	271	269.13	1.0033	-0.328
57	3.57	1	0	0	1	0	0	0	1	0	0	0	0	0	0	0	66	42	40.986	1.0024	-0.238
58	1.44	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	33	35	34.364	0.9976	0.244
59	1.25	1	0	0	0	0	0	0	0	0	0	0	1	0	1	0	286	146	146.15	0.9923	0.771
60	5.12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	115	387	390.02	0.9898	1.022
61	2.97	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	527	194	196.89	0.9804	1.956
62	3	1	1	0	0	1	1	0	1	0	0	0	0	1	0	0	115	32	31.953	0.9743	2.57

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	before crash frequency	after crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
63	3.05	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	51	15	14.951	0.9599	4.009
64	4.6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	99	123	128.56	0.9496	5.039
65	0.78	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	68	151	158.16	0.9491	5.089
66	2.9	0	0	0	1	0	0	0	0	0	0	1	0	1	0	1	38	19	19.331	0.9419	5.807
67	2.17	0	0	1	0	1	0	0	1	0	0	0	0	1	0	0	307	176	186.09	0.9409	5.914
68	1.24	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	140	46	48.605	0.9283	7.175
69	0.66	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	5	5	4.615	0.9244	7.562
70	1.22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	8	8.116	0.9238	7.618
71	1.76	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	172	269	290.43	0.9231	7.686
72	1.22	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	84	144	156.12	0.9168	8.322
73	2.71	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	646	201	219.93	0.9099	9.007
74	1.13	0	1	0	0	1	0	0	0	1	1	0	0	1	0	0	201	84	91.539	0.9082	9.183
75	0.85	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	298	208	230.64	0.8981	10.19
76	1.56	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	98	31	33.979	0.8876	11.238
77	1.98	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	12	27	29.656	0.8875	11.253
78	0.86	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	33	94	105.15	0.8867	11.327
79	7.45	0	0	1	0	0	1	0	1	0	0	0	0	1	0	0	638	167	187.4	0.8865	11.353
80	0.61	0	0	0	0	1	1	0	0	0	0	0	0	1	0	0	47	40	44.392	0.883	11.699
81	6.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	477	213	240.45	0.8822	11.778
82	0.62	1	0	0	1	0	1	0	0	0	0	0	0	0	0	0	17	4	4.035	0.8645	13.554
83	5.97	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	7	4	4.2	0.8596	14.045
84	2.57	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	113	27	30.704	0.8541	14.588

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	before crash frequency	after crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
85	2.3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	51	29	34.088	0.8316	16.845
86	0.63	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	93	25	29.337	0.8281	17.193
87	3.35	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	413	136	163.68	0.826	17.399
88	0.51	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	63	29	34.703	0.8153	18.469
89	2.36	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	11	12.934	0.8153	18.471
90	1.46	0	1	0	0	0	0	0	1	0	0	0	1	0	0	1	190	49	59.414	0.8119	18.814
91	1.92	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	18	57	70.579	0.7979	20.211
92	1.08	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	15	23	28.069	0.7957	20.434
93	1.18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	200	183	229.92	0.7926	20.74
94	2.44	0	1	0	0	0	0	0	1	1	0	0	0	1	0	1	237	120	150.57	0.7919	20.806
95	5.86	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	95	39	48.941	0.7815	21.854
96	1.29	0	1	0	0	0	0	0	1	1	1	0	0	1	0	0	151	39	49.176	0.779	22.097
97	1.54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	246	111	142.07	0.7761	22.386
98	1.42	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	222	140	179.8	0.7745	22.552
99	6.17	0	1	0	0	0	0	1	1	1	1	0	0	0	0	0	70	20	24.975	0.7728	22.719
100	1.91	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	223	100	128.92	0.77	23.005
101	0.83	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	49	61	78.303	0.7694	23.058
102	1.19	0	0	0	0	0	0	0	1	0	0	0	1	1	0	0	660	190	248.09	0.7629	23.709
103	0.93	0	0	0	1	0	0	0	1	1	1	0	0	1	0	0	58	25	32.298	0.7538	24.622
104	1.58	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	48	28	37.034	0.7394	26.065
105	0.95	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	47	28	37.292	0.7328	26.723
106	2	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	266	81	110.6	0.726	27.405

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	before crash frequency	after crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
107	1.27	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	71	23	31.2	0.717	28.304
108	2.91	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	334	153	212.94	0.7153	28.475
109	1.4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	214	88	123.68	0.7061	29.388
110	5.43	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	47	21	28.961	0.7054	29.463
111	4.15	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	143	416	593.12	0.7002	29.977
112	0.62	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	25	7	9.253	0.6918	30.822
113	2.96	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	432	356	518.63	0.6851	31.486
114	1.16	1	1	0	0	0	0	0	1	0	0	0	0	0	0	0	7	9	12.363	0.6771	32.295
115	1.9	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	38	17	24.489	0.6701	32.992
116	1.8	0	1	1	0	0	0	0	1	0	0	0	0	1	0	0	180	36	53.195	0.6651	33.489
117	1.08	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	17	7	9.76	0.6598	34.018
118	1.11	1	1	0	0	0	0	0	1	0	0	0	1	0	0	0	195	29	43.143	0.6588	34.117
119	6.89	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	476	110	166.27	0.6577	34.227
120	1.65	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	185	262	412.73	0.6333	36.667
121	0.99	1	0	0	0	0	0	0	1	0	0	0	1	0	0	0	43	26	43.423	0.5872	41.282
122	7.12	1	0	1	0	0	1	0	1	0	0	0	0	0	0	1	5	7	11.498	0.58	42.001
123	2.07	1	0	0	1	0	1	0	1	0	0	0	0	0	0	0	63	10	17.374	0.5516	44.841
124	1.45	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	136	98	179.78	0.5422	45.781
125	1.52	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	39	72.473	0.5326	46.741
126	0.85	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	13	5	8.933	0.5078	49.217
127	5.32	0	0	0	0	0	1	0	0	1	1	0	0	0	0	0	42	21	46.886	0.44	55.999
128	1.23	1	1	0	0	0	0	0	0	0	0	0	1	0	0	0	76	79	185.04	0.4247	57.526

Project ID	Total length	Widening	Signal Update	Signal Installation	Guardrail Improvement	Guardrail Installation	Pave Shoulder	Add shoulder	Drainage Improvement	Add left turn lane	Add Right turn lane	Add lane	Lighting Improvement	Sidewalk	Median widening	Access Improvement	before crash frequency	after crash frequency	EB estimate of total crashes in After period (had no treatment been applied)	Index of effectiveness for total crashes	Percent reduction in total crashes
129	0.76	0	1	0	0	0	0	0	1	0	0	0	0	1	0	1	65	16	37.037	0.4213	57.875
130	1.25	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	17	9	21.301	0.4063	59.375
131	2.22	1	0	0	1	0	0	0	0	1	1	0	0	0	0	0	4	4	8.978	0.4052	59.478
132	1.63	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	88	35	87.477	0.3958	60.419
133	2.9	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	50	6	14.801	0.387	61.302
134	2.89	0	0	0	1	0	1	0	1	1	1	0	0	0	0	0	33	4	10.593	0.3537	64.631
135	0.94	1	0	0	0	0	0	0	1	1	1	0	1	0	0	0	54	7	30.082	0.2256	77.442
136	0.77	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	6.178	0.1413	85.868

LIST OF REFERENCES

Abdel-Aty, M., Radwan, E., 2000. Modeling traffic accident occurrence and involvement. Accident Analysis and Prevention 32(5), 633-642.

Abdel-Aty, M., Wang, X., 2006. Crash Estimation at Signalized Intersections along Corridors: Analyzing Spatial Effect and Identifying Significant Factors. Transportation Research Record 1953, Transportation Research Board, National Research Council, Washington, D.C., 98-111.

Benneson, J., McCoy, P., 1993. Estimation of Safety at Two-Way Stop-Controlled Intersection on Rural Highways. Transportation Research Record 1401, Transportation Research Board, National Research Council, Washington, D.C., 83-89.

Benneson, J., McCoy, P., Eitel, D., 1993. Interchange versus At-Grade Intersection on Rural Expressways. Transportation Research Record 1395, Transportation Research Board, National Research Council, Washington, D.C., 39–47.

Boyle, A., Wright, C., 1984. Accident 'Migration' after Remedial Treatment at Accident Blackspots. Traffic Engineering & Control.

Cleveland, D., 1987. Effect of Resurfacing on Highway Safety, State-of-the-Art Report 6: Relationship between Safety and Key Highway Features: A Synthesis of Prior Research, Transportation Research Board, National Research Council, 78–95.

Construction Office Reports, FDOT, http://www.dot.state.fl.us/construction/. Last Accessed February, 2008.

Council, F., Reinfurt, D., Campbell, B., Roediger, F., Carroll, C., Dutt, A., Dunham, J., 1980. Accident Research Manual. Highway Safety Research Center, University of North Carolina.

Davis, G., 2000. Crash Reduction Factors and Causal Inference in Traffic Safety Studies: A Review. Accident Analysis and Prevention, Vol. 32, 95-109.

Financial Management Database (Intranet), FDOT, http://webapp01.dot.state.fl.us/FinancialProjectSearch. Accessed December, 2007.

Hanley, K., Gibby, A., Ferrara, T., 2000. Analysis of Accident Reduction Factors on California State Highways. Transportation Research Record 1717, Transportation Research Board, National Research Council, Washington, D.C., 37–45.

Harwood, D., Bauer, K., Potts, I., Torbic, D., Richard, K., Kohlman Rabbani, E., Hauer, E., Elefteriadou, L., 2003. Safety Effectiveness of Intersection Left- and Right-Turn Lanes. Transportation Research Record 1840, Transportation Research Board, National Research Council, 131–139

Hauer, E., 2001. Overdispersion in modelling accidents on road sections and in Empirical Bayes estimation. Accident Analysis and Prevention 33, 799-808.

Hauer, E., 1997. Observational Before–After Studies in Road Safety. Pergamon/Elsevier Science, Inc., Tarrytown, N.Y.

Hauer, E., Terry, D., Griffith, M., 1994. Effect of Resurfacing on the Safety of Two-Lane Rural Roads in New York State. Transportation Research Record 1467, Transportation Research Board, National Research Council, 30–37.

Hughes, W., Prothe, L., McGee, H., Hauer, E., 2001. Impacts of Resurfacing Projects with and Without Additional Safety Improvements. NCHRP Research Results Digest 255, Transportation Research Board, Washington, D.C.

Introduction to SAS. UCLA: Academic Technology Services, Statistical Consulting Group, from http://www.ats.ucla.edu/stat/sas/. Accessed June 24, 2007.

Lyon, C., Persaud, B., Lefler, N. Carter, D., Eccles, K., 2008. Safety Evaluation of Installing Center Two-Way Left-Turn Lanes on Two-Lane Roads. Transportation Research Board, 87th Annual Meeting, Washington, D.C.

McDonald, J., 1953. Relation between Number of Accidents and Traffic Volume at divided Highway Intersections. Highway Research Board.

McGee, H., Huges, W., Daily, K., 1995. Effect of Highway Standards on Safety. NCHRP Report 374, Transportation Research Board, National Research Council, Washington, D.C.

Mountain, L., Fawaz, B., 1992. The Effect of Engineering Measures on Safety at Adjacent Sites. Traffic Engineering & Control, Vol. 33, No. 1, 10-14.

National Highway Traffic Safety Administration, 2005. Traffic safety facts 2003: A compilation of motor vehicle crash data from the Fatality Analysis Reporting System and the General Estimate System, Washington, D.C.

Noyce, D., Talada, V., Gates, T., 2006. Safety and Operational Characteristics of Two-Way Left-Turn Lanes: Final Report. Minnesota Department of Transportation.

Pendleton, O., 1996. Evaluation of Accident Analysis Methodology. Report FHWA-RD-96-039, Federal Highway Administration, Washington, D.C.

Pendleton, O., 1992. A Systemwide Methodology for Evaluating Highway Safety Studies. Texas Transportation Institute. The Texas A&M University System, College Station.

Pendleton, O., 1991. Application of New Crash Analysis Methodologies: Volume 1-General Methodology. Texas Transportation Institute. The Texas A&M University System, College Station.

Persaud, B., Lyon, C., 2007. Empirical Bayes before–after safety studies: Lessons learned from two decades of experience and future directions. Accident Analysis and Prevention 39, 546-555.

Persaud, B., Retting, R., Lyon, C., 2004. Crash reduction following installation of centerline rumble strips on rural two-lane roads. Accident Analysis and Prevention 36, 1073-1079.

Persaud, B., Retting, R., Garder, P., Lord, D., 2001. Safety Effect of Roundabout Conversions in the United States: Empirical Bayes Observational Before-After Study. Transportation Research Record 1751, Transportation Research Board, National Research Council, Washington, D.C.

Persaud, B., Hauer, E., Retting, R., Valluripalli, R., Mucsi, K., 1997. Crash Reductions Related to Traffic Signal Removal in Philadelphia. Accident Analysis and Prevention, Vol. 29(6), 803-810.

Persaud, B., 1992. Road Safety- A Review of the Ontario Experience and Relevant Work Elsewhere. Ontario Ministry of Transportation.

Persaud, B., 1990. Black spot identification and treatment evaluation. The Research and Development Branch, Ontario, Ministry of Transportation.

Project Contract Documents (Intranet), FDOT, http://webapp01.dot.state.fl.us/enterpriseinformationportal/edms/documentsearch.asp. Accessed February, 2008.

Project Plans (Intranet), FDOT, http://bilby.imageapi.com/dot/main.aspx. Last Accessed February, 2008.

RCI Features and Characteristics Handbook, 2001. Florida Department of Transportation, Transportation Statistics Office, Tallahassee, FL.

Shen, Q., 2007. Development of Safety Performance Functions For Empirical Bayes Estimation of Crash Reduction Factors. (Ph. D Thesis): Florida International University, 206 p.

Srinivasan, R., Council, F., Lyon, C., Gross, F., Lefler, N., Persaud, B., 2008. Safety Effectiveness of Selected Treatments at Urban Signalized Intersections. Transportation Research Record 2056, Transportation Research Board, National Research Council, Washington, D.C., 70-76.

The GENMOD Procedure. SAS Institute Inc., Cary, North Carolina, USA, http://support.sas.com/onlinedoc/913/docMainpage.jsp. Accessed May, 2008.

Video Log (Intranet), FDOT, http://webapp01.dot.state.fl.us/videolog/. Last Accessed May, 2008.

Wang, J., 1994. The Application of an Improved Accident Analysis for Highway Safety Evaluations. Report FHWA-RD-94-082, Federal Highway Administration, Washington, D.C.

Webb, G., 1995. The Relation between Accidents and Traffic Volumes at Signalized Intersections. ITE proceedings, 149-167.

Yuan, F., Ivan, J., 2001. Safety Benefits of Intersection Approach Realignment on Rural Two-Lane Highways. Presented at the 80th Annual Meeting of the Transportation Research Board, Washington, D.C.

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