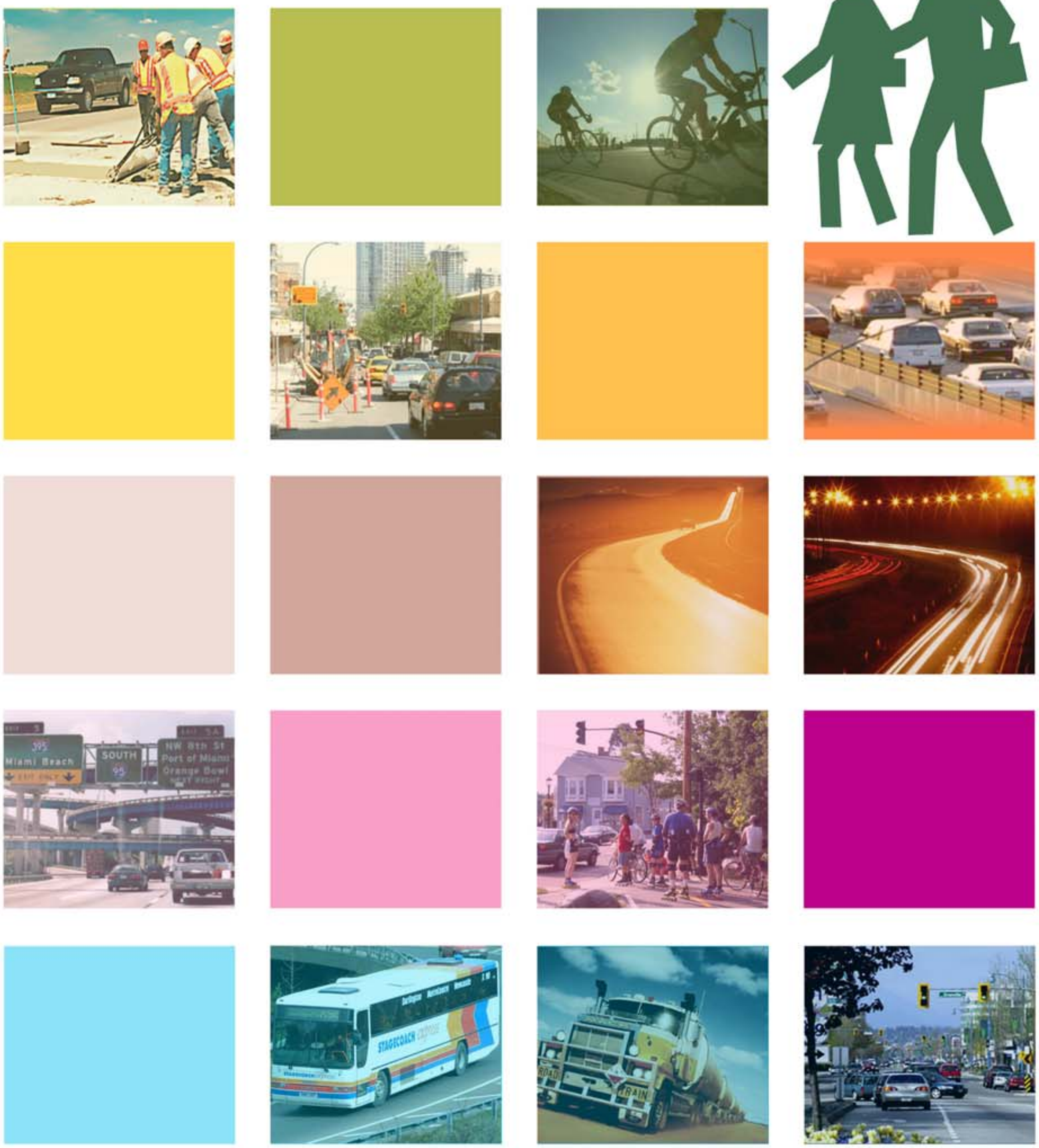
Florida Department of Transportation

Update of Florida Crash Reduction Factors and Countermeasures to Improve the Development of District Safety Improvement Projects

Final Report

April 2005



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Final Report

Update of Florida Crash Reduction Factors and Countermeasures to improve the Development of District Safety Improvement Projects

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Prepared by:

Albert Gan, Ph.D.
Associate Professor

Joan Shen, P.E.
Graduate Research Assistant

and

Adriana Rodriguez
Graduate Research Assistant

Lehman Center for Transportation Research
Department of Civil and Environmental Engineering
Florida International University
10555 West Flagler Street, EC 3680
Miami, Florida 33174

in cooperation with

Safety Office
State of Florida Department of Transportation
605 Suwannee Street, M.S. 53
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15. Supplementary Notes

Mr. Patrick Brady of the Safety Office at the Florida Department of Transportation served as the project manager for this project.

Crash reduction factors (CRFs) are used to estimate the expected reduction in crashes that will occur during a given period as a result of implementing a proposed safety improvement project. This report describes an effort to update the existing CRFs for the Florida Department of Transportation (FDOT) for use in benefit-cost analysis and to develop an automated mechanism to allow continued update of CRFs as new improvement projects become available. A web database application that runs on the FDOT intranet was developed. The system, called Crash Reduction Analysis System Hub (CRASH), provides a means to systematically maintain Florida's safety improvement projects. It also provides capabilities to update CRFs based on the before-and-after study method and perform benefit-cost and before-after analyses for project evaluation. As part of this study, a comprehensive literature on the CRF development methods was performed and a state-of-the-practice survey of the State Departments of Transportation was also conducted. This report also includes a review of the new CRF development effort that is being undertaken by the Federal Highway Administration (FHWA) to apply the Empirical Bayes (EB) method to overcome the well-known regression-to-the-mean problem associated with the current before-and-after development method.

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DISCLAIMER

EXECUTIVE SUMMARY

Introduction

Crash Reduction Factors (CRFs) are used to estimate the expected reduction in crashes that will occur during a given period as a result of implementing a proposed countermeasure. This estimate is needed to perform an economic evaluation of a potential countermeasure. This report documents an effort by the Florida Department of Transportation (FDOT) to update its CRFs and to develop a computer system to systematically maintain safety improvement projects implemented by its district offices to facilitate regular CRF updates.

State-of-the-Art and State-of-the-Practice Reviews

As part of this study, a review of the current methods of developing CRFs was performed. In addition, a state-of-the-practice survey of the state Departments of Transportation (DOTs) was conducted. Before-and-after and cross-sectional methods were found to be the two existing methods for developing CRFs, with the before-and-after method being more widely used. Three existing before-and-after methods were reviewed: (1) the simple before-and-after study method, (2) the before-and-after study with comparison group method, and (3) the before-and-after study with Empirical Bayes (EB) method.

The method used in calculating CRFs in Florida has been based on the commonly used simple before-and-after approach. This approach is easy to implement and has been used widely by state DOTs. However, this approach is also known to suffer a widely recognized problem known as the regression-to-the-mean (RTM)—a statistical phenomenon that occurs when a non-random sample is selected from a population. This selection bias is a direct result of the general practice to select high-crash locations for safety improvements. When data from these locations are used to derive CRFs, the resultant CRFs will tend to overestimate the crash reduction for a treatment site.

In addition to the RTM problem, the simple before-and-after study method is also vulnerable to other known problems, including crash migration, maturation, and external causal factors. The before-and-after study with comparison group method is considered a better approach than the simple method due to its ability to account for the effects of maturation and external causal factors. However, the accuracy of this method is highly dependent on the availability of comparison sites and the similarity between the comparison and treatment sites.

The Empirical Bayes (EB) method has been introduced by researchers as a means to addressing the RTM problem, although it is also more difficult to implement. The idea behind this method in mitigating the RTM effect is to predict the number of crashes expected to occur during the after period had the countermeasure not been implemented. For this prediction, the EB method requires the information from both the treatment site and the reference sites. The information from the reference sites is estimated based on a safety performance function (SPF), which is simply a mathematical relationship that links crash occurrence to traffic and geometric characteristics for a particular roadway type. Findings from the literature review and the state DOTs survey are summarized in chapters two and three of this report, respectively.

Future Directions

Two levels of SPFs can be found in the literature. The "full" SPF predicts crashes as a function of traffic volumes and roadway design conditions. The regression coefficients from full SPFs can be used to derive CRFs. While such regression models have been found to be good predictors of the overall crash experience, the individual coefficients often do not adequately predict the incremental effects of particular roadway design variables. Consequently, a second level of SPFs, referred to as the "traffic" SPFs, has been suggested. A traffic SPF relates crash occurrence to only the traffic volumes. To predict the number of crashes at a site, the crashes predicted by traffic SPF is adjusted by a number of so-called accident modification factors (AMFs), which are multiplicative factors that are used to adjust the base crash frequency (as predicted by a "traffic" SPF) due to the effects of individual roadway design features such as lane width, shoulder width, etc.

The implementation of the EB method to account for the RTM bias is important but non-trivial. In 2001, the Federal Highway Administration (FHWA) entered into a major contract to develop an EB-based system known as *SafetyAnalyst* (http://www.safetyanalyst.org/index.htm). This system is aimed at providing the state and local highway agencies with a comprehensive set of tools to improve their programming of site-specific highway safety improvements. This national system will have default SPFs and AMFs developed from studies throughout the U.S. and Canada. States will have the option to replace these default values with localized SPFs and AMFs to better represent the local crash experience.

To take advantage of the new capability from *SafetyAnalyst* to improve its safety improvement programs, it is recommended that the FDOT develop a system that can help to prepare the data needed to go into the system and to perform regression analysis to develop and update Florida specific SPFs and AMFs. The goal will be to develop an information infrastructure that supports Florida's use of the *SafetyAnalyst* national model, which is an EB-based system that is designed to address the RTM problem associated with the simple before-and-after method currently used by most state DOTs, including FDOT.

Computer Database and Analysis System

The development of the Crash Reduction Analysis System Hub (CRASH) system in this study provides a good start for the longer-term effort to improve Florida's safety improvement programs. It also provides a platform for FDOT to support applications of the *SafetyAnalyst* system. Developed as a web-based application that runs on FDOT's Intranet system, CRASH is able to perform the following tasks in a highly automated manner:

1. Recording and maintaining improvement projects,
2. Updating CRFs based on the latest available improvement project and crash data, and
3. Applying calculated CRFs in the benefit-cost analyses of specific projects.

In addition, the system provides various functions for data retrieval and exportation for different analysis and reporting purposes. Detailed instructions on how to use the system are included in chapter four of this report.

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CHAPTER 1
INTRODUCTION

1.1. Background

Highway safety is a major public concern in our daily life. Traffic crashes cause fatalities, physical injuries, property damages, as well as highway congestion. In 2003, there were 42,643 fatalities, 2,889,000 injuries, and 4,365,000 cases of property damages in the United States, costing the nation more than 230 billion dollars (NHTSA, 2005). In order to improve highway safety, Congress passed the 1966 Highway Safety Act, which required state Departments of Transportation (DOTs) to develop and implement safety improvement programs. Identification of high-hazard locations and evaluation of the effectiveness of highway safety improvements are essential elements of these programs. The standard procedure for identifying and eliminating hazardous locations consists of the following six general steps (Davis, 2000):

1. Identifying high-hazard locations based on reported crash data.
2. Obtaining detailed design problems in the high-hazard locations by conducting engineering studies.
3. Identifying possible countermeasures for hazardous locations.
4. Predicting the effect of potential countermeasures in terms of reduced numbers of crashes or severity of crashes.
5. Implementing countermeasures with the highest net benefits on investment.
6. Evaluating the effectiveness of the countermeasures after implementation.

Two important steps in the above procedure are to identify crash causation and predict the reduction in crashes through highway improvements. Each proposed improvement must first be identified and evaluated to ensure that it has a sufficiently high probability of reducing the number and the severity of crashes, so that the improvements result in an overall economic benefit. Within a given budget and a vast highway system, available safety funds must be spent more wisely. Therefore, traffic engineers must identify the highest hazardous locations and select the most effective countermeasures that will produce the greatest benefit-cost ratios.

The total benefit of implementing a countermeasure includes the costs saved resulting from the number of crashes or crash severity reductions; and the total cost of implementing a countermeasure includes construction and possibly maintenance costs. The determination of benefits from countermeasures depends on projected crash reductions, which is calculated as the expected number of crashes without the countermeasures multiplied by a crash reduction factor (CRF). Thus, CRF is simply a quantitative statement of the percentage of crashes that a countermeasure is expected to reduce.

1.2. Problem Statement

In 1987, the Florida Department of Transportation (FDOT) contracted with the University of Florida (UF) to develop a set of Florida specific CRFs based on 237 improvement projects submitted by various FDOT district offices. In the study, a total of 103 countermeasures were identified and selected for analysis, but data were available for only 58 of the countermeasures. Of the 58 countermeasures that have data, only 24 were found to have resulted in significant reduction in total crashes. Since the completion of the UF study, hundreds of safety improvement projects have been implemented throughout the state. In addition, shortcomings associated with the commonly used before-and-after method of developing CRFs have become better recognized and at the center stage is the validity of CRFs developed using the method.

1.3. Project Goal and Objectives

In light of the state problems, this project aims to improve existing CRFs by accomplishing the following specific objectives:

1. Perform a thorough review of the literature on the state-of-the-art research in CRFs and countermeasures.
2. Conduct a survey of all U.S. State Departments of Transportation to identify the state-of-the-practice in CRFs and countermeasures.
3. Update existing Florida CRFs with data from additional safety improvements projects to improve their accuracy.
4. Develop CRFs for countermeasures that were not developed in the UF study due to insufficient data to provide a more complete set of CRFs for use by District Offices.
5. Create a database of safety improvement projects and a user-friendly application software to interface with the database to facilitate continued update of CRFs.

1.4. Report Organization

The remaining chapters of this report are organized as follows: Chapter 2 provides a review of the existing methods used to develop CRFs and the limitations associated with each method. Chapter 3 summarizes results from a survey of state Departments of Transportation on the state-of-the-practice of CRF development and applications. Chapter 4 describes a user-friendly web application developed to maintain Florida's safety improvement projects and to develop and apply CRFs in benefit-cost analysis. Chapter 5 introduces an ongoing national effort to develop Accident Modification Factors (AMFs) and Safety Performance Functions (SPFs) as part of a new approach for developing CRFs. Finally, chapter 6 provides a summary of this report and recommendations for future work.

CHAPTER 2
EXISTING CRF DEVELOPMENT METHODS AND THEIR LIMITATIONS

2.1. Introduction

As described in the previous chapter, crash reduction factors (CRFs) are used to estimate the expected reduction in crashes that will occur during a given period as a result of implementing a proposed countermeasure. This estimate is needed to perform an economic evaluation of potential countermeasures. National Cooperative Highway Research Program (NCHRP) Report 162 (Laughland *et al.*, 1975) first identified the need for development of a national comprehensive set of CRFs for each state to evaluate safety improvement projects. However, this need has not been met. As a result, many states have developed their own CRFs and/or have adopted CRFs from other states (Strathman *et al.*, 2001). This chapter attempts to provide a synthesis of the CRF development methods and their associated problems.

2.2. CRF Development Methods

Before-and-after and cross-sectional are two methods used to develop CRFs. In a before-and-after study, the safety effect of a countermeasure is determined by the difference in the number of crashes occurring before the improvement with those occurring after. In contrast to the before-and-after study, the cross-sectional approach usually employs regression methods to estimate crash frequencies from a large sample of roadway segments whose design attributes vary systematically (Strathman *et al.*, 2001). Such regression models estimate the marginal effects of changes in highway design attributes on crash frequencies. Tarko *et al.* (1998) summarized the major differences between these two methods as follows:

> "…The key difference between before-and-after and cross-sectional studies is not in the different methods used to analyze the data (as a matter of fact, they can be similar) but rather in the different concept of how to investigate the safety effect. In the before-and-after study, the idea is to investigate these locations where a given improvement has been applied within the period of analysis, while for the cross-sectional analysis, the investigated locations do not experience any major changes within the period of analysis. Thus, the before-and-after study focuses on the changes in safety over time, while the cross-sectional analysis focuses on the differences in safety between locations. …"

One major advantage of the cross-sectional method is that the regression models can be used in sensitivity analysis of alternative highway improvements. One major disadvantage is that it does not take into account the effects of factors that are not included in the model (Benekohal, 1991). On the other hand, the before-and-after approach has the advantage of conforming to the idea of a controlled experiment. The approach analyzes the sites with only one or more improvements, while other characteristics are approximately constant. The main disadvantage is that the cost of proper design and execution of such studies, particularly over the range of relevant safety countermeasures, could be beyond the means of some state DOTs (Strathman *et al.*, 2001).

The before-and-after method is the more widely used approach for developing CRFs. The main data used in this study are the before and after crash counts. Crashes that occurred during the construction period are not included in the analysis (Griffith, 1999). Two or three years are often used for the before and after periods. Pendleton (1991) suggested that three years may be excessive, in that it may be more likely to allow external factors to enter into the analysis, for instance, a change in posted speed, pavement conditions, etc. Hauer (1997) recommended the use of a period of three years if data are available and no significant changes in external factors have occurred.

Michaels (1966) suggested that the following factors be considered in the design of before-and-after studies:

1. Some measure of vehicle-miles is needed for both the before and after periods in order to equate crash exposure.
2. The traffic volumes for each of the two periods should be approximately the same.
3. The composition of the traffic on the study section should be unchanged during each of the two periods.
4. The crash total in the after period should be corrected for any existing trends.
5. If crash data for several years before modification are available, and show a variation of no more than 20 percent from year to year, they may be averaged.

2.3. Before-and-After Methods

The following three types of before-and-after methods exist in the literature:

1. The simple (or naive) before-and-after study method.
2. The before-and-after study with comparison group method.
3. The before-and-after study with Empirical Bayes (EB) method.

These methods are reviewed in detail in the following subsections.

2.3.1. Simple Before-and-After Study Method

The concept of the simple before-and-after study is straightforward. It is based on the assumption that if nothing has changed, the crash experience before improvement is a good estimate of what would have happened on the after period without improvement. The basic formula for deriving a CRF based on this method is:

$$CRF = \frac{(N_b - N_a)}{N_b} = 1 - \frac{N_a}{N_b} \qquad (2\text{-}1)$$

where N_b and N_a are, respectively, the number of crashes at a treated site before and after the improvement took place. When N_a is greater than N_b, the CRF is negative and the countermeasure would be expected to increase, rather than reduce, crashes. In actual application, exposure to crashes is often considered in order to account for any changes in crash exposure that may have occurred between the before and after periods. Accordingly, the CRFs are usually calculated based on crash rates as follows:

$$CRF = \frac{(CR_b - CR_a)}{CR_b} = 1 - \frac{CR_a}{CR_b} \tag{2-2}$$

where CR_b and CR_a are, respectively, the crash rates at a treated site before and after improvement. The equation used to compute the crash rates is:

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

where

$$Exposure = \frac{(Total\ Miles) * (Number\ of\ Days) * (Mean\ AADT)}{1{,}000.000} \tag{2-4}$$

$$Mean\ \ AADT = \frac{Sum\ \ of\ \ AADT\ from\ \ each\ \ crash}{Total\ \ Number\ \ of\ \ Crashes} \tag{2-5}$$

With this method, in essence, the safety effect of a countermeasure is simply determined directly by the difference between the crash rate before and the crash rate after the countermeasure is implemented.

All existing CRFs have been developed based on the simple before-and-after approach. However, it has been found that this method can lead to inaccurate and potentially misleading conclusions because the method is known to subject to the following problems:

1. Regression-to-the-mean
2. Crash migration
3. Maturation
4. External causal factors

Elvik (1997) found that, in general, the more of these problems are accounted for, the less effective a countermeasure appears to be. This points to the importance of taking into account the impacts of these problems in CRF development.

2.3.1.1. Regression-to-the-Mean

Regression-to-the-mean, also known as a "regression artifact" or "bias by selection", is a statistical phenomenon that occurs whenever a non-random sample is selected from a population. The problem has been known for many years and is perhaps the most frequently cited problem associated with before-and-after studies. In practice, a location is usually selected for treatment for the reason that it has an unusually high number of crashes than other similar sites based on recent crash records. The locations with high crash frequencies for the before periods thus tend to have higher reductions in crash frequency after improvements, that even without any treatments, the crash frequencies would likely reduce simply because the sites tend to 'regress' or return to the long-term mean number of crashes (Council *et al.*, 1980).

Council *et al.* (1980) showed the effect of regression-to-the-mean with a hypothetical example, illustrated in Figure 2-1. In Figure 2-1 the number of crashes ranges from 8 to 32, with an average of 20. It can be seen that if an improvement were constructed in 1973 in response to the large number of crashes that occurred in 1972 the results would have shown a 28 percent of crash reduction after treatment. While the treatment may have some effect, some portion of the crash reduction was due to the regression to the mean and not the improvement. Consequently, the effectiveness of the treatment will be overestimated. Failing to account for the regression-to-the-mean effect in an analysis could thus generate statistically significant results for treatments that are actually ineffective (Council *et al.*, 1980; Ermer *et al.*, 1992).

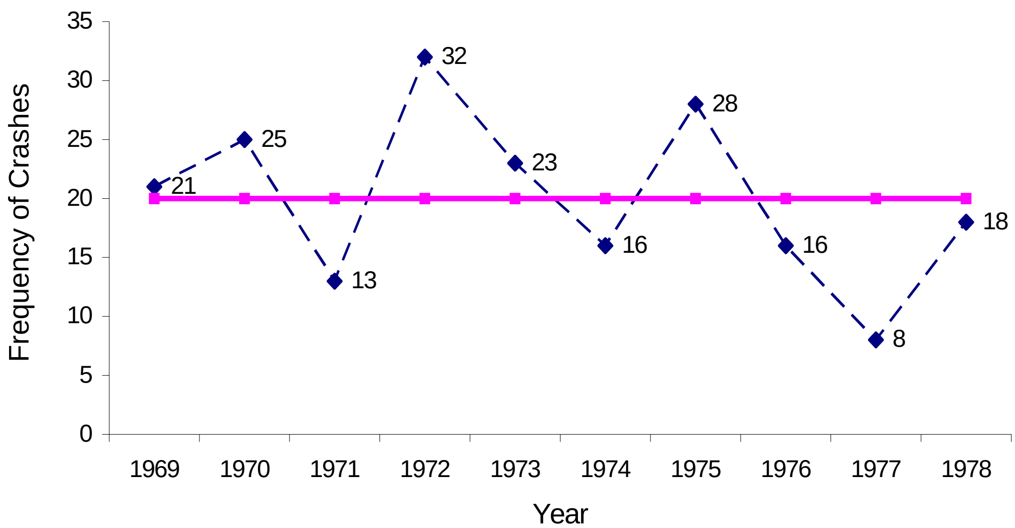


Figure 2-1. Regression-to-the-Mean Example

2.3.1.2. Crash Migration

The problem of crash migration can be geographic and non-geographic. Geographic migration is a transfer of crashes from a treated site to surrounding locations as a result of a treatment. For instance, when a particular highway curve is improved, crashes at that curve may decrease, but crashes at the next curve may increase. Non-geographic migration, on the other hand, involves a shift across severity levels and/or crash types due to a treatment. For example, installing light poles can reduce nighttime crashes, but may increase fixed-object crashes, which may also increase the overall crash severity. In recent before-and-after safety studies, researchers have been more interested in geographic migration than non-geographic migration, since methods already exist to account for non-geographic crash migration. Thus, the term "crash migration" is usually referred to as "geographic crash migration" (Pendleton, 1992).

The existence of crash migration has been known for over 20 years since Boyle and Wright (1984) first drew attention to the problem. Since then a number of researchers have tried to demonstrate that crash migration exists and can be observed. When crash migration occurs, crashes may be observed to decline at treatment sites, they may increase elsewhere. Accordingly, it was suggested that the assessment of safety improvement should be based on crash data collected over a wider area rather than simply at the treated site itself. This allows changes in the number of crashes for the expanded site locations to reflect both the treatment effect at the treated sites and the crash migration effect at the surrounding sites (Mountain and Fawaz, 1989).

Mountain and Fawaz (1992) used 500 meters as a limit for selecting the surrounding sites and concluded that crash migration did occur because of treatment and that the area of influence varied with time and distance from the treated site. They also summarized six possible explanations of crash migration phenomena. The first three explanations, given below, imply that the migration is in some way related to treatment.

1. Improvement at a site changes drivers' behavior. For example, the improvement at a site could reduce drivers' awareness of the need for caution for other nearby sites. This reduced awareness may persist for some distance downstream, and increase the risk of a crash at the surrounding area of a treated site (Boyle and Wright, 1984).

2. The existence of 'end effects' in certain types of improvements that cause drivers to fail to adjust adequately to changes in highway conditions. For instance, the addition of traffic lanes may shift crashes to the merge section downstream.

3. A treatment may increase in crash exposure at adjacent sites. Some types of improvement cause a redistribution of traffic flow so that vehicle volume decrease in treated sites and increase in the surrounding area. For example, installation of speed humps will tend to increase crashes on adjacent roads as drivers reroute to avoid roads with humps.

The second three explanations below suggested that crash migration is unrelated to treatment:

1. Crash migration is merely a statistical artifact due to a reverse regression-to-the-mean effect. Maher (Maher, 1987 and 1990) suggested that crash migration could be the result of a combination of regression-to-the-mean downwards from the high crash counts at treated sites and regression-to-the-mean upwards from the low crash counts at surrounding sites.

2. Crash migration is caused by a physical deterioration of the neighboring sites, for example, a decrease in skid-resistance or pavement marking.

3. Crash migration is part of a rising trend in crashes that would have occurred without any treatment at the surrounding area.

Short and Robertson (1998), for example, found no evidence to support crash migration. Some researchers have used statistical models to estimate regression to the mean at both treated and surrounding sites, while others accepted the recorded number of crashes at both sites as unbiased estimates of the expected number of crashes. It has been found that studies that use either of these designs account for the effect of crash migration (Elvik 1997). Elvik (1997) performed a meta-analysis of 36 studies and concluded that more research was needed to determine how widespread crash migration was and the mechanisms that could be used to explain it. Current research on crash migration remains inconclusive.

2.3.1.3. Maturation

Crash numbers or crash rates on a roadway often show trends due to temporal changes in factors such as traffic flow, weather, economy, crash reporting practices, etc. Council *et al.* (1980) referred to these general trends in crash numbers or rates over time as "maturation." Analysis of treatment effectiveness at improved locations must consider crash trends to obtain accurate results. For example, if a treatment at selected sites shows a change in crash numbers or rates between before and after periods, it is possible that this change was due to the implemented countermeasure; however, it might also be an extension of a continuing decreasing trend that had been occurring for years. If this crash trend had not been realized, it might be concluded that the observed decrease in crash numbers or rates from the before period to the after period was simply due to the change in design standards. While this could be the case, another alternative cause of this decrease could simply be the continuing decrease in crash counts resulting from the combination of many other factors (Council *et al*., 1980).

Figures 2-2 (a) to (c) illustrate the problem of maturation. In Figure 2-2 (a), the crash frequencies for before and after a treatment are given as B and A, respectively. The reduction in crashes following the treatment is thus equal to (B-A). This reduction is based on the assumption that the underlying crash trend is as shown in Figure 2-2 (b). However, if the crash history exhibits the trend shown in Figure 2-2 (c), the reduction, B-A, would have been overestimated, since the crash trend is such that, even without treatment, the crash frequency would likely fall somewhere close to the extension of the dotted line in Figure 2-2 (c), giving a reduction close to B-A. The simple before-and-after design does not consider the effect of this problem (Council *et al*., 1980).

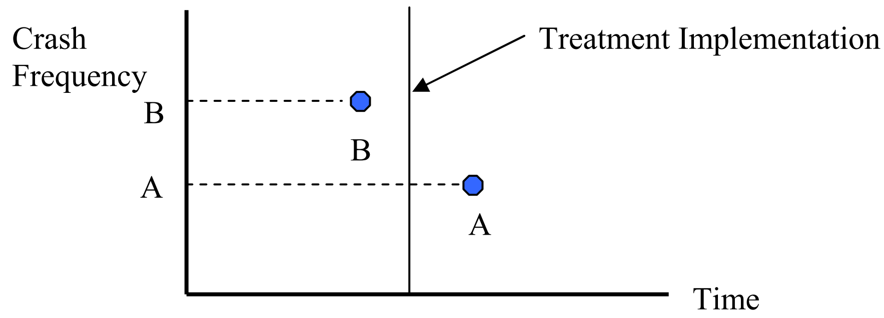
2.3.1.4. External Causal Factors

The factors that influence the safety of highways can be classified into two types (Hauer, 1997):

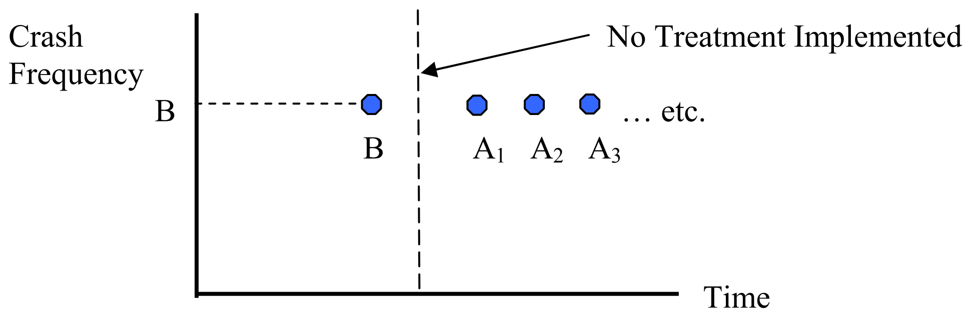
1. Factors that can be recognized, measured, and understood, such as traffic volume growth. This type of factors can be accounted for explicitly in the calculation of CRFs. For example, some states (Ermer *et al.*, 1992; Yuan *et al.*, 1999) have used the following equation to adjust for the effect of traffic growth:

$$\textit{Adjusted CRF} = \frac{(N_b / V_b) - (N_a / V_a)}{N_b / V_b} = 1 - \left(\frac{N_a}{N_b}\right)\left(\frac{V_b}{V_a}\right) \tag{2-6}$$

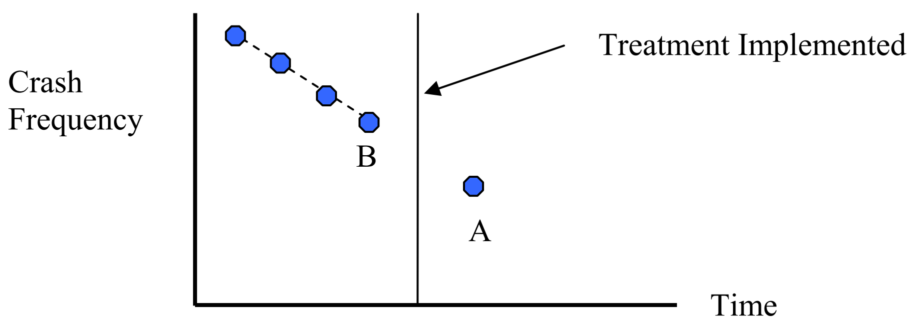
   where N_b and N_a are, respectively, the number of crashes at an improvement site before and after the improvement was constructed, and V_b and V_a are the traffic volumes associated with the before and after numbers of crashes, respectively. In this case, although the modification aims to improve the accuracy of the CRFs by adjusting for traffic growth, it requires historical AADT data that are not always available in sufficient quantity and quality at some state DOTs.



(a)



(b)



(c)

Figure 2-2. Effects of Crash Trends on Crash Reduction Estimation

2. Factors that cannot easily be recognized, understood, or measured, such as precipitation, economic conditions, vehicle fleet, etc. A major problem with the simple before-and-after study is that it cannot distinguish between the effect of the treatment and the effect of such causal factors that may have also changed from the 'before' to the 'after' period.

2.3.1.5. Remarks

Despite the many potential problems associated with the simple before-and-after method, this approach has been widely used on the basis of one or more of the following justifications (Hauer, 1997):

1. It has traditionally been the most widely used in the evaluation of highway improvements, so that the CRFs developed with this method can be compared and verified with reported CRFs.
2. No other study design can reach the statistical precision attainable in a simple before-and-after study.
3. It is known that the regression-to-the-mean effect is not significant and does not greatly affect the results of the analysis.
4. Selected sites usually have a long high crash history; thus, sites with short-term increase in crashes are excluded.

2.3.2. Before-and-After Study with Comparison Group Method

To solve the external causal factors and maturation problems, researchers have developed the before-and-after study with comparison group method. A comparison group is a group of control sites selected as being similar enough to the treatment sites in traffic volume and geographic characteristics. By this method, crash data at the comparison group are used to estimate crashes that would have occurred at the treated sites if the treatment had not been made. This method can potentially produce more accurate estimates than a simple before-and-after method. Its strength increases as the similarity between treated and comparison sites increases (Mountain *et al.*, 1992).

The before-and-after with comparison group method is based on two fundamental assumptions (Hauer, 1997):

1. The factors that affected safety have changed in the same way from the before period to after the improvement on both treatment and comparison groups, and
2. The changes in the various factors influence the safety of treatment and comparison groups in the same manner.

Under these assumptions, it can be assumed that the change in the number of crashes before and after the implementation of countermeasures in the treated sites, if the treatment had not been improved, would have been in the same proportion as that for the comparison group. Accordingly, the expected number of crashes in the after period for the treated sites without the improvement, N_{at}, can be predicted as the observed number of crashes in the before period for the treatment group, N_{bt}, multiplied by the ratio of after-to-before crashes at the comparison sites, R_c, as follows (Hauer, 1997):

$$N_{at} = N_{bt} \times R_c \tag{2-7}$$

The CRF can thus be estimated using Equation 2-1.

Different formulas have been proposed to compute CRFs on the basis of the before-and-after study with comparison group method. One of these formulas is based on the so-called odds (or cross-product) ratio, as follows:

$$CRF = Odds\ Ratio - 1 \tag{2-8}$$

If the resulting CRF is negative, it indicates a decrease in crashes due to treatment; otherwise, the improvement increases the number of crashes at treated sites (Pendleton, 1991 and 1996; Griffin, 1982). Note that this definition is the reverse of that of Equation 2-1, which defines a positive CRF for crash reduction. Pendleton (1991 and 1996) proposed the following formula for odds ratio:

$$Odds\ Ratio = \frac{M / N}{K / L} \tag{2-9}$$

where

- K = before crash counts for treatment group,
- L = after crash counts for treatment group,
- M = before crash counts for comparison group, and
- N = after crash counts for comparison group.

Thus, *M/N* is the odds of the before-and-after crashes in the comparison group and *K/L* is the same odds for the treatment group. Griffith (1999) and Hauer (1997) defined another odds ratio, as follows:

$$Odds\ Ratio = \frac{(KN)}{(LM)(1+1/L+1/M)} \tag{2-10}$$

where the variables are as defined previously. This formula used the sums of the before-and-after crashes to calculate the overall effectiveness of the countermeasure at the treatment sites.

Since the number of treatment and comparison sites are not always equal, an adjustment is needed to extrapolate the results from the comparison sites to the treatment sites. Al-Masaeid (1997) proposed use of the following equation to compute the reduction in the total number of crashes per year:

$$N = (N_{bt} - N_{at}) - (N_{bc} - N_{ac})\left(\frac{n_t}{n_c}\right) \tag{2-11}$$

where

- N = Total number of crashes reduced at treatment sites,
- N_{bt} = Total number of crashes that occurred at treatment sites in the before periods,
- N_{at} = Total number of crashes that occurred at treatment sites in the after periods,
- N_{bc} = Total number of crashes that occurred at comparison sites in the before periods,
- N_{ac} = Total number of crashes that occurred at comparison sites in the after periods,
- n_t = Number of treatment sites, and
- n_c = Number of comparison sites.

The corresponding CRF is computed as follows:

$$CRF = \left(\frac{N}{N_{bt}} \right) \times 100 \tag{2-12}$$

Benekohal and Hashmi (1992) proposed another formula for estimation of crash reduction, as follows:

$$N = \frac{(N_{bt} - N_{at}) - (N_{bc} - N_{ac})}{2} \tag{2-13}$$

where all the variables are as defined above. Because the increase in traffic volume will increase the number of crashes on the treatment sites, the total number of crashes is adjusted by a K factor, i.e., $N \times K$, to account for the impact from the increase in traffic volume during the service life of an improvement.

Although the before-and-after study with comparison group method solves a problem in the simple before-and-after method by considering natural time-related factors in both periods, its practical use is sometimes limited because of the difficulty in finding a sufficient number of similar sites that are left without treatment. Thus, the biggest challenge in using this method is in defining and collecting data for a truly comparable group. The likelihood ratio chi-square (χ^2) test is typically used to test for comparability for the before period in both groups. If a large chi-square value is obtained, the comparison group lacks comparability during the before period and the analysis would be terminated. On the other hand, non-significance in the chi-square value means that the treatment and comparison groups are comparable.

Griffith (1999) cited two types of comparisons that can be used in this method: the before-and-after study with yoked comparison and the before-and-after study with a comparison group. The first type of comparison is the usual approach. It involves a one-to-one matching between a treatment site and a comparison site. The second type involves a group of sites selected to match the group of treatment sites. There may be more or fewer comparison sites than treatment sites. Pendleton (1991) suggested that the size of a comparison group should be at least five times larger than the treatment sites. It is important that between the treatment and comparison groups there is a close agreement in the monthly or yearly time series of crash frequencies during the period before improvement (Griffith, 1999).

Hauer (1997) suggested that a comparison group should meet the following requirements:

1. The length of before and after periods for the treatment and the comparison group should be the same.
2. There should be confident that the change in the factors that affected safety is similar for both groups.
3. The number of crashes in the comparison group should be sufficiently large compared with the number in the treatment group.

4. When a sequence of sample odds ratios is calculated from historical crash counts, their sample mean is close to 1 and their variance is small.

2.3.3. Before-and-After Study with Empirical Bayes (EB) Method

Of all the problems associated with the simple before-and-after method, the regression-to-the-mean problem is generally considered the most serious. The before-and-after study with Empirical Bayes (EB) method has been developed to adjust for the regression-to-the-mean bias. The method is based on the following three assumptions:

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

The idea behind the EB method in mitigating the regression-to-the-mean effect is to predict the number of crashes that would have been expected to have occurred during the after period had the treatment not been implemented. Several methods exist to predict this expected number of crashes (Hauer, 1997; Wright *et al.*, 1988; Mountain *et al.*, 1992; Mountain and Fawaz, 1991). In general, these methods consist of the following two steps (Hauer, 1997):

1. Establishes the foundation for the prediction by estimating what the expected frequency of target crashes in the 'before' period was.
2. Based on this foundation, predicts how the expected number of crashes would have changed from the 'before' to the 'after' period as a result of changes in traffic, weather, and other factors.

With these steps, the EB method uses data from the crash history of a treated site, as well as the information of what is known about the safety of reference sites with similar geometric characteristics, to estimate how many crashes would have occurred at the treated site had no improvements been made. The joint use of the information from treatment and reference sites is based on a weighted average, as follows (Hauer *et al.*, 2001):

$$\textit{Estimate of the expected crashes at treatment sites} = \textit{Weight} \times \textit{Crashes expected at reference sites} + \textit{(1-Weight)} \times \textit{Actual crashes at treatment sites} \qquad (2\text{-}14)$$

where $0 \le \text{Weight} \le 1$. Thus, the expected number of after crashes had no improvement been made at the treatment sites is a function of how the 'weight' assigned to the crashes expected at the reference sites. If the 'weight' is chosen to be near 1, then the estimate of the expected crashes for treatment sites is close to the mean of its reference sites; if the 'weight' is chosen to be near 0, then the estimate of the expected crashes at the treatment sites will mainly reflect the recorded count of crashes.

The method for deriving the variables in Equation 2-14 is well described by Hauer (1997). Using his notation, $k_1, k_2, k_3, \ldots$ are the number of crashes at references sites 1, 2, 3, …, respectively, whose characteristics were determined to be similar to those at the treatment sites. If $E(k)$ is the expected number of crashes at the reference sites and K is the actual crash count at the treatment sites, then $E(k|K)$ is the estimate of the expected number of crashes at the treatment sites given that the sites recorded K crashes. Accordingly, Equation 2-14 can be expressed as follows:

$$E(k|K) = \alpha E(k) + (1-\alpha)K \tag{2-15}$$

where α is the weight factor, which can be shown to have the following expression:

$$\alpha = \frac{1}{1+\dfrac{VAR(k)}{E(k)}} \tag{2-16}$$

where $VAR(k)$ is the variance of the expected number of crashes at the reference sites. Hauer (1997) suggested the following two methods for calculation of $E(k)$ and $VAR(k)$: (1) the method of sample moments, (2) the multivariate regression method. The formulas for the method of sample moments are:

$$E(k) = \bar{k} \tag{2-17}$$

$$VAR(k) = s^2 - \bar{k} \tag{2-18}$$

where $\bar{k}$ and s^2 are the sample mean and variance, respectively, of the crashes at the reference sites. They can be calculated from the following equations:

$$\bar{k} = \frac{\sum kN_k}{N} \tag{2-19}$$

$$s^2 = \frac{\sum (k-\bar{k})^2 N_k}{N} \tag{2-20}$$

where N is the number of reference sites, N_k is the number of treatment sites that have recorded k crashes during a specified period. This method requires a larger number of samples. The larger the reference sites, the more accurate the estimates are.

For the multivariate regression method, several studies have used the following model:

$$E(k) = \beta_0 \times X_1^{\beta_1} \times X_2^{\beta_2} \times X_3^{\beta_3} \times X_4^{\beta_4} \times ... \tag{2-21}$$

$$VAR(k) = \frac{[E(k)]^2}{b} \tag{2-22}$$

where β_0 is a constant, β_1, β_2, β_3, β_4, … are the parameters of the independent variables, X_1, X_2, X_3, X_4, …, and b is a parameter associated with the Gamma distribution that can be estimated from the crash data using the maximum likelihood method. The independent variables represent factors such as traffic flow, road section length, number of lanes, shoulder width, intersection density, etc. An example of a multivariate regression model for the total crashes per year (N) for four-leg signalized intersections on rural two-lane highways is given below (*FHWA, 1999*):

$$N = exp(-5.46 + 0.60 ln\ ADT_1 + 0.20\ ln\ ADT_2 - 0.40PROTLT - 0.018PCTLEFT_2 + 0.11VEICOM + 0.026PTRUCK + 0.041ND_1) \quad (2\text{-}23)$$

where

ADT_1, ATD_2 = average daily traffic for major and minor roads;
PROTLT = presence of protected left-turn signal phase on one or more major-road approaches, = 1 if present; = 0 if not present;
$PCTLEFT_2$ = percentage of minor-road traffic that turns left at the signal during the morning and evening hours combined;
VEICOM = grade rate for all vertical curves (crests and sags) within 250 ft of the intersection along the major and minor roads;
PTRUCK = percentage of trucks (vehicles with more than four wheels) entering the intersection for the morning and evening peak hours combined; and
ND1 = number of driveways within 250 ft of the intersection on the major road.

Compared to the method of sample moments, this method has the following two advantages: (1) it provides estimates of $E(k)$ and $VAR(k)$ for reference sites that match the characteristics of the treatment sites exactly, and (2) a large number of reference sites is not needed for any particular combination of characteristics (Hauer, 1997).

Several studies have compared the performances of the three different before-and-after methods. It was found that the simple before-and-after method generally overestimates the safety benefits of treatments and results in erroneous conclusions if care is not taken to avoid the regression-to-the-mean bias. The studies also indicate that the results of the EB method were generally comparable to those obtained from the before-and-after with comparison group method. Therefore, the EB method can be used if a suitable and sufficiently large number of comparison locations is not available (Rimiller, 2001). Although the EB method helps to account for the regression-to-the-mean bias and is more precise than the other two methods, it has one potential weakness in that it imposes some assumptions about the probability distribution of crash occurrences. In addition, the EB method is also more difficult to implement. In a recent Federal Highway Administration (FHWA) study, an EB-based software program called Empirical Bayesian Estimation of Safety in Transportation (EBEST) was developed (Pendleton, 1991 and 1996; Wang, 1994). However, according to the FHWA project manager who oversaw the project development, EBEST was outdated and its use was not advised (Michael Griffith, FHWA, personal communication, March 20, 2002).

2.4. Cross-Sectional Method

As stated earlier, cross-sectional analysis employs regression methods to statistically estimate crash frequencies from a large sample of roadway segments whose design attributes vary systematically. The accuracy of such models is affected by how closely a model expresses the relationship between crash frequency and its predictor variables. Most cross-sectional studies include principal roadway cross-section attributes such as number of lanes, lane width, shoulder width, surface type, median type, turning lane, vertical grade, and horizontal and vertical curve characteristics, etc. Also, many applications include traffic volume and composition as covariates. While cross-sectional method is useful in sensitivity analysis and evaluation of alternative highway improvement policies, it does not take into account the effects of parameters that are not included in the model, for example, driver population and local conditions (Benekohal, *1991*).

The cross-sectional method is generally used for two purposes (*Tarko et al., 1998*):

1. Develop predictive model for the expected number of crashes.
2. Quantify the safety impact of highway improvements by CRFs.

These two objectives are different and require focus on the different aspects of the analysis. The first objective is to develop the most efficient model that has as few variables as possible but estimates the crash frequency with the lowest error. The second objective is to estimate as many regression parameters representing safety impacts as possible.

There are two steps in a cross-sectional study. The first step is to select a proper regression model for estimating the relationship between highway design attributes and crash experience. Different regression models are found in literature, such as Poisson, Zero-inflated Poisson, Negative Binomial, Zero-inflated Negative Binomial, Ordinary Least Squares, etc. A large number of such regression models exist in the literature and a review of these models is beyond the scope of this report. For illustrative purposes, one example of Negative Binomial log-linear model developed by Indiana DOT (*Tarko et al., 1998*) has the following functional form:

$$A = kLQ^{\beta} \exp(\alpha X) \tag{2-24}$$

where

- A = expected number of crashes,
- L = length of the section (in miles),
- Q = AADT on the road section,
- X = explanatory variables, and
- k, α, β = regression parameters.

The linear relationship between the number of crashes and the length of the section is obvious. Twice as many crashes are expected on a twice longer homogeneous section. Since the relationship between crashes and AADT may be non-linear, the parameter β is added.

The second step is to develop CRFs for the countermeasures. A CRF due to a change in a given condition is determined by computing the difference in the predicted crashes between the before and after conditions and dividing that value by the predicted crashes in the before conditions (*Al-Masaeid, 1990*).

Although the cross-sectional approach has the advantages that it draws on readily available data maintained by state DOTs, reflects state-specific circumstances, and can be undertaken for a small fraction of the cost of comparable before-and-after studies, they tend to be less reliable than the before-and-after method because of the tendency to underestimate the safety effectiveness of countermeasures. Moreover, the cross-sectional approach requires an extensive amount of data to ensure proper specification, and is subject to estimation problems related to data quality. This may explain one reason the cross-sectional method has not been widely used. In the state survey described in chapter 3, only Oregon DOT and Indiana DOT have used this method to develop their CRFs. While the number of design-related factors in cross-sectional models appears to be increasing over time, as state DOTs have automated their roadway inventory data, it is still doubtful that the coverage of crash models will ever be sufficiently comprehensive to effectively substitute for the present system, which encompassed hundreds of countermeasures in differing contexts (*Strathman et al., 2001*).

2.5. Summary

Crash reduction factors (CRFs) are used to predict the change in the number of crashes or crash rates that a countermeasure can be expected to cause. Before-and-after and cross-sectional methods are the two existing methods for developing CRFs. The before-and-after method is the more widely used approach for developing CRFs. Three before-and-after methods have been used: (1) the simple before-and-after study method, (2) the before-and-after study with comparison group method, and (3) the before-and-after study with Empirical Bayes (EB) method. The simple before-and-after study method is commonly used by state DOTs to develop CRFs, despite its vulnerability to several factors that tend to overestimate the crash reduction of a countermeasure. The before-and-after study with comparison group method is considered a better approach than the simple method due to its ability to account for the effects of maturation and external causal factors. However, the accuracy of this method is highly dependent on the availability of comparison sites and the similarity between the comparison and treatment sites. The EB method accounts for the regression-to-the-mean bias and is potentially more accurate than the other two methods, but it is also more difficult to implement.

Four problems associated with the simple before-and-after studies were described: (1) regression-to-the-mean, (2) crash migration, (3) maturation, and (4) external causal factors. The need to control for factors (1), (3), and (4) are well recognized by researchers. Some studies have found that the more these factors are accounted for, the less effective a treatment was. Crash migration, on the other hand, is a more controversial problem. Some researchers believe crash migration is a real phenomenon, while others believe it to be only a reverse of the regression-to-the-mean effect. In general, the impact of crash migration remains inconclusive. If the impact of crash migration is significant, it could seriously undermine the benefits of safety improvement programs. Research is needed to address the many issues related to crash migration, including how real and widespread crash migration is, how is crash migration related to changes in driver perception, expectancy or behavior, and how should the area surrounding the treatment site be defined. In addition, because analysis associated with a crash migration study is necessarily area-wide, the study area may include roadways of different jurisdictions (e.g., state and county). Thus, crash data maintained by different jurisdictions, which may be of different reporting standards and quality, will need to be used.

In addition to crash migration, there remains a number of study design issues that require additional research, some of which include: (1) the appropriate length of the before and after analysis periods,

(2) better guidelines for selecting the reference group, (3) the size of a reference group that will sufficiently adjust for regression-to-the-mean bias, (4) the number of sites that can adequately measure a treatment effect at the treated sites, and (5) proper statistics for providing sufficient information on which to base an evaluation of the quality of the study and conclusions drawn.

CHAPTER 3
STATE-OF-THE-PRACTICE SURVEY

3.1. Introduction

This chapter summarizes findings from a survey of the state-of-the-practice by state DOTs on the development and application of CRFs. A letter was mailed to all state DOTs in February 2002 to request for information on CRFs and benefit-cost analysis. E-mail and telephone follow-ups were conducted for the states that did not respond within one month after the letter was sent. A total of 42 states (84%) eventually responded to the request. Some states provided detailed information and manuals, while others replied with an email or a letter describing the general procedure they use for selecting improvement projects.

3.2. General Results

Among the 42 respondents, eight states reported that they did not use CRFs in evaluating safety projects. Thirty-four states indicated that they used some type of CRFs in their safety improvement programs. In these 34 states, nineteen indicated that their states had developed their own CRFs. Among the remaining 15 states that had not developed their own CRFs, five completely adopted CRFs from the other states while the rest used CRFs from published literature or a combination of literature and CRFs from other states. Seven states indicated that they were updating their CRFs at the time of the request. Of the 19 states that had developed their own CRFs, New York developed the greatest number of factors (204), with Missouri the closest second (163), and Vermont used the fewest factors (10). Most respondents developed less than 100 CRFs. The CRF reports from Kentucky, Florida, New York, and FHWA were adopted by the other states the most often. Table 3-1 provides a summary of these general findings.

Table 3-1. CRF Development Status in Different States

CRF Status	States
Developed their own CRFs or part of CRFs	Alaska, Arizona, California, Florida, Idaho, Indiana, Iowa, Kentucky, Michigan, Minnesota, Missouri, Montana, New York, Ohio, Oklahoma, Oregon, Texas, Vermont, Virginia
Updating or developing CRFs at the time of survey	Connecticut, Florida, Kentucky, New York, Ohio, Oregon, Virginia
Use CRFs from literature and other States	Alabama, Colorado, Connecticut, Indiana, Kentucky, Louisiana, Michigan, Montana, Nebraska, North Carolina, Pennsylvania, South Carolina, South Dakota, Virginia
Adopted CRFs completely from other states	Delaware, Maine, Maryland, Nevada, West Virginia
Did not indicate how their CRFs were developed	Idaho, Iowa, Minnesota, Montana
Do not use CRFs	Arkansas, Hawaii, Massachusetts, Mississippi, North Dakota, Utah, Wisconsin, Wyoming
Did not respond to survey	Georgia, Illinois, Kansas, New Hampshire, New Mexico, Puerto Rico, Rhode Island, Tennessee, Washington

3.3. CRF Development Methods

Before-and-after and cross-sectional methods are the only two methods used to develop CRFs, with the before-and-after method being the most widely used. Table 3-2 summarizes the CRF development methods used in the states that have developed their own CRFs.

Table 3-2. CRF Methods Used by States

Before-and-After Method	Alaska, Arizona, California, Florida, Idaho, Indiana, Iowa, Kentucky, Minnesota, Montana, New York, Ohio, Oklahoma, Texas, Vermont
Cross-Sectional Method	Missouri, Oregon

3.4. CRF Classification

CRFs are generally classified based on:

1. Total or all crashes.
2. Crash severity, including fatal, injury, and property-damage-only.
3. Crash types, such as rear-end, head-on, left-turn, right-turn, angle, sideswipe, fixed-object, etc.

Table 3-3 summarizes the CRF types as developed by the particular states themselves. When only a total CRF is provided for a countermeasure, some states provide proportions to allow estimation of crash reduction by crash severity and/or crash type.

Table 3-3. CRF Types Used by States

CRF Types	States
By Total Only	Idaho, Indiana, Iowa, Michigan, Texas, Vermont
By Total and Crash Type	Arizona, California, New York, Oklahoma
By Crash Type and Crash Severity	Minnesota, Ohio, Virginia
By Total, Crash Severity, and Crash Type	Alaska, Florida, Kentucky, Missouri, Montana, Oregon

3.5. Before and After Periods

Most states use three years for both before and after periods, while others used one or two years. Idaho, for example, uses a minimum of three years of crash history but prefers five years of data. Only Vermont used five years for both the before and after periods.

3.6. Formulas Used for Multiple Countermeasures

Multiple countermeasures are often applied to a treated site. Obviously, the multiple CRFs involved cannot be simply added together and must be applied one after another to produce a total CRF that reflects the aggregated effect of the countermeasures on crash reduction. Different formulas have been used to determine the total CRF. The following formula is the most widely used:

$$CRF_t = CRF_1 + (1 - CRF_1)CRF_2 + (1 - CRF_1)(1 - CRF_2)CRF_3 + \ldots \quad (3\text{-}1)$$

where

CRF_t	=	Total CRF,
CRF_1	=	CRF for the first countermeasure,
CRF_2	=	CRF for the second countermeasure, and
CRF_3	=	CRF for the third countermeasure.

Several states indicated that the individual CRFs for specific countermeasures in this equation should be listed from the highest to the lowest value. However, the total CRF is in fact not affected by the order of the CRFs involved, i.e., regardless of how the CRFs are ordered, the total CRF will be the same. This is evidenced from a different expression of the same equation that some states use, including Michigan, Arizona, and Kentucky.

$$CRF_t = 1 - (1 - CRF_1)(1 - CRF_2)(1 - CRF_3)\ldots \quad (3\text{-}2)$$

A different formula with the following expression is used by Delaware, California, Idaho:

$$CRF_t = \frac{\sum_{i=1}^{n} (A_i)(CRF_i)}{A_t} \quad (3\text{-}3)$$

where

CRF_t	=	Total CRF,
CRF_i	=	CRF for countermeasure i,
A_i	=	Crashes before countermeasure i,
A_t	=	Total number of crashes before countermeasures, and
n	=	Number of countermeasures.

The use of this formula is less intuitive and an example is given below for clarification:

Given:

Signal Modification:	26% reduction in crashes
Radii Improvement:	15% reduction in crashes
Left-turn:	30% reduction in crashes
Number of crashes:	57

Calculations:

57 crashes x 26%	= 14.8 crashes reduced by signal modification
(57 - 14.8) x 15%	= 6.3 crashes reduced by radii improvement
(57-14.8 - 6.3) x 30%	= 10.8 crashes reduced by left-turn lane
Total of crashes reduced	= 14.8 + 6.3 + 10.8
Total CRF	= 31.9/57 = 56%

Alabama (1998) uses the following formula:

$$CRF_t = \sum_{i=1}^{n} \left(\frac{1}{i}\right) CRF_i(\%) \tag{3-4}$$

where

CRF_t	=	Total CRF for the safety improvement,
CRF_i (%)	=	Crash reduction factor used in decreasing order for countermeasure i, and
n	=	Number of countermeasures.

This formula ranks CRFs in order of effectiveness. Table 3-4 summarizes the total CRF calculations using these formulas for an example involving three countermeasures. The total CRF computed from Equation 3-1 is, as expected, the same as that for Equation 3-2. Equation 3-3 tends to give a more conservative estimate of the total CRF.

Table 3-4. Example Illustrating Calculation of Combined CRFs

Countermeasures	Crashes	Partial CRFs	Overall CRFs
Install exclusive left-turn phasing	37	70%	Eq. (3-1) 87.63%
Close off-ramp	12	45%	Eq. (3-2) 87.63%
Install warning sign in advance of intersection.	25	25%	Eq. (3-3) 50.74% Eq. (3-4) 100.83%

3.7. Summary of State-Developed Crash Reduction Factors

The CRFs developed by states other than Florida are listed individually in Appendix B. Note that although Ohio and Oregon have developed CRFs and provided information on how they determined the CRFs, they did not provide the actual CRFs. In addition, Idaho is not included because most of its CRFs were adopted from Missouri.

Table 3-5 explains the legends used in Tables 3-6 to 3-14, which summarize CRFs from the tables from Appendix B into the following eight major categories of safety improvements, respectively:

- Channelization improvements
- Construction/reconstruction improvements
- Traffic sign improvements
- Traffic signal improvements
- Illumination improvements
- Pavement improvements
- Roadway delineation and pavement marking improvements
- Regulation improvements
- Roadside improvements

In these summary tables, the CRFs for those improvements that are available from different states are shown in percentage and the state origin of each CRF is indicated by the two-digit state code in parentheses. An average CRF, shown in underline, is calculated for each table cell that has more than one CRF. It is noted that, when computing the averages:

- The CRFs from Kentucky were not included because they were derived mainly from averaging CRFs from other states.

- The CRFs from Minnesota cannot be included because they are stratified by crash severity.

- The CRFs from New York are stratified further by two levels of AADT. Each level is treated as the equivalent of an individual state.

The CRFs presented in these tables may be used with caution when the Florida counterparts are not available. The user may choose to use the average value from all listed states (values provided in Tables 3-6 through 3-14) or compute manually an average that includes only those states that are judged to be similar to Florida.

Table 3-5. Legends for CRF Tables (Tables 3-6 – 3-14)

Crash Type	State	Notes
ALL: All crashes	AK: Alaska	(a) ADT less than 400
F: Fatal	AZ: Arizona	(b) ADT 400 to 1499
I: Injury	CA: California	(c) ADT 1500 to 3000
PDO: Property-damage-only	IN: Indiana	(d) For two-lane roads
HO: Head-on	IA: Iowa	(e) Rural area
RE: Rear-end	KY: Kentucky	(f) Left-turn
RA: Right-angle	MI: Michigan	(g) Right-turn
SS: Sideswipe	MN: Minnesota (fatal and injury crashes)	(h) Warning arrow
LT: Left-turn	mn: Minnesota (property-damage-only crashes)	(i) Speed plate
RT: Right-turn	MO: Missouri	(j) Includes curves
FO: Fixed-object	MT: Montana	(k) 4-leg red-yellow
Ped: Pedestrian	NY: New York (AADT>5000/lane)	(l) 3-leg red-yellow
ROR: Run-off-road	ny: New York (AADT<5000/lane)	(m) Includes curves
WP: Wet pavement	OK: Oklahoma	(n) Urban area
OT: Overturn	TX: Texas	(o) Per feet
N: Nighttime	VT: Vermont	(p) Collision with guardrail
T: Train-related	VA: Virginia	

Table 3-6. CRFs for Channelization Improvements

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
Channelization intersection	17(IN) 25(KY) 25(MO) 27(MT)(m) 25(OK) 22				25(MN) 50(mn)	33(MN)		28(mn)	45(MO)			100(MN)				
Provide left-turn lane (with signal)	25(KY) 25(MO) 28(MT) 30(OK) 28								45(KY) 50(MO) 24(NY) 45(OK) 40					28(NY)		28(NY)
Provide left-turn lane (without signal)	35(CA) 35(KY) 35(MO) 25(MT)(a) 40(OK) 34								50(KY) 55(OK) 55							
Channelization with no left-turn phase	15(MO) 15(CA) 15															
Channelization with existing left-turn phase	35(MO) 35(CA) 35															
Modify channelization at signalized intersection																
Modify channelization and add signal																
Traffic channelization and turning lanes	15(CA)															
Painted lane	32(MO)					75(MO)										
Protected lane with curb or raised bars	67(MO)			62(MO)		93(MO)										
Install two-way left-turn lane in median	25(CA) 30(KY) 35(MO) 25(OK) 34(MT) 30(AZ) 30		20(MO)	35(MO)	36(AZ) 67(MN) 64(mn) 36	36(MO) 36(AZ) 32(MN) 38(mn) 36	20(MI) 31(MN) 23(mn) 20	32(MN) 37(mn)	33(MO) 33(AZ) 17(MN) 38(mn) 33			19(AZ)	37(MO) 37(AZ) 90(MN) 16(mn) 37			

Table 3-6. CRFs for Channelization Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
Channelize two-lane to three-lane	32(MO)		59(MO)			46(MO)		46(MO)	46(MO)							
Channelize four-lane to five-lane	28(MO)		42(MO)			40(MO)		40(MO)	40(MO)							
Add mountable median	15(KY) 15(MO) 15	90(AK)														
Add non-mountable median	25(KY) 25(MO) 25											25(AK)				
Add left and right turning lanes with signal	14(NY) 41(ny) 28					38(NY) 64(ny) 51	42(NY) 70(ny) 56	38(NY) 64(ny) 51								
Provide right-turn lane	25(KY) 25(MO) 25(MT) 25(OK) 25					65(MI)	50(OK)	20(MI)		50(KY) 56(MI) 50(MO) 53						
Increase turn lane length	15(KY) 15(MO) 40(MT)(b) 40(MT)(c) 15(OK) 28															
Roadway redesign/relocate driveways	50(OK)															

Table 3-7. CRFs for Construction/Reconstruction Improvements

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
REALIGNMENT																
Realignment (general)	50(CA)															
Reconstruct curve																
Horizontal alignment changes (general)	35(IA) 41(NY) 59(ny) 45	87(VA)	87(VA)	87(VA)	64(NY) 67(ny) 66	24(NY) 73(ny) 49					87(NY) 68(ny) 78		79(NY) 90(ny) 85	24(NY) 73(ny) 49		
Construct a more gradual horizontal curve	38(IA) 40(KY) 40(MO) 39															
Change from 20 to 10 degrees	48(MO)															
Change from 15 to 5 degrees	63(MO)															
Change from 10 to 5 degrees	45(MO)															
Improve vertical curve	57(IA) 40(KY) 40(MO) 49															
Improve vertical alignment		87(VA)	87(VA)	83(VA)												
Improve horizontal and vertical curve	50(CA) 73(IA) 50(KY) 50(MO) 58															
Improve sight distance at intersection	30(IN) 40(KY) 40(MO) 30(MT) 25(OK) 31															
Superelevation correction	40(KY) 40(OK) 40												50(MO)			
Shoulder construction	9(IN)															
Shoulder repair	20(IN)															
SEPARATING DEVICES																
Construct vertical separation of intersection roadways	80(TX)															

Table 3-7. CRFs for Construction/Reconstruction Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
Install concrete barrier rail (inside and outside curve)		39(MT)	39(MT)													
Install median barrier (general)	36(AZ) 20(CA) 5(MO) 19(NY) 19(ny) 15(OK) 19	65(MO)	40(MO)				54(NY) 58(ny) 56						35(AZ) 35(MO) 35			
Install raised median	20(CA) 25(MT) 23				75(AK)											
Install a 1 to 12 ft. Median		75(MO)	2(MO)													
Install a 13 to 30 ft Median		85(MO)	5(MO)													
Install concrete median barrier		90(MO)	10(MO)													
Add painted median																
Increase median width																
Install/improve curbing											50(MO)					
Install/improve median barrier near gore area	17(NY) 17(ny) 17					39(NY) 39(ny) 39							56(NY) 56(ny) 56			
Close median opening					100(MO)	50(MO)	100(MO)	50(MO)	100 (MO)							
Add flush median	52(NY) 44(ny) 48								78(NY) 72(ny) 75							
Add flush median width refuge for left turns	44 (NY) 24(ny) 34				52(NY)	40(NY) 44(ny) 42		52(NY)	77(NY)					40(NY) 44(ny) 42		
PAVEMENT WIDENING																
Replace active warning devices with bridge or tunnel	95(MO)			88(MO)	55(ny)			55(ny)	58(ny)							
Widen pavement	25(KY) 25(MO) 59(NY) 37(ny) 40	50(VA)	50(VA)	50(VA)					69(NY) 77(ny) 73							

Table 3-7. CRFs for Construction/Reconstruction Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
Widen shoulder (paved)	20(CA) 8(IA) 57(AZ) 32(MT) <u>29</u>	50(VA)	50(VA)	50(VA)	75(AZ) 15(MI) <u>45</u>			41(AZ) 15(MI) <u>28</u>			15(MI)	71(AZ)	60(AZ)			
Widen shoulder (paved) 2 ft											16(MO)		16(MO)			
Widen shoulder (paved) 4 ft											29(MO)		29(MO)			
Widen shoulder (paved) 6 ft											40(MO)		40(MO)			
Widen shoulder (paved) 8 ft											49(MO)		49(MO)			
Widen shoulder (unpaved)	15(CA)(d) 30(CA)(e) 30(CA)(f) 22(IA) <u>22</u>															
Widen shoulder (unpaved) 2 ft											13(MO)		13(MO)			
Widen shoulder (unpaved) 4 ft											25(MO)		25(MO)			
Widen shoulder (unpaved) 6 ft											34(MO)		34(MO)			
Widen shoulder (unpaved) 8 ft											43(MO)		43(MO)			
Construct paved shoulder					86(MT)											62(MT)
Pave shoulder	15(KY) 15(MO) <u>15</u>															
Stabilize shoulder	25(KY) 25(MO) <u>25</u>															
Widen shoulder/Flatten slope	20(CA) 8(IA) <u>14</u>															
Widen lane (general)	56(AZ)	50(VA)	50(VA)	50(VA)	70(AZ) 5(MI)(o) <u>70</u>			52(AZ) 5(MI)(o) <u>52</u>			5(MI)(o)		49(AZ)	5(MI)(o)		
Widen lane, add 1 ft To both sides					12(MO)			12(MO)					12(MO)			
Widen lane, add 2 ft To both sides					23(MO)			23(MO)					23(MO)			
Widen lane, add 3 ft To both sides					32(MO)			32(MO)					32(MO)			

Table 3-7. CRFs for Construction/Reconstruction Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
Widen lane, add 4 ft To both sides					40(MO)			40(MO)					40(MO)			
Add 4 feet shoulder(bike lane)																
ADDITIONAL LANES																
Add acceleration /deceleration lane	75(AK) 25(IA) 10(KY) 10(MO) 10(MT) 10(OK) 26					75(AK)		75(AK)								
Add lanes	25(AZ) 25(IA) 10(IN) 25(MO) 20(MT) 31(NY) 20(ny) 22	39(MO)	23(MO)	27(MO)	53(AZ) 53(MO) 44(NY) 97(MN) 50 (mn) 38(ny) 47	32(AZ) 32(MO) 52(NY) 53(MN) 53(mn) 42(ny) 40	45(NY) 15(MN) 46 (mn) 35(ny) 40	30(AZ) 30(MO) 44(NY) 35(MN) 64 (mn) 38(ny) 36	71(MN) 67 (mn)				44(AZ) 44(MO) 26(MN) 50 (mn) 44	52(NY) 42(ny) 47		
Add through lane	28(MT)															
Add left turn lane with physical separation	19(NY) 51(ny) 35					28(NY) 50(ny) 39	55(NY) 68(ny) 62		24(NY) 24(ny) 24					28(NY) 50(ny) 39		
Add left turn lane with painted separation	50(ny)					39(NY) 54(ny) 47	49(NY) 62(ny) 56		35(NY) 57(ny) 46					39(NY) 54(ny) 47		
Add turning lanes	6(AZ) 25(IA) 20(IN) 17				13(MN)	14(MN) 14 (mn)	13(AZ) 15(MN) 44 (mn) 13	59(AZ) 8 (mn) 59	24(AZ) 35(MN) 33 (mn) 24			50(MN)	25(MN) 25(mn)			
Reconstruct turning lanes	26(IN)															
Add double left-turn lane					75(MN)	29(MN) 32(mn)	20(MN) 8 (mn)	50(MN)	47(MN) 71 (mn)				8(MN) 13(mn)			
Add T-intersection turn and bypass lane					13(mn)	18(MN) 21(mn)	24(MN) 53(mn)	30 (mn)	36(MN) 28 (mn)				40(mn)			
Detached left-turn lane					100(MN) 100 (mn)	11(MN) 56 (mn)	58(MN) 54 (mn)		50(MN)				50(mn)			

Table 3-7. CRFs for Construction/Reconstruction Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
Shoulder bus lanes					50(MN) 86 (mn)		34(MN) 31 (mn)	27(MN) 8(mn)	42(MN) 57 (mn)				27(mn)			
Truck escape ramp	18(AZ)					33(AZ)							75(CA)			
Truck escape lanes	100(VT)															
New turning pockets						90(AK)		90(AK)								
BRIDGES																
Bridge replacement	45(KY) 100(VT) 100															
Widen bridge (general)	36(AZ) 48(IA) 40(IN) 45(KY) 45(MO) 47(MT) 55(TX) 45	92 (VA)	92 (VA)	95 (VA)	50 (AK) 40 (MI) 45			50(AK) 57(AZ) 40(MI) 49			50(AK) 40(MI) 45		44(AZ)			
Widen bridge from 18 to 24 ft	68(MO)															
Widen bridge from 20 to 24 ft	56(MO)															
Widen bridge from 22 to 24 ft.	36(MO)															
Widen bridge from 18 to 30 ft.	93(MO)															
Widen bridge from 20 to 30 ft.	90(MO)															
Widen bridge from 22 to 30 ft.	86(MO)															
Replace two-lane bridge	45(MO)															
Repair bridge deck	13(IN) 15(KY) 15(MO) 14															
Bridge parapet	5(OK)															
Bridge rail upgrade	20(OK)	60 (OK) 92 (VA) 76	30 (OK) 92 (VA) 61	50 (VA)												

Table 3-7. CRFs for Construction/Reconstruction Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
INTERSECTION																
Increase turning radii	15(KY) 15(MO) 10(MT) 13					15 (MI)		15 (MI)			15 (MI)	15 (MI)		15 (MI)		
Improve sight distance	75(AK) 7(AZ) 20(CA) 35(IA) 30(KY) 30(MO) 33				75(AK) 10(MO) 100(MN) 43	10(AZ)	21(AZ) 21(MO) 70 (mn) 21	75(AK) 10(MO) 43	13(AZ) 13(MO) 13			10(MO)	100(MN) 100(mn)			
FREEWAY																
Construct interchange	60(AK) 55(KY) 55(MO) 55(TX) 57															
Modify entrance/exit ramp	25(KT) 25(MO) 25															
Construct frontage road	40(MO)															
Install glare screen																15(KT) 15(MO) 15
PEDESTRIAN																
Construct pedestrian bridge or tunnel	5(MO)											100(AK) 67(AZ) 90(KY) 90(MO) 86				
Install sidewalk												75(AK) 89(AZ) 65(KY) 65(MO) 65(OK) 74				
Pedestrian signing	4(AZ)											15(AZ)				
Construct grade separation		90(VA)	90(VA)	90(VA)												

Table 3-7. CRFs for Construction/Reconstruction Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
DRAINAGE																
Improve drainage	20(KY) 32(NY) 32(ny) 32														40(KT)	
Provide adequate drainage	20(MO)														40(MO)	
Provide proper Superelevation	40(MO) 49(MT) 45															
Safety treatment of drainage structure	60(MT)															
Extend drainage structure to clear zone	30(MT)															
Lengthen culverts	48(IA) 40(OK) 44															
Remove headway and delineate (outside shoulderine)	35(IA)															

Table 3-7. CRFs for Construction/Reconstruction Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II			III										IV	V
	All	F	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N
GUARDRAIL																
Install guardrail	19(AZ) 16(IA) 4(IN) 5(KY) 5(MO) 11	65(KY) 65(MO) 65	40(KY) 40(MO) 40										30(MO) 30(AZ) 30			
Upgrade guardrail	15(AZ) 20(CA) 7(IN) 5(KY) 5(MO) 7(MT) 15(OK) 9(NY) 18(ny) 6(VT) 11	50(KY) 50(MO) 50	35(KY) 35(MO) 35			27(NY) 41(ny) 34					18(NY) 31(NY)(p) 23(ny) 40(ny)(p) 21		26(MO) 32(NY) 26(AZ) 28	27(NY) 41(ny) 34		
Install guardrail at bridge	44(MT) 20(NY) 22(ny) 24(IA) 11(AZ) 24	90(MO)	45(MO)			32(NY) 37(ny) 35								32(NY) 41(ny) 37	50(AZ)	
Install guardrail along ditch			26(MO)													
Install guardrail along embankment			42(MO)													
Install guardrail at road edge	15(OK)	23(MT)	23(MT)										50(AK)			
Install guardrail-median barrier	5(KY)	65(KY) 31(MT) 48	40(KY) 31(MT) 36													
Install guardrail-inside curves		28(MT)	28(MT)													
Install guardrail-outside curves		63(MT)	63(MT)													
Install guardrail at culverts	24(IA) 30(OK) 27															
Install guardrail to shield trees		65(MO)	51(MO)													
Install guardrail to shield fixed objects as rocks and steel posts	14(AZ)		31(MO)								100(AZ)					

Table 3-8. CRFs for Traffic Sign Improvements

Improvement	Crash Reduction Factor (%)											
	I	II		III							IV	V
	All	F	I	HO	RE	RA	SS	LT	Ped	ROR	WP	T
Install or upgrade traffic signs	100(AZ) 5(CA) 15(IN) 13(NY) 28(ny) 20(OK) 30							34(NY) 34(ny) 34		100(AZ)		100(AZ)
Illuminated sign installation	15(IN)											
Upgrade with breakaway supports	20(CA)											
WARNING SIGNS												
Install warning signs (General)	25(MO) 25(KY) 25											
Install warning signs in advance of intersections	30 (KY)											
Install warning signs in advance of intersections (Urban)	30(MO)											
Install warning signs in advance of intersections (Rural)	40(MO)											
Install warning signs in advance of curves	30(MO) 23(MT)(h) 29(MT)(i) 30	55(MO)	20(MO)	29(MO)						30(MO) 30(KY) 30		
Install stop ahead sign	15(NY)											
Advance curve warning with advisory speed	20(CA)											
Upgrade warning devices at railroad crossings	27(IA)											
Add signs at railroad crossings	80(IN) 50(IA) 65											30(MO) 30(KY) 30
Rail grade crossing removal	18(IN)											

Table 3-8. CRFs for Traffic Sign Improvements (cont.)

Improvement	Crash Reduction Factor (%)											
	I	II		III							IV	V
	All	F	I	HO	RE	RA	SS	LT	Ped	ROR	WP	T
Install school zone signs	15(KY) 15(OK) 15(MO) 20(MT) 20(TX) 18											
Install pavement condition signs	5(IA)										20(MO) 20(KY) 20	
REGULATORY SIGNS												
Replacement of standard sign with large stop signs	19(NY)											
Install stop sign (2-way)	35(MO) 35(KY) 35											
Change to all-way stop sign from two-way stop sign	50(CA) 55(KY) 55(MO) 53(MT) 53				13(MO)	72(MO)		20(MO)	39(MO)			
Install yield sign	45(MO) 25(AK) 23(NY) 31					43(AZ)						
Install lane use signs					10(MO)		20(MO)					
GUIDE SIGNS												
Install guide signs	15(KY) 15(MO) 15											
Install variable message sign	15(KY) 15(MO) 15(OK) 15											

Table 3-9. CRFs for Traffic Signal Improvements

Improvement	Crash Reduction Factor (%)													
	I	II		III									IV	V
	All	I	PDO	HO	RE	RA	SS	LT	RT	Ped	ROR	OT	WP	T
Install signal (general)	15(CA) 20(IA) 13(IN) 25(KY) 25(MO) 20(OK) 20(NY) 38(ny) 22				20(NY) 22(ny) 21	60(AK) 42(AZ) 65(KY) 65(MO) 65(OK) 43(NY) 74(ny) 58						20(NY) 22(ny) 21		
Install signal at channelizated intersection														
Install signal at non-channelizated intersection														
Install signal and channelization				27(mn)		67(MN) 63(mn)	54(MN)	24(mn)		100(mn)	35(MN)			
Install signal from two-way stop	28(MO)	43(MO)				74(MO)								
Install signal from two-way stop and add left-turn lane	36(MO)	53(MO)			8(MO)	74(MO)								
Install a temporal signal				83(mn)		39(MN) 73(mn)	50(MN)	11(mn)						
Signal revision				15(MN) 58(mn)	14(MN) 25(mn)	33(MN) 33(mn)	59(MN) 35(mn)	53(MN) 35 (mn)		10(MN)				
SIGNAL UPGRADE														
Upgrade signal (general)	15(CA) 15(IA) 11(IN) 20(KY) 20(MO) 22(MT) 19(NY) 37(ny) 20(OK) 62(VT) 25			52(NY) 32(ny) 47(MN) 61(mn) 42	26(NY) 41(ny) 22(MN) 32(mn) 34	37(NY) 47(ny) 29(MN) 32(mn) 42	52(NY) 32(ny) 50(MN) 28(mn) 42	26(NY) 38(ny) 27(MN) 21(mn) 32		33(mn)	37(MN) 52(mn)	26(NY)		
Upgrade signal and add pedestrian feature														

Table 3-9. CRFs for Traffic Signal Improvements (cont.)

Improvement	Crash Reduction Factor (%)													
	I	II		III									IV	V
	All	I	PDO	HO	RE	RA	SS	LT	RT	Ped	ROR	OT	WP	T
Upgrade signal-optical program	15(OK)													
Replace signal or stop-controlled 4-leg intersection with a single-lane roundabout	75(AK)													
Replace signal or stop-controlled 3-leg intersection with a single-lane roundabout	50(AK)													
Install 12-inch lenses	10(KY) 10(MO) 10													
Install visors or back-plates						20(KY) 20(MO) 20								
Install optically programmed signal lenses	15(KY) 15(MO) 15			20(MO)	10(MO)	10(MO)		10(MO)						
No left-turn lane	51(MO)	52(MO)			24(MO)	69(MO)		28(MO)						
Existing left-turn lane	44(MO)	25(MO)			35(MO)	74(MO)		2(MO)						
Left-turn lane added	84(MO)	87(MO)			72(MO)	83(MO)		87(MO)						
SIGNAL PHASING														
Improve signal phasing	25(KY) 25(MO) 25			75(MN)	17(mn)	30(MN) 46(mn)		75(OK) 55(MN) 63(mn) 75		14(MN)	62(MN) 28(mn)			
Add exclusive left-turn phase (protected)	15(AZ) 25(KY) 25(MO) 30(MT) 36(NY) 30(ny) 27				35(NY) 27(ny) 31	80(AK) 56(NY) 54(ny) 63		35(AZ) 70(KY) 70(MO) 46(NY) 41(ny) 48				35(NY) 27(ny) 31		
Add protected/permissive left turn phase	10(KY) 10(MO) 10							40(MO) 40(OK) 40						

Table 3-9. CRFs for Traffic Signal Improvements (cont.)

Improvement	Crash Reduction Factor (%)													
	I	II		III									IV	V
	All	I	PDO	HO	RE	RA	SS	LT	RT	Ped	ROR	OT	WP	T
Improve timing	10(KY) 10(MO) 10													
Change in signal operation, from pre-timed to traffic actuated	28(NY) 39(ny) 34			60(NY) 81(ny) 71	26(NY) 53(ny) 40	32(NY) 41(ny) 37	26(NY) 53(ny) 40	30(NY)						
Install traffic actuated signal						10(MO)	20(MO)	80(MO)						
Install/improve pedestrian signal	25(KY) 25(MO) 15(MT) 20									55(KY) 55(MO) 50(OK) 53				
Improve yellow change interval	15(KY) 15(MO) 15					30(KY) 30(MO) 30								
Add all-red interval	15(MO)					30(MO)								
Install new flashing red/yellow signal	26(NY) 25(ny) 26	50(VA)	50(VA)	50(VA)		36(NY) 35(ny) 36								
REMOVAL														
Remove unwarranted signal	100(AZ) 50(KY) 50(MO) 75(OK) 75				100(AZ) 90(MO) 95									
FLASHING BEACON														
Install flashing beacon (general)	25(IA) 7(IN) 30(KY) 30(MO) 25(OK) 22			100(MN) 29(mn)	47(MN)	25(MN)					44(MN) 44(mn)			

Table 3-9. CRFs for Traffic Signal Improvements (cont.)

Improvement	Crash Reduction Factor (%)													
	I	II		III									IV	V
	All	I	PDO	HO	RE	RA	SS	LT	RT	Ped	ROR	OT	WP	T
Install flashing beacon at intersection	30(KY) 30(MO) 4(MT)(j) 39(MT)(k) 70(MT)(l) 30(OK) <u>30</u>													
Install signal-flashing beacon-curve	30(OK)													
Install intersection advance warning flashers	25(KY) 25(MO) 27(MT)(m) 25(OK) <u>25</u>													
Install general advance warning flashers	35(KY) 35(MO) 35(OK) <u>35</u>			67(MN)	16(mn)	73(MN) 62(mn)	33(MN) 83(mn)	67(MN) 79(mn)			40(MN) 54(mn)			
Upgrade flashing beacon (general)	9(IN) 10(TX) <u>10</u>													

Table 3-9. CRFs for Traffic Signal Improvements (cont.)

Improvement	Crash Reduction Factor (%)													
	I	II		III									IV	V
	All	I	PDO	HO	RE	RA	SS	LT	RT	Ped	ROR	OT	WP	T
ROAD CROSSINGS														
General railroad crossings														70(KY) 70(MO) 70
Add flashing lights at railroad crossings	43(AZ)													65(KY) 65(MO) 65
Add automatic gates at railroad crossings														75(KY) 75(MO) 75
Add automatic gates and flashing lights														75(KY) 75(MO) 75
Replace railroad crossing with road separation	39(IA)													100(AK)
Eliminate railroad crossing	75(IA)													
Upgrade from rail signs to flashers														75(AK)
Upgrade from rail signs to gates														90(AK)
Upgrade from rail road flashers to gates														90(AK)
Improve rail road crossing sight distance														25(AK)

Table 3-10. CRFs for Illumination Improvements

Improvement	Crash Reduction Factor (%)															
	I	II		III										IV	V	VI
	All	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N	T
Illumination (general)	19(AZ) 37(IN) 25(KY) 28														30(AZ) 50(KY) 30	
Improve street lighting	25(IN) 25(MO) 25														50(MO) 50(OK) 50	
Install/improve lighting at roadway segment	20(IA) 25(KY) 25(MO) 23														20(AK) 45(KY) 45(MO) 45(OK) 37	
Install/improve lighting at intersections	36(CA) 30(KY) 30(MO) 33														50(AK) 67(CA) 50(KY) 50(MO) 64(MT) 50(OK) 56	
Install/improve lighting at interchanges	25(KY) 25(MO) 25														50(KY) 50(MO) 50(OK) 50	
Install/improve lighting at railroad crossings	62(IA) 30(KY) 30(MO) 46														60(KY) 60(MO) 60(OK) 60	25(AK) 60(MO) 43
New safety lighting															15(CA)	
Animal reflectors	10(AZ)														25(AZ)	
Luminaries replacement	16(IN)															
Bridge lighting installation	59(IN)															

Table 3-11. CRFs for Pavement Improvements

Improvement	Crash Reduction Factor (%)															
	I	II		III										IV	V	VI
	All	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N	T
PAVEMENT TREATMENT																
Pavement treatment (general)	25(KY)													50(KY)		
Deslick pavement	13(MO)			10(MO)	40(MO)	10(MO)	10(MO)			10(MO)	10(MO)	10(MO)		65(MO)		
Groove pavement	14(IA) 10(CA) 25(KY) 25(MO) 21(NY) 37(ny) 21				35(NY) 54(ny) 45					19(NY) 36(ny) 28		40(NY) 41(ny) 41	35(NY) 54(ny) 45	60(KY) 60(MO) 54(NY) 64(ny) 59		
Maintenance and Bit-overlay				31(MN)	21(MN)	16(MN) 23(mn)	29(mn)	37(MN) 13(mn)			33(MN) 42 (mn)	19(MN) 30(mn)				
Mill concrete surface				38(MN)	1(MN)	42(MN) 52(mn)	57(MN)	57(MN) 57(mn)				41(MN)				
Resurface curve with skid-resistant overlay	10(CA) 24(MT) 17			86(MO)										51(MO)		
Resurface with skid resistant pavement	7(IN) 13(NY) 8(ny) 9					23(NY) 31(ny) 27								42(NY) 35(ny) 39		
Resurfacing with open-grad mix	75(NY) 75(ny) 75			90(NY) 90(ny) 90			90(NY) 90(ny) 90			93(NY) 93(ny) 93				91(NY) 91(ny) 91		
Resurfacing with Verglimit				31(NY) 31(ny)												
Resurface and superelevation	28(NY) 28(ny) 28													51(NY) 51(ny) 51		
Skid treatment with overlay	20(NY) 13(ny) 17			61(NY) 43(ny) 19(MN) 30(mn) 52	12(MN) 21(mn)	23(NY) 23(ny) 11(MN) 31(mn) 23	61(NY) 43(ny) 12(MN) 27(mn) 52	41(MN) 34(mn)		34(NY) 43(ny) 39	3(MN)	28(MN) 29(mn)		50(NY) 23(ny) 37		

Table 3-11. CRFs for Pavement Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II		III										IV	V	VI
	All	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N	T
Skid treatment with grooving	22(NY) 37(ny) 30				35(NY) 54(ny) 45					19(NY) 36(ny) 28		40(NY) 41(ny) 41	35(NY)	54(NY) 64(ny) 59		
Overlay	9(AZ) 27(IA) 18			12(MN) 16(mn)	19(AZ) 6(MN) 10(mn) 19	16(MN) 22(mn)	25(MN) 14(mn)	11(MN) 22(mn)			100(MN)	13(AZ)		39(AZ)		
Resurface (general)	7(AZ) 25(KY) 25(MO) 25(OK) 19											25(AZ)		45(KY) 45(MO)		20(AZ)
Install rumble strips	53(AZ) 25(KY) 25(MO) 18(MT) 32			80(AZ) 75(MN) 100(mn) 80	50(MN)	54(MN) 47 (mn)	100(MN)	33(MN) 60 (mn)				54(AZ) 50(AK) 50(CA) 50(mn) 51				
Pavement shoulder grooving/strip	18(AZ) 25(OK) 22											27(AZ)				
Groove shoulder	25(MO)	18(MO)	17(MO)									27(MO)				
Install rumble strips at stop controlled approach	28(MT)															
Rumble strips on approaches to intersections					90(AK)											
Make surface improvements at railroad crossings	34(MO)		39(MO)													90(AK)

Table 3-12. CRFs for Road Delineation and Pavement Marking Improvements

Improvement	Crash Reduction Factor (%)															
	I	II		III										IV	V	VI
	All	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N	T
Add pavement markings	48(AZ) 5(CA) 25(IA) 15(KY) 13(MO) 20(MT) 15(OK) 21				58(AZ)							22(AZ)				56(AZ)
Add pavement markings at railroad crossings	48(MO)	42(MO)	51(MO)		58(MO)											25(AK) 15(MO) 15(OK) 18
Add reflectorized raised pavement markings	11(AZ) 4(IN) 10(MO) 16(VT) 10			20(MO) 12(AZ) 16			13(AZ) 20(MO) 17			10(MO)		33(AZ) 10(MO) 22		25(KY) 25(MO) 25	16(AZ) 20(KY) 20(MO) 30(OK) 22	
Add "no passing" striping	53(MT)			40(MO) 40(KY) 40			40(KY) 40(MO) 40									
Add centerline markings	35(KY) 35(MO) 30(OK) 33															
Add edge line markings	30(AZ) 4(IA) 15(KY) 15(MO) 38(NY) 44(ny) 15(OK) 25(TX) 24	15(MO)	8(MO)		50(NY) 45(ny) 48					59(NY) 66(ny) 63		30(AZ) 30(KY) 30(MO) 30	50(NY) 45(ny) 48			

Table 3-12. CRFs for Road Delineation and Pavement Marking Improvements (cont.)

Improvement	Crash Reduction Factor (%)															
	I	II		III										IV	V	VI
	All	I	PDO	HO	RE	RA	SS	LT	RT	FO	Ped	ROR	OT	WP	N	T
Add/improve pedestrian crosswalk	25(MT)										25(KY) 25(MO) 25(OK) 25					
Add wider markings															25(KY) 25(MO) 25(OK) 25	
Add thermoplastic pavement markings	35(NY) 14(ny) 25									80(NY) 56(ny) 68						
Intersection striping	18(IN)															
Delineation (general)	11(AZ)			67(AZ)			67(AZ)					34(AZ)			25(AZ)	
Install post-mounted delineators	25(MT)														30(KY)	
Install post-mounted delineators on horizontal curve	20(AK) 25(MO) 30(MT) 25															
Install chevron signs	20(CA) 50(MT) 35															
Install chevron alignment sign on horizontal curve	35(MO)															
Install delineation at bridges Delineation tangent section	40(MO) 50(AK) 39(MT) 43															

Table 3-13. CRFs for Regulation Improvements

Improvement	Crash Reduction Factor (%)								
	I	II	III						
	All	PDO	RE	RA	SS	LT	FO	Ped	ROR
Prohibit on-street parking	8(IN) 35(KY) 35(MO) 22		10(MO)	10(MO)	30(MO)		40(MO)	30(MO)	
Change angle parking to parallel	59(MO)								
Set appropriate speed limit	20(KY) 20(MO) 36(MT) 28	35(MO)							
Change two-way roadway to one-way roadway (intersection crashes)	30(KY) 26(MO) 26								
Change two-way roadway to one-way roadway (mid-block crashes)	43(MO)								
Prohibit left-turns	45(KY) 45(MO) 45		30(MO)			90(MO)		10(MO)	
Prohibit right-turn-on-red at signalized intersections			20(MO)	30(MO)	20(MO)				30(MO)
Upgrade no-passing zones	30(IN)								

Table 3-14. CRFs for Roadside Improvements

Improvement	Crash Reduction Factor (%)											
	I	II			III							
	All	F	I	PDO	HO	RE	SS	RT	FO	Ped	ROR	OT
Remove fixed objects	61(AZ) 20(CA) 30(KY) 30(MO) 30(MT) 17(NY) 18(ny) 25(OK) 29	50(KY) 50(MO) 50	30(KY) 30(MO) 30			44(NY) 42(ny) 43			100(AK) 75(MI) 88		71(AZ)	44(NY) 42(ny) 43
Relocate fixed objects	25(KY) 25(MO) 55(MT) 25(OK) 35	40(KY) 40(MO) 40	25(KY) 25(MO) 25						90(AK) 40(MI)(a) 20(MI)(n) 65			
Improve gore area	25(KY) 25(MO) 25											
Install impact attenuators	41(AZ) 20(CA) 35(IA) 5(KY) 5(MO) 50(MT) 20(OK) 29	90(AK) 75(KY) 75(MO) 83	50(KY) 50(MO)								45(AZ)	
Relocate utility poles to increase offset from road (from 2 to 6 ft)								50(MO)				
Relocate utility poles to increase offset from road (from 3 to 8 ft)								46(MO)				
Relocate utility poles to increase offset from road (from 5 to 10 ft)								36(MO)				
Eliminate poles by burying utility lines	40(MO)											
Flatten side-slope (general)	25(IA) 30(KY) 32(MT) 45(NY) 43(ny) 30(OK) 35								62(NY) 62(ny) 62		10(AZ)	

Table 3-14. CRFs for Roadside Improvements (cont.)

Improvement	Crash Reduction Factor (%)											
	I	II			III							
	All	F	I	PDO	HO	RE	SS	RT	FO	Ped	ROR	OT
Flatten side-slope (from 2:1 to 4:1)	6(MO)							10(MO)		10(MO)		
Flatten side-slope (from 2:1 to 5:1)	9(MO)							15(MO)		15(MO)		
Flatten side-slope (from 2:1 to 6:1)	12(MO)							21(MO)		21(MO)		
Flatten side-slope (from 3:1 to 4:1)	5(MO)							8(MO)		8(MO)		
Flatten side-slope (from 3:1 to 5:1)	8(MO)							14(MO)		14(MO)		
Flatten side-slope (from 3:1 to 6:1)	11(MO)							19(MO)		19(MO)		
Flatten side-slope (from 4:1 to 6:1)	7(MO)							12(MO)		12(MO)		
Flatten side-slope (from 5:1 to 7:1)	8(MO)							14(MO)		14(MO)		
Install animal fencing (only collisions with animals)	90(KY) 90(MO) 70(MT) 80		91(MO)	61(MO)	85(AZ)	37(AZ)	54(AZ)					
Install snow fencing (only collisions related under snow conditions)	71(AZ) 35(MT) 53											
Install object markers	16(AZ) 16(MO) 16	41(MO)	17(MO)	14(MO)						29(MO)	29(AZ)	
Increase roadside clear zone recovery distance												
Increase roadside clear zone recovery distance (add 5 ft)									13(MO)		13(MO)	
Increase roadside clear zone recovery distance (add 8 ft)									21(MO)		21(MO)	
Increase roadside clear zone recovery distance (add 10 ft)									25(MO)		25(MO)	
Increase roadside clear zone recovery distance (add 15 ft)									35(MO)		35(MO)	
Increase roadside clear zone recovery distance (add 20 ft)									44(MO)		44(MO)	

3.8. CRF Applications and Economic Analysis Methods

CRFs are applied in an economic analysis to help select the most potentially beneficial countermeasures for implementation. The benefit-cost (B/C) ratio, i.e., the ratio of the expected benefits to the costs of the improvement, is the most popular analysis method used among the states for the Highway Safety Improvement Program (HSIP). To qualify for highway safety funding, the project must have a B/C ratio greater than 1.0. States have used different ways of applying CRFs in the calculation of the B/C ratio.

The states of California, Idaho, and Texas refer to the B/C ratio as a Safety Index (SI). For example, the SI used by Texas (2002), called the Safety Improvement Index (SII), is calculated as follows:

$$S = \frac{R(C_f F + C_i I + C_p P)}{Y} - M \tag{3-5}$$

$$Q = \left(\frac{A_a - A_b}{A_b} \div L \right) S \tag{3-6}$$

$$B = \frac{S + \frac{1}{2}Q}{1.08} + \sum_{i=2}^{L} \left[\frac{(S + \frac{1}{2}Q) + (i-1)Q}{1.08^i} \right] \tag{3-7}$$

$$SII = \frac{B}{C} \tag{3-8}$$

where

- S = Annual savings in crash costs (equal to crash cost savings per year less annual maintenance costs),
- R = Percentage reduction factor (it represents the percentage reduction in crash costs or severity that can be expected as a result of the improvement),
- F = Number of fatal and/or incapacitating injury crashes,
- C_f = Cost of a fatal and/or incapacitating injury crash,
- I = Number of non-incapacitating and/or possible injury crashes,
- C_i = Cost of a non-incapacitating and/or possible injury crash,
- P = Number of property-damage-only cashes,
- C_p = Cost of a property-damage-only crash,
- Y = Number of years of crash data,
- M = Change in annual maintenance costs for the proposed project relative to the existing situation,
- Q = Annual change in crash cost savings,
- A_a = Projected average annual ADT at the end of the project service life,

A_b = Average annual ADT during the year before the project is implemented,
L = Project service life,
B = Present worth of project benefits over its service life, and
C = Initial cost of the project.

Texas' SII incorporates adjustments to provide additional benefit for:

- Locations experiencing increasing traffic over the project life,
- Improvements that will reduce maintenance costs, and
- Projects expected to have long service lives over which construction costs can be amortized.

Virginia (2002) uses the following formula to calculate the B/C ratio for its Hazard Elimination Safety Projects:

$$\frac{B}{C}=\frac{\sum((((NF\times PRF)+(NI\times PRI))\times QDollars)+(NPD\times AAPD\times PRPD))_{improvement}\times ATGR}{(PECost+R/W\ \&UtilCost+ConstCost)\times K} \tag{3-9}$$

where

NF = Number of related fatal crashes per year,
PRF = Percent reduction in fatal crashes,
NI = Number of related injury crashes per year,
PRI = Percent reduction in injury crashes,
$QDollars$ = Weighted average cost of fatal and injury crashes at all similar locations,
NPD = Number of related property-damage-only crashes per year,
$AAPD$ = Annual average cost of property-damage-only crashes,
$PRPD$ = Percent reduction in property-damage-only crashes,
$ATGR$ = Projected district annual traffic growth rate,
$\sum(\ldots)_{improvement}$ = Sum of the estimated reduction in crash costs due to each improvement,
$PECost$ = Estimated preliminary engineering costs,
$R/W\&UtilCost$ = Estimated right-of-way and utilities costs,
$ConstCost$ = Estimated construction cost, and
K = Capital recovery factor = $\frac{i(1+i)^n}{(1+i)^n-1}$ where i = interest rate and n = average service life (year).

Some states combine fatal and injury crashes to calculate the crash costs. The combination of fatalities and injuries reduce the possibility of selecting an improvement project on the basis of chance, since fatality figures are relatively small. For example, Montana (2002) combines the fatal and injury crash benefit calculations into a single quotient called "Q", defined as follows:

$$Q=\frac{\text{Cost of Fatal Crash (F + II)} + \text{Cost of Injury Crash (NI + PI)}}{\text{Number of (Fatal Crashes + Injury Crashes)}} \tag{3-10}$$

where

F = Number of fatalities,
II = Number of incapacitated injuries,
NI = Number of non-incapacitating injuries, and
PI = Number possible injuries.

Thus, "Q" is the average cost per fatality and injury combined. The formula used to calculate the B/C ratio is defined below:

$$\frac{B}{C} = \frac{\left[\frac{ADT_a}{ADT_b}\right] \times \left[Q\left(A_{fi}\right)P_{fi} + C_{pd}\left(A_{pd}\right)P_{pd}\right]}{\left[C(K)\right] + M} \tag{3-11}$$

where

Q = Average cost per fatal and injury combined,
ADT_a = Projected average daily traffic after improvement,
= $1.03^{L} + 1$ where L = number of years for the life of the project,
ADT_b = Average daily traffic before improvement
= $1.03^{-S} + 1$ where S = number of years of the crash records used in the analysis,
A_{fi} = Average number of annual fatalities or injuries combined,
P_{fi} = Expected percent reduction in fatalities or injuries,
A_{pd} = Average annual property-damage-only crashes,
C_{pd} = Cost per property-damage-only crashes,
P_{pd} = Expected percent reduction in property-damage-only crashes,
C = Capital costs,
K = Capital recovery factor (interest rate), and
M = Change in annual maintenance or operations costs.

Indiana (1994) assumes that the crashes will increase at the same rate as the traffic volume; thus, the number of crashes is proportional to the average daily traffic (ADT). The crash reduction for each severity class and for each year of service life of the improvement is estimated as follows:

$$CR = N_a \times CRF \times CPF \tag{3-12}$$

where

CR = Crash reduction by year of service life,
N_a = Number of crashes (from crash data),
CRF = Crash reduction factor, and
CPF = Crash projection factor; it used to project the number of crashes in a given year. It is assumed to be equal to the factor used to project the increase in ADT.

When calculating the crash reduction benefits, CRF is applied to the total number of crashes, regardless of the number of people or vehicles involved, as follows:

$$\textit{Crash Reduction Benefits (CRB) = CR x Crash Cost} \tag{3-13}$$

$$\textit{Adjusted Reduction Benefits } (B_{adjust}) = PWF \times CRB \tag{3-14}$$

where PWF is the present worth factor. The B/C ratio is computed as:

$$\frac{B}{C} = \frac{K \times B_{ajust}}{K\left[I_c + (M_{ac} \times PWF_{Eps}) - T \times PWF_{SP})\right]} \tag{3-15}$$

where

K	=	Capital recovery factor for the last year of the improvement's service life,
B_{adjust}	=	Summation of yearly adjusted benefits,
I_c	=	Initial cost,
M_{ac}	=	Annual maintenance cost,
PWF_{EPS}	=	Present worth factor (equal payment series),
PWF_{SP}	=	Present worth factor (single payment), and
T	=	Terminal value.

Kentucky (1974) uses the present worth method to calculate the improvement benefits and costs, and applies them in a dynamic programming (DP) method to select the optimal combination of safety improvement projects within the constraint of a given budget. Benefits and costs are the inputs for this dynamic program and are calculated as follows:

$$C = S + \frac{A[(1-i)^{L} - 1]}{i(1-i)^{L}} \tag{3-16}$$

$$B = \left[\frac{\frac{(1+t)^{(L+1)}}{(1+i)} - 1}{\frac{(1+t)}{(1+i)} - 1} - 1 \right] \times \frac{\sum_{m=1}^{J} \sum_{n=1}^{3} R_m N_{mn} P_n}{T} \tag{3-17}$$

where

C	=	Present worth cost of improvement,
S	=	Construction cost,
A	=	Yearly maintenance cost,
i	=	Present interest rate,
L	=	Life of improvement,
B	=	Present worth benefit,
t	=	Exponential growth rate factor for traffic volume,
T	=	Time (years) of crash history,
J	=	Number of crashes causes associated with the location,
R_m	=	Percent reduction of m-th cause affected by the improvement,
N_{mn}	=	Number of crashes associated with m-th cause, and

P_n = Average cost of a crash (n = 1 = fatality; n = 2 = non-fatal injury; n = 3 = property-damage-only).

Some states focus on the severity of crashes rather than the number of crashes. For example, Alaska (2002) uses crash cost reduction factors instead of crash number reduction factors. Specific crash cost reduction factors were developed by the State with spreadsheets that automate all calculations. Crash cost reduction factors are applied only to those crashes that are susceptible to correction by each improvement instead of to all crashes. This B/C ratio is calculated as follows:

$$\frac{B}{C} = \frac{CR + M_d}{C_c + M_i} \tag{3-18}$$

where

CR = Estimated annual reduction in crash cost,
M_d = Decrease in annual maintenance cost,
M_i = Increase in annual maintenance cost, and
C_c = Annualized construction cost.

Although B/C ratio is the most widely used method to prioritize alternative high-crash locations for independent projects, other methods have been used. Arizona (1991) uses an Incremental B/C Analysis (ΔB/ΔC) method to determine whether extra increments of cost are justified for a particular location or for considering improvements at two or more locations. This method assumes that the relative merit of a project is measured by its change in benefits and costs, compared to the next lower-cost alternative. This process is repetitive and always selects one out of all the proposed countermeasures as the most beneficial. The steps for using the Incremental B/C Analysis method are as follows:

1. Determine the benefits, costs, and the resulting B/C ratio for each countermeasure.
2. List countermeasures with a B/C ratio greater than 1.0 in order of increasing cost.
3. Calculate the incremental B/C ratio of the second lowest-cost countermeasure compared to the lowest-cost countermeasure. Pick the second lowest-cost countermeasure if this ratio is positive; else pick the lowest-cost countermeasure.
4. Continue in order of increasing costs to calculate the incremental B/C ratio for each countermeasure compared to the last-picked countermeasure.
5. Stop when the incremental B/C ratio (disregarding negative ratios) is less than 1.0.

Vermont (1991) uses two economic analysis techniques, the benefit-cost (B/C) ratio method and the cost-effectiveness (C/E) method. The C/E method provides an indicator of which projects are most cost effective, and therefore justifiable, based on which projects will prevent more crashes at a lower cost. The measure of effectiveness that best represents the improvement's objective indicates the safety benefits for any given improvement. The improvement's annual costs are calculated based on the B/C ratio method.

Ohio (2002) uses the rate-of-return method to select improvement projects. The rate-of-return is a measure of expected "yield" of the safety countermeasure. This method computes an estimated interest rate for a safety countermeasure at which the estimated net present annual worth of the countermeasure minus the estimated improvement cost is equal to zero. The net present annual worth of the countermeasure is the expected dollar value of safety benefits in terms of crashes prevented. The estimated improvement costs include those expected costs required for implementation and maintenance of the countermeasure.

Missouri (1999) uses the average-net-savings method to rank mutually exclusive projects. These are the projects involving more than one option for improving a site, but only one can be implemented. For example, a site that could be improved by either adding a median barrier or adding a continuous two-way left-turn lane, only the countermeasure that will result in the greatest benefit can be chosen.

South Carolina (2002) uses the net-benefit method, a procedure recommended by the Federal Highway Administration, to determine highway safety improvements. The net-benefit method is a procedure used to determine the expected net benefits of a countermeasure. The net benefit is obtained by subtracting the equivalent uniform annual costs from the equivalent uniform annual benefits. The procedure is based on the premise that the relative merit of a countermeasure is measured by its expected net annual benefit.

3.9. Summary

Crash reduction factors (CRFs) are used to estimate the expected reduction in crashes that will occur during a given period as a result of implementing a safety countermeasure. National Cooperative Highway Research Program (NCHRP) Report 162 identified the need for development of a national comprehensive set of CRFs for each state to evaluate safety improvements; this appeal, however, has not been answered. As a result, many states have developed their own CRFs or adopted CRFs from the other states, or both. In the chapter, CRFs developed by various states were summarized in a series of tables. General findings from this review are summarized below:

- Eight states did not use CRFs in evaluating safety projects; nineteen states have developed their own CRFs; five states adopted CRFs completely from the other states while the rest used CRFs from published literature or a combination of literature and other states; and seven states indicated that they were updating their CRFs at the time of the survey.

- Of the 19 states that have developed their own CRFs, 17 used the before-and-after method to develop their CRFs and two used the cross-sectional method.

- The most common length of before and after periods used was three years.

- Different formulas were used by states to compute the total CRF for multiple treatments.

- Some states developed CRFs based on only the total crashes while others included detailed CRFs by crash type and crash severity.

- Different formulas and methods of economic analysis have been used by various states to compute benefits and costs for selecting countermeasures for a project.

CHAPTER 4
DEVELOPMENT OF COMPUTER SYSTEM

4.1. Introduction

While the Florida Department of Transportation (FDOT) maintains a comprehensive crash database for the state roadway system, it does not have a central database for safety improvement projects. Consequently, historical data for safety improvement projects are maintained separately at various district offices in various formats and are not easily accessible for developing CRFs and for other purposes. This chapter describes a web-based database application that was developed to systematically maintain statewide safety improvement project data to facilitate the continual process of updating CRFs. The system, called the Crash Reduction Analysis System Hub (CRASH), allows the following tasks to be performed in an automated manner:

1. Recording and maintaining improvement projects,
2. Updating CRFs based on the latest available improvement project and crash data, and
3. Applying calculated CRFs in the benefit-cost analyses of specific projects.

In addition, the system provides various functions for data retrieval and exportation for different analysis and reporting purposes.

4.2. System Components

The CRASH program was designed as a Microsoft ASP.NET web application that works with Microsoft ACCESS databases. The system in its initial version consists of the following four major database components:

1. Safety improvement projects since 1992
2. Historical crash records from 1984 through 2003
3. Crash reduction factors and associated statistics
4. User management information.

Figure 4-1 shows the initial screen of the system, which includes the following six functional components (front-end) that work with the above databases (back-end):

1. **Project Analysis**: This functional component allows one to perform the following functions:

    - Start New Project: To perform a new benefit-cost analysis for a project.
    - Edit Projects: To make changes to one or more previously saved analysis projects.
    - View Projects: To view one or more previously saved analysis projects.

2. **Historical Projects**: This functional component allows one to perform the following functions:

    - Add Project: To enter information for an existing project of which analysis has been performed.

- Edit Projects: To add post-construction information for projects that have been completed or are under construction.
- View Projects: To view projects that have been completed or are under construction.
- Generate HSIP Report: To generate the standard Highway Safety Improvement Program (HSIP) report.
- Before-After Analysis: To generate before-and-after statistics for selected projects to evaluate their effectiveness.

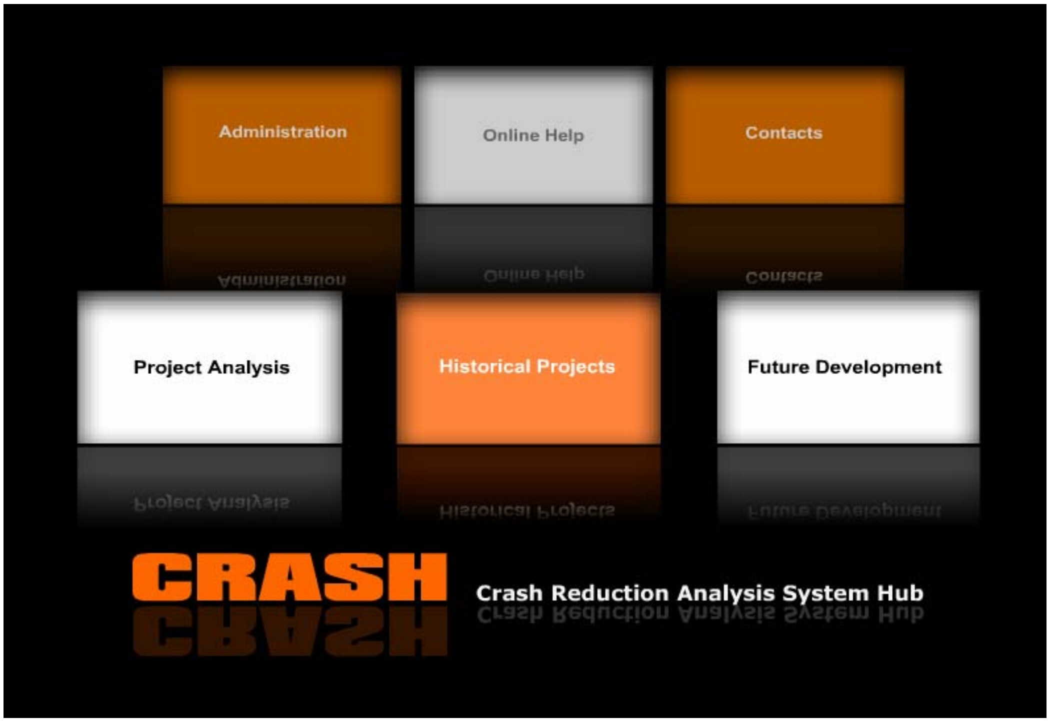


Figure 4-1. CRASH Main Screen

3. **Future Development**: This functional component is reserved for future development in support of FDOT application of SafetyAnalyst, a new system currently under development by the Federal Highway Administration. For more information about the project, please visit the SystemAnalyst homepage at http://www.safetyanalyst.org/.

4. **Administration**: This functional component is mainly used by the system administrator or a designated person in the FDOT Central Office to perform the following functions:

- User Management: To manage usernames and passwords for access to various system components (for system administrator only).
- View CRFs: To generate the list of current Florida CRFs and to view detailed summary statistics associated with the calculation of each CRF.
- Update CRFs: To update the crash reduction factors after the new project and data are added (for system administration only).

- Maintain Types: To add and edit safety improvement project types (for system administrator only).
- Assign Types: To review projects and assign improvement types to projects (for system administrator only).
- Append New Records: To append crash records from a new data year (for system administrator only).

5. **Online Help**: This functional component provides access to the CRASH online help, tabulated CRFs from other states, state-by-state CRFs, and the final report for the project that develops this web application.

6. **Contact**: This functional component lists contact information for technical support and general information on the system.

To access any of these functional components, click the corresponding over-sized button shown in either orange or white color.

4.3. System Access Requirements

CRASH runs as a web application on the FDOT intranet system. To access the CRASH website, the user must first be given authorization via the assignment of a User Name and a Password. This authorization is in addition to the authorization the user needs for access to FDOT's Intranet. The current contact for access authorization is:

Patrick A. Brady, P.E.
FDOT Safety Office
605 Suwannee Street, M.S. 53
Tallahassee FL 32399-0450
Phone: (850) 245-1502 or (850) 245-1500
Fax: (850) 245-1554 or SC 205-1554
Email: patrick.brady@dot.state.fl.us

Depending on the need, a user will be assigned access to certain pages and functionalities. Section 4.7.1 details such assignment by the System Administrator, which is a person in the Central Office who is in charge of CRASH system maintenance. Figure 4-2 shows the login screen that prompts the user for a User Name and a Password. When the system is idled for more than half hour, the user will be prompted this screen when trying to resume the session.

4.4. Browser Requirements

CRASH can be accessed through a regular web browser. While it has not been tested on other browsers, the system has been well-tested on Internet Explorer (IE). The minimum display resolution is 1024x768. This is also the recommended resolution.

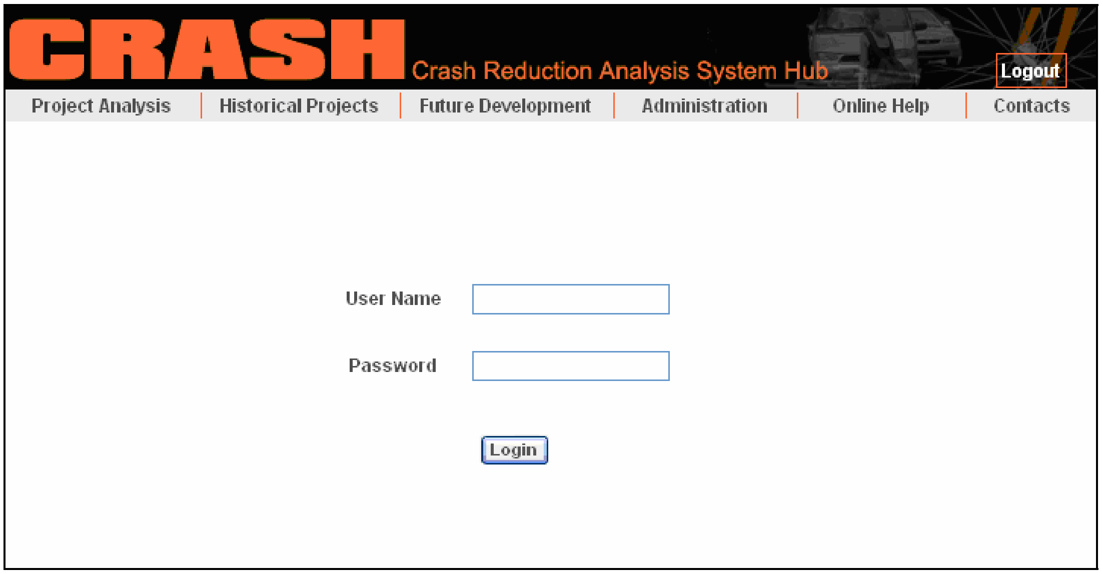


Figure 4-2. CRASH Login Screen

<u>4.5. Project Analysis</u>

This component allows the user to quickly and conveniently perform a benefit-cost analysis for a potential improvement project, add a new improvement project to the project database, and view or edit an existing project. Analysis projects selected for implementation can be saved to the FDOT database and contribute directly to the continued update of CRFs.

4.5.1. Data Variables

Variables for improvement projects can be pre-construction and post-construction. Data for pre-construction variables are entered during a benefit-cost analysis. Data for post-construction variables are entered only after a project is selected and the construction is completed. Pre-construction variables include those in the standard benefit-cost analysis form, plus several variables required for Highway Safety Improvement Program (HSIP) reporting. Figure 4-3 shows, as a CRASH report, the standard benefit-cost analysis form used by FDOT. Post-construction variables include those that are known only after a project is selected and approved for construction, including the beginning and ending of construction period.

State of Florida Department of Transportation

SAFETY OFFICE BENEFIT-COST ANALYSIS

1. Submitted by CO-MRM
2. Date Submitted 1/13/2005
3. Project No. ______ WPA No. ______ Skid (I.D.) ______
4. Alternative No. ______ FM No. 2133232 SN NB 325838 Speed 50
5. X Safety Priority; ______ Environmental Study
6. District 2 County/Section 72290 SubSection 000 State Road 933 U.S. Road 0023

7.

	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Total Length
Beginning Milepost	1.9						
Ending Milepost	2.611						
Length	0.711						0.711
Node							

8. Description of Location/Facility Type I-95 AT I-295 NORTH END OF TOWN

9. Cause of Crash Problems (list and discuss)

10. Proposed Improvements (list and discuss) ROADWAY LIGHTING

		1999	2000	2001	2002		AVG
11.	No. of Crashes	10	9	9	13		10
12.	No. of Crashes Reduced	8	1	4	3		4

14. Crash Information for Facility

Cost/Crash	$50,000
Crash Cleanup	$200
Interest Rate	7.00%

13.

Type of Crash	CRF(%)	Number of Crashes	Crashes to be prevented
Angle	90.46	2	2
Fixed-Object	16.58	11	3
Right-Turn	75.70	0	0
Left-Turn	70.11	0	0
Rear-End	-14.45	10	-2
Head-On	100.00	1	1
Sideswipe	50.86	1	1
Pedestrian	-55.48	0	0
Ran-Off-Rd	73.12	8	6
Others	55.20	8	5
Total		41	16

15. Annual Cost of Improvements

Type	Cost	Life	CF	Annual Cost
A. R-O-W				
B. P.E.C.E.I.	$10,740	20	0.0944	$1,014
C. Structure				
D. Roadway	$29,150	20	0.0944	$2,752
E. Contingency				
F. Signals/Signing	$20,550	10	0.1424	$2,926
G. Subtotal				$6,692
H. Change in Maintenance				
I. Crash Cleanup				($800)
J. Other				
K. Total				$5,892

16. Benefits

A. Crash Reduction: No. 4 at $50,000 — $200,000
B. Other
C. Other
Total Annual Benefit $200,000

17. Benefit-Cost Ratio 33.94

Prepared by	Approved by	Date

Comments/Crash Reduction Method:

High Crash Listings:

Figure 4-3. Standard Benefit-Cost Analysis Form as Displayed in CRASH

4.5.2. Start a New Benefit-Cost Analysis

To perform a new benefit-cost analysis, select the **Project Analysis|Start New Project** menu item. This will bring up the screen shown in Figure 4-4, which shows the top portion of the benefit-cost analysis form. In this form, the user can press the Tab key to move from one field to another. Some of the fields are self-calculated, which are obviously not accessible by either the Tab key or the mouse pointer.

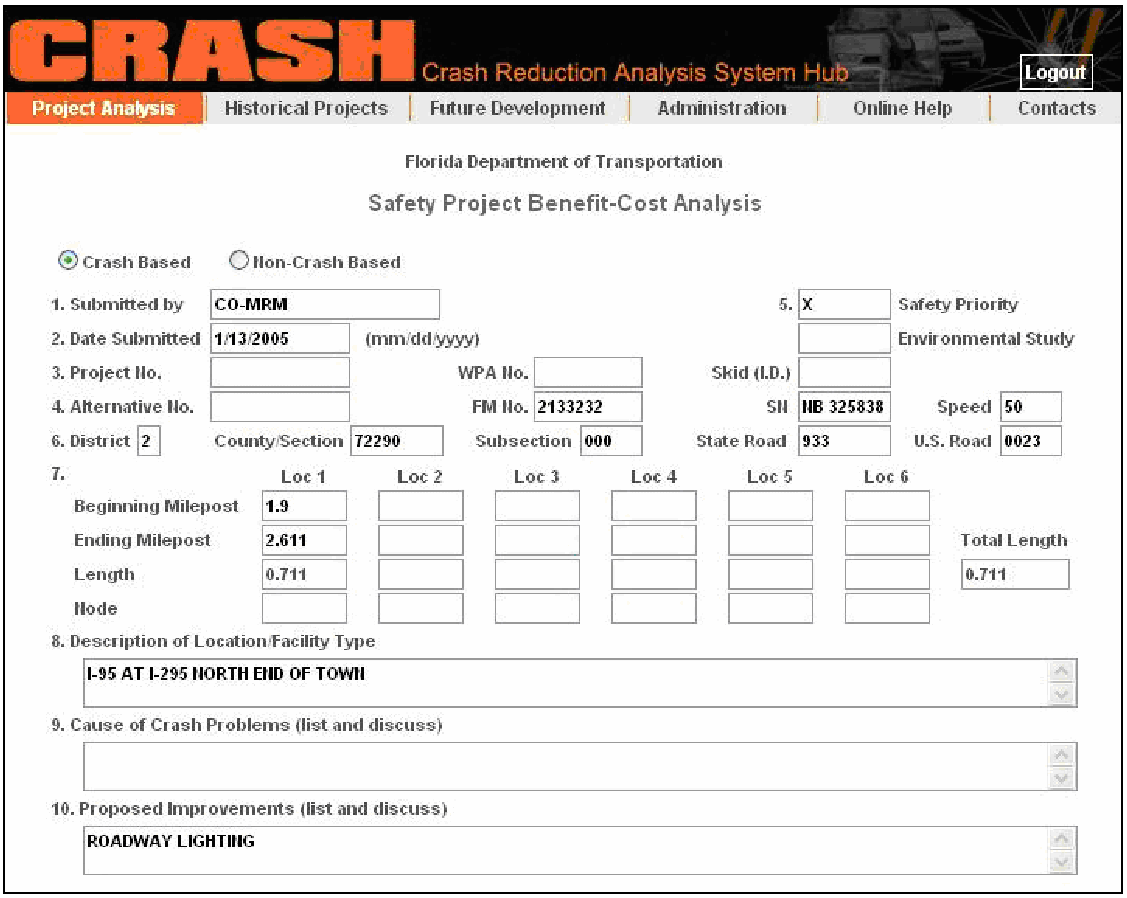


Figure 4-4. Standard Benefit-Cost Analysis Form in CRASH

The first item on the form is for specifying whether an improvement project is crash based or non-crash based. The default is crash based, which is for projects that are being considered in response to specific crash problems. Unlike crash based projects, which are reactive in nature, non-crash based projects would include proactive projects such as school zone signing, pavement markings, sidewalks, elder driver programs, etc. When the non-crash based option is selected, item 9 of the form will change from "Cause of Crash Problems" to "Non-crash Based Project Justification".

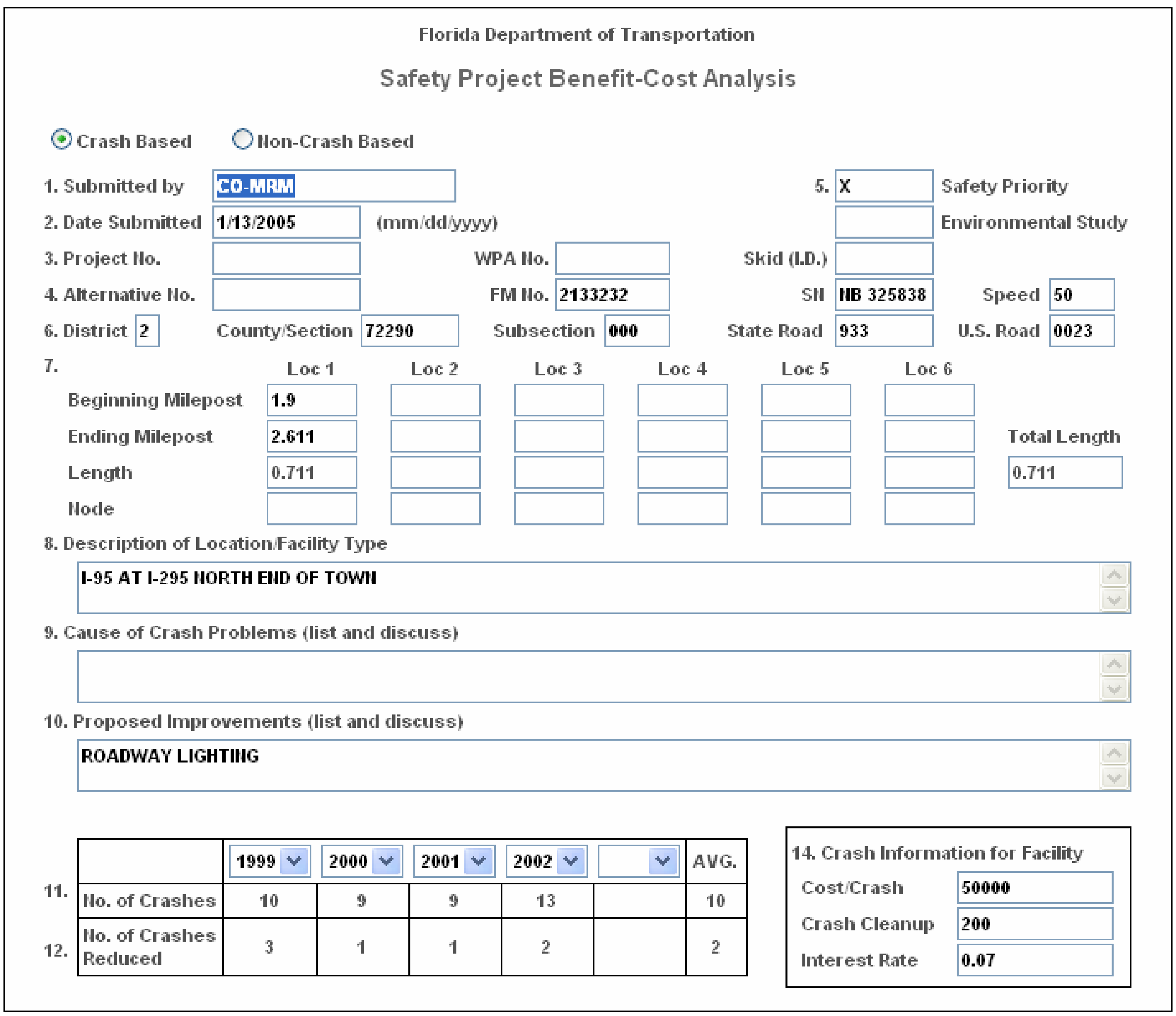
The location fields, including County and Section, Subsection, Beginning Milepost, and Ending Milepost, are required for a project to be saved. Up to six different locations of a project may be entered. This is used when a project involves multiple disjointed locations, for example, improve lighting at several interchanges.

An important capability of the benefit-cost analysis form is that it allows the user to automatically retrieve crash statistics and CRFs into the form for calculation. This replaces the previously time-consuming, non-repeatable, and potentially error-prone manual data entry process.

Important: *To help the State improve the accuracy of crash reduction factors, it is important that a project is described in as much detail as possible.*

4.5.2.1. Retrieve Crash Records into Analysis

Once the data have been entered in the location fields, the user can simply select a data year from the dropdown menu, as shown on the bottom left corner of Figure 4-5, to automatically retrieve crash statistics. As soon as a specific data year is selected, the crash records that are specific to the project location will be automatically retrieved, summarized, and displayed. Up to five years of crash records may be included in the analysis.


Florida Department of Transportation

Safety Project Benefit-Cost Analysis

Crash Based   Non-Crash Based

1. Submitted by: CO-MRM
2. Date Submitted: 1/13/2005 (mm/dd/yyyy)
3. Project No.:   WPA No.:   Skid (I.D.):
4. Alternative No.:   FM No.: 2133232   SN: NB 325838   Speed: 50
5. X Safety Priority; Environmental Study
6. District: 2   County/Section: 72290   Subsection: 000   State Road: 933   U.S. Road: 0023

7.

	Loc 1	Loc 2	Loc 3	Loc 4	Loc 5	Loc 6	Total Length
Beginning Milepost	1.9						
Ending Milepost	2.611						
Length	0.711						0.711
Node							

8. Description of Location/Facility Type: I-95 AT I-295 NORTH END OF TOWN
9. Cause of Crash Problems (list and discuss):
10. Proposed Improvements (list and discuss): ROADWAY LIGHTING

		1999	2000	2001	2002		AVG.
11.	No. of Crashes	10	9	9	13		10
12.	No. of Crashes Reduced	3	1	1	2		2

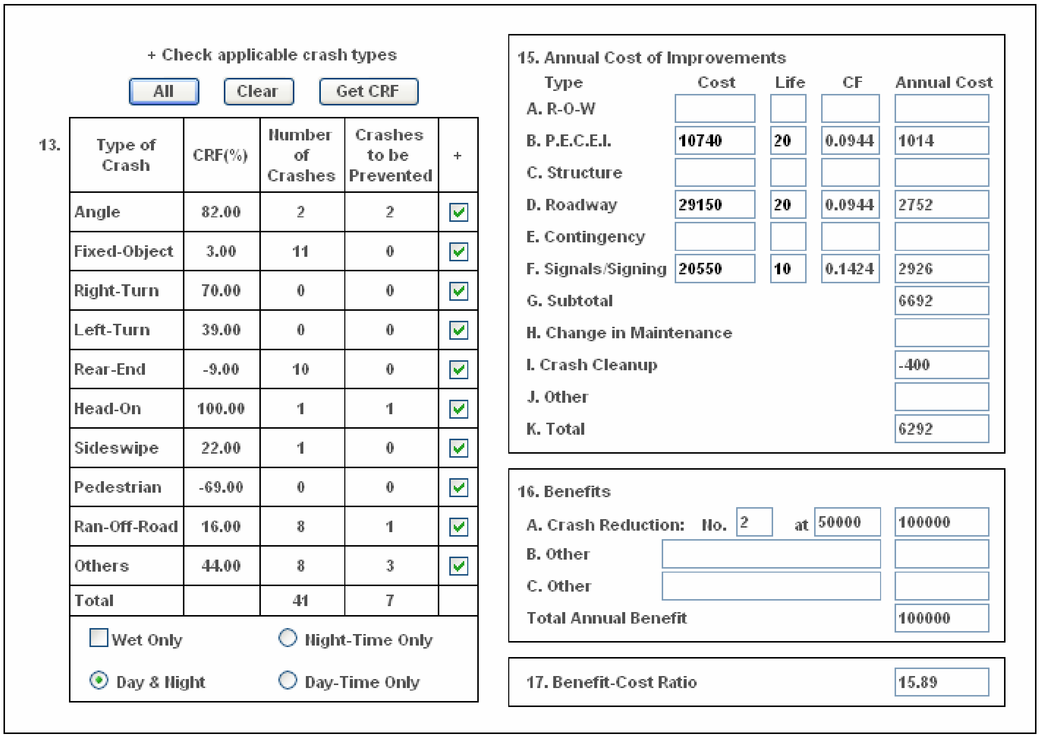
14. Crash Information for Facility
Cost/Crash: 50000
Crash Cleanup: 200
Interest Rate: 0.07

Figure 4-5. Automated Crash Record Retrieval

4.5.2.2. Apply Crash Reduction Factors

To obtain an estimate of the number of crashes to be prevented as a result of an improvement project(s), the CRFs associated with the particular type of project(s) must be specified. To do this:

1. Click the **Get CRF** button on the form shown in Figure 4-6. The screen shown in Figure 4-7 will pop up.



\+ Check applicable crash types

All | Clear | Get CRF

13.

Type of Crash	CRF(%)	Number of Crashes	Crashes to be Prevented	+
Angle	82.00	2	2	☑
Fixed-Object	3.00	11	0	☑
Right-Turn	70.00	0	0	☑
Left-Turn	39.00	0	0	☑
Rear-End	-9.00	10	0	☑
Head-On	100.00	1	1	☑
Sideswipe	22.00	1	0	☑
Pedestrian	-69.00	0	0	☑
Ran-Off-Road	16.00	8	1	☑
Others	44.00	8	3	☑
Total		41	7	

☐ Wet Only ○ Night-Time Only

◉ Day & Night ○ Day-Time Only

15. Annual Cost of Improvements

Type	Cost	Life	CF	Annual Cost
A. R-O-W				
B. P.E.C.E.I.	10740	20	0.0944	1014
C. Structure				
D. Roadway	29150	20	0.0944	2752
E. Contingency				
F. Signals/Signing	20550	10	0.1424	2926
G. Subtotal				6692
H. Change in Maintenance				
I. Crash Cleanup				-400
J. Other				
K. Total				6292

16. Benefits

A. Crash Reduction:	No. 2 at 50000	100000
B. Other		
C. Other		
Total Annual Benefit		100000

17. Benefit-Cost Ratio 15.89

Figure 4-6. Automated CRF Retrieval

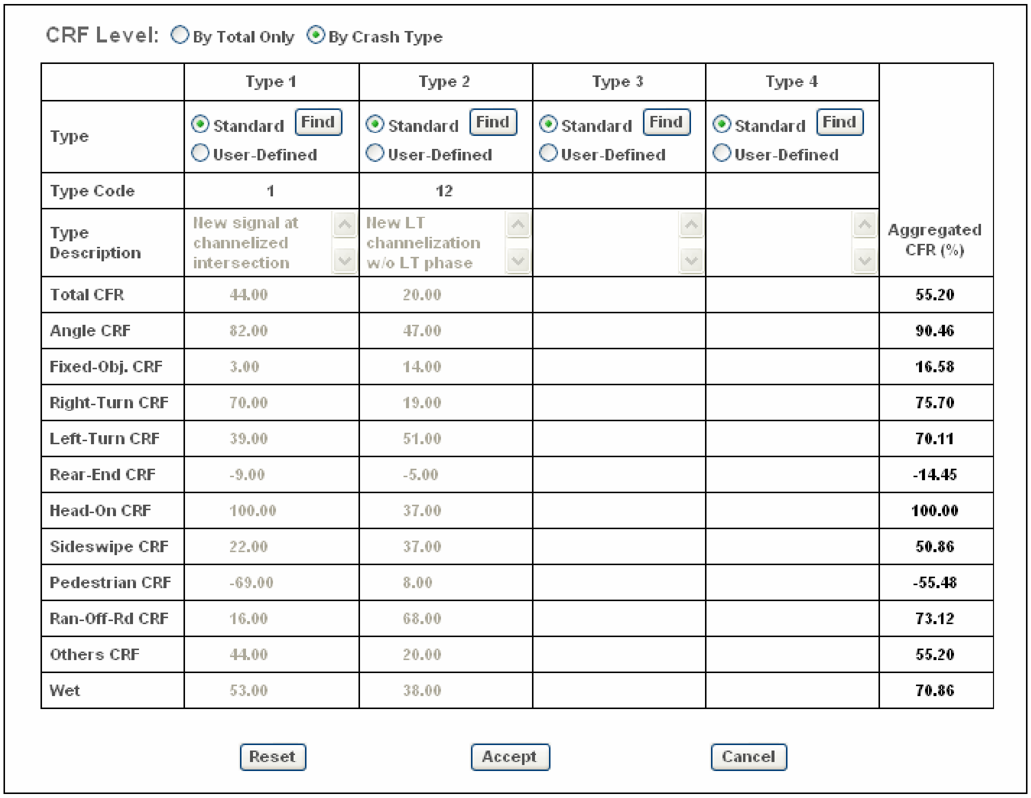
2. Select to apply either a single CRF based on the total crashes (default) or detailed CRFs for different crash types.

3. Select whether to apply standard or user-defined CRFs. Choose up to four different improvement types if a project involves multiple improvements. The aggregated CRFs, shown on the last column of Figure 4-7, will be automatically calculated based on the following formula and:

$$CRF_t = CRF_1 + (1 - CRF_1)CRF_2 + (1 - CRF_1)(1 - CRF_2)CRF_3 + \ldots$$

where

CRF_t = Aggregated CRF,
CRF_1 = CRF for the first improvement project,
CRF_2 = CRF for the second improvement project, and
CRF_3 = CRF for the third improvement project.


CRF Level: ○ By Total Only ⦿ By Crash Type

	Type 1	Type 2	Type 3	Type 4	
Type	⦿ Standard Find ○ User-Defined	⦿ Standard Find ○ User-Defined	⦿ Standard Find ○ User-Defined	⦿ Standard Find ○ User-Defined	
Type Code	1	12			
Type Description	New signal at channelized intersection	New LT channelization w/o LT phase			Aggregated CFR (%)
Total CFR	44.00	20.00			55.20
Angle CRF	82.00	47.00			90.46
Fixed-Obj. CRF	3.00	14.00			16.58
Right-Turn CRF	70.00	19.00			75.70
Left-Turn CRF	39.00	51.00			70.11
Rear-End CRF	-9.00	-5.00			-14.45
Head-On CRF	100.00	37.00			100.00
Sideswipe CRF	22.00	37.00			50.86
Pedestrian CRF	-69.00	8.00			-55.48
Ran-Off-Rd CRF	16.00	68.00			73.12
Others CRF	44.00	20.00			55.20
Wet	53.00	38.00			70.86

Reset Accept Cancel

Figure 4-7. Screen for Selecting Crash Reduction Factors

To use standard CRFs, click the **Find** button in Figure 4-7 to bring up the screen shown in Figure 4-8, which shows a list of available improvement types. Note that on this list, the number of projects (N) available to develop the CRFs is given at the end of each improvement type in parentheses. It is advisable to use only those with a project sample size of at least five. The user will be prompted an advisory message when an improvement type with a sample size less than five is selected. The user can select an improvement type from the list by clicking the appropriate item. The corresponding CRFs will be listed on the right. Click **Accept** to retrieve the CRFs and exit from the screen.

If the CRFs for a specific improvement type are not available, they must be obtained from another source and entered manually as user-defined CRFs. To use CRFs from other sources (i.e., user-defined), simply enter the factors in the appropriate fields manually. When CRFs are user-defined, a "**" note will appear on top of the selected CRFs to indicate that the CRFs being used are non-standard. Tables 3-6 to 3-13 and Appendix B provide some CRFs developed by other states.

Once the CRFs are selected, the user can click the **Accept** button to retrieve the CRFs into the benefit-cost analysis form. By default, all CRFs for different crash types are included. The user may uncheck any crash types that are not applicable to the specific improvement project (see Figure 4-6). Unchecked crash types are excluded from the analysis.

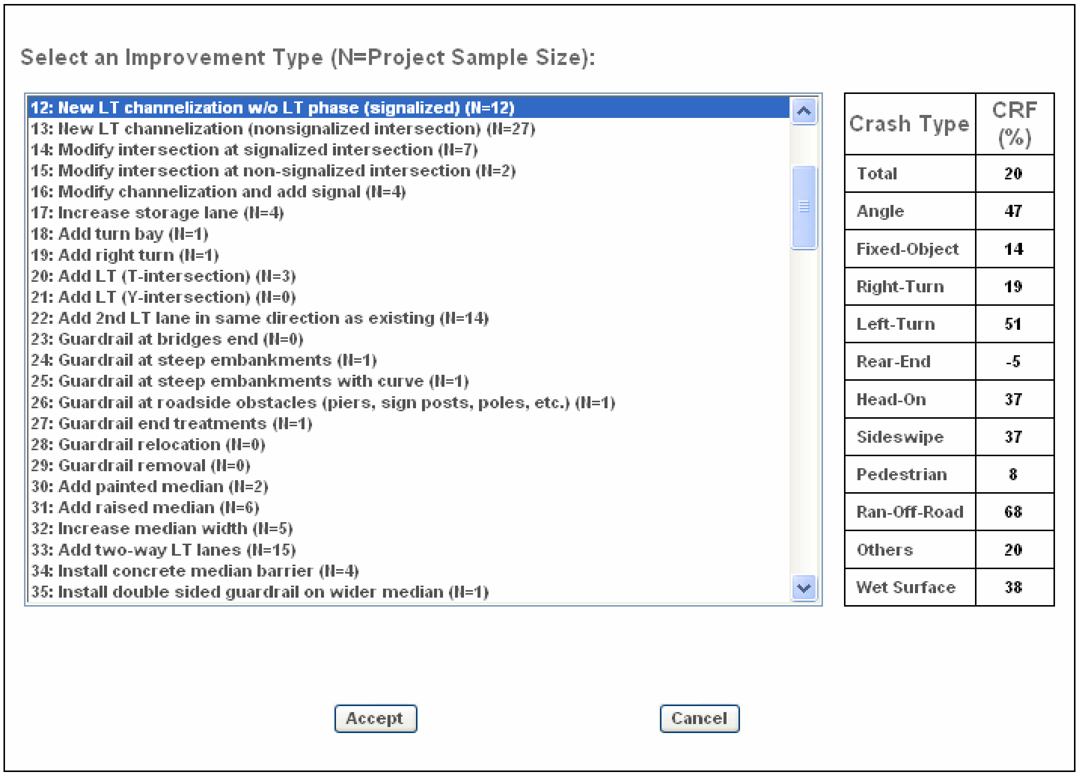


Figure 4-8. Screen for Selecting CRFs

The list of improvement type selected will be listed under the **Selected CRF Safety Improvement Type(s)** box, as shown on Figure 4-9 as part of the pre-construction additional information for HSIP report. If only one improvement type has been selected, it will be listed as the Assigned Safety Improvement Type in the last box on the form. If more than one improvement type has been selected, this box will show "0-Improvement Type Not Assigned". The user can click the dropdown button to show the list of improvement type and select one that is the primary improvement type. Note that the assignment of improvement type can also be performed through **Administration| Assign Types** menu option, which allows a group of projects to be assigned by a specific person. See section 4.7.5 for additional information on this option.

After an analysis form is completed, it may be saved to the database by clicking the **Save** button at the bottom of the benefit-cost analysis form. A saved project may be edited or viewed using the **Project Analysis|Edit Projects** and **Project Analysis|View Projects**, respectively. To print the form, simply click the **Print** button. This will bring up a print preview screen. Clicking on the **Print** button again on this screen will send the screen to the printer. The user may also click the **Send to Historical** button to transfer the entered data into the historical project form, where information on project construction can be entered. See section 4.6 for more information on historical projects.

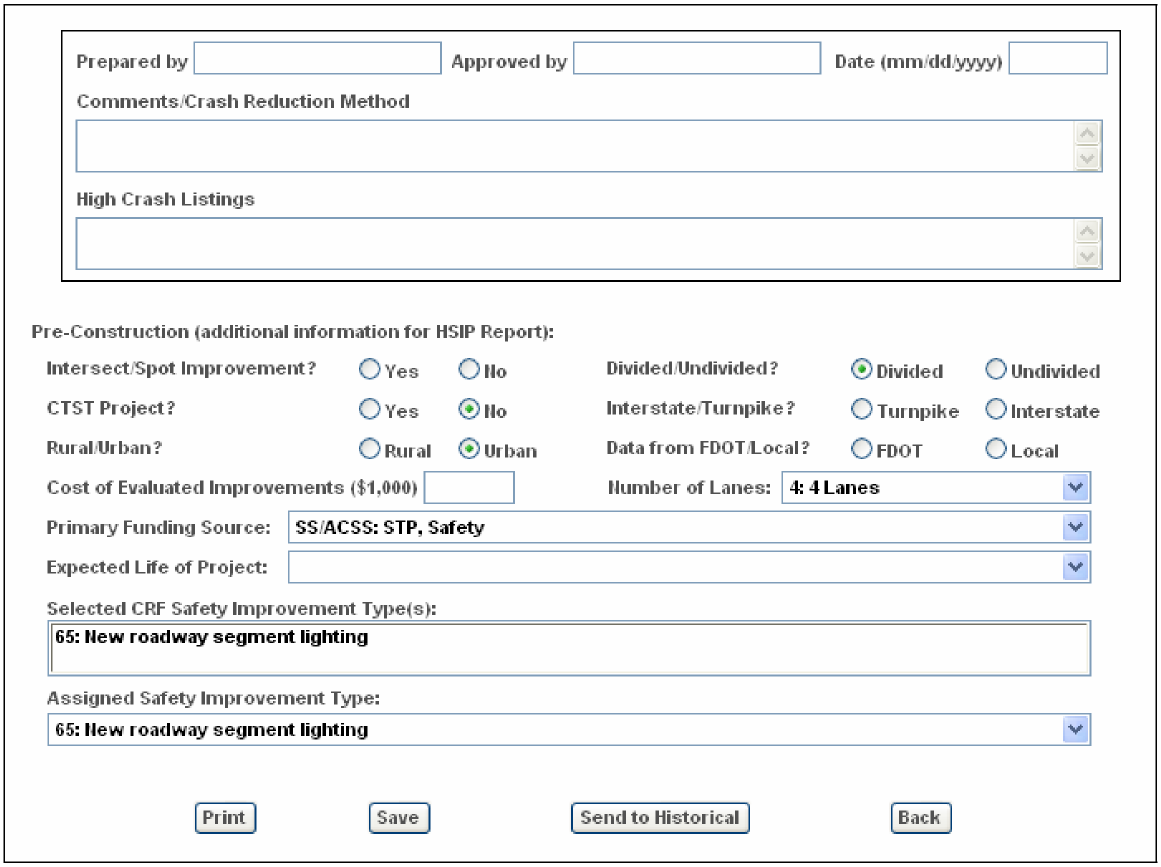


Figure 4-9. Pre-Construction Information for HSIP Report

4.5.3. Edit and View Projects

Saved projects can be either edited or viewed. In general, district users are allowed to view all projects from all districts, but can only edit projects from their own districts. Editing projects can also include deletion of a project record(s) from the database.

To edit or view projects, the user selects **Project Analysis|Edit Projects** and **Project Analysis|View Projects**, respectively. The user will be presented a set of filters as shown in Figure 4-10. The filters allow the user to retrieve only a subset of the projects that meet the filter conditions. Any combinations of the filters can be used. All filters are independent, except for the District and County. In this case, the user is allowed to select only a county that is under a selected district. When a filter is left unspecified, it is not used and no constraints will be imposed based on that filter.

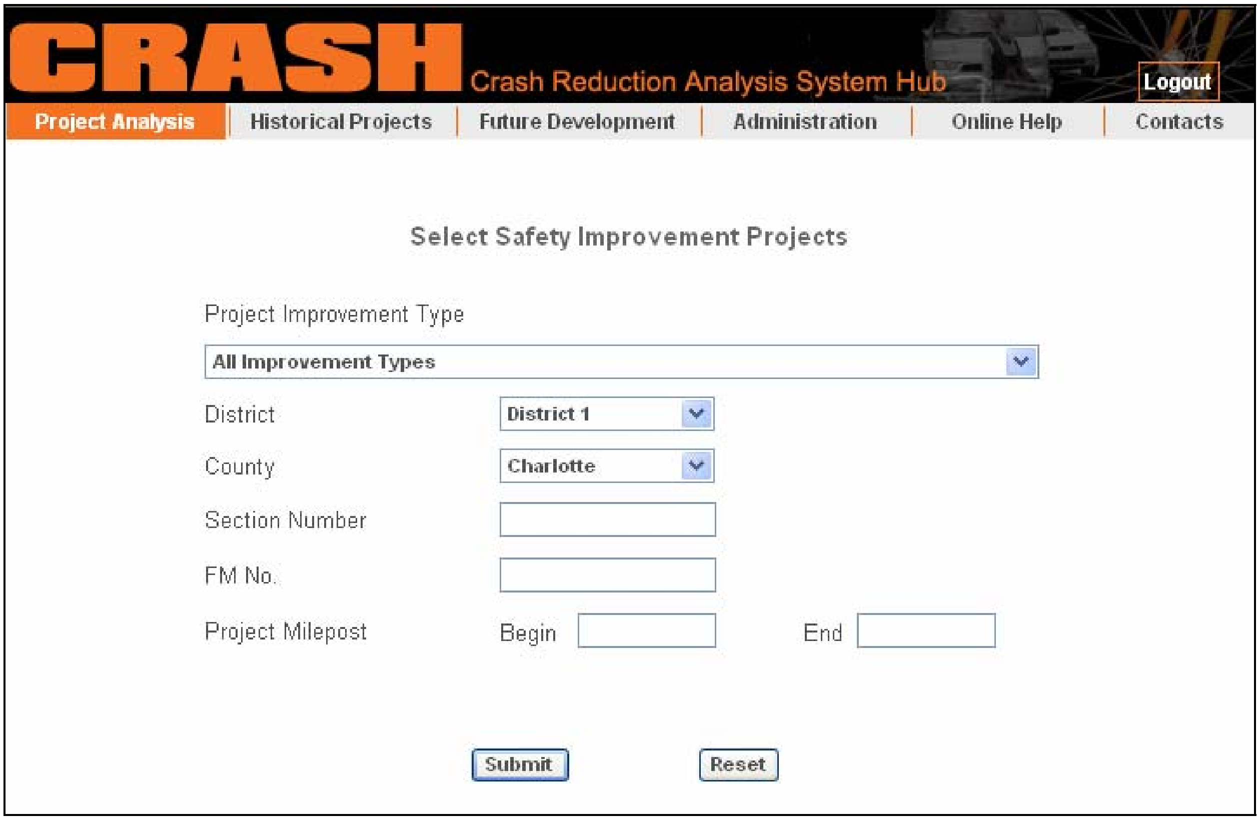


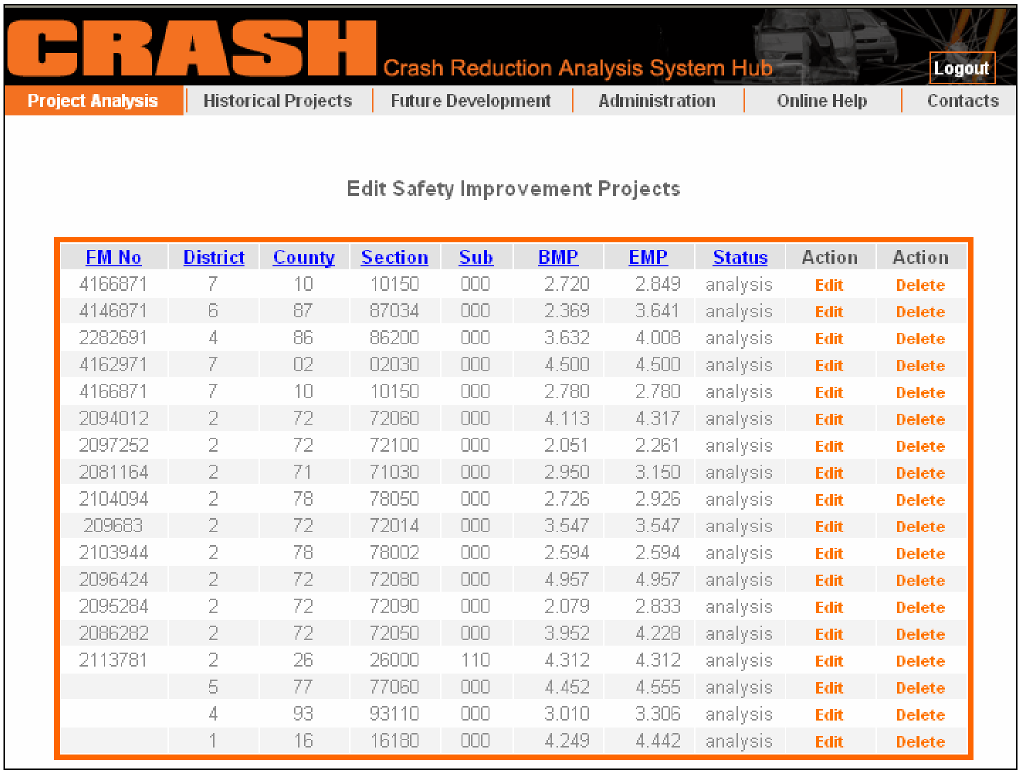
Figure 4-10. Project Filters to Select Projects for Editing and Viewing

Once the filters are specified, the user can click the **Submit** button to retrieve all projects that satisfy the filter conditions. All retrieved projects will be listed. Figures 4-11 and 4-12 each shows an example of a list of retrieved projects. The list includes several major location variables, plus the FM Number and the project status. The user can click the column header to sort the list. Clicking once will sort the list in the ascending order and clicking it again will sort it in the descending order.

For the **Status** column, a project can be assigned one of the following status:

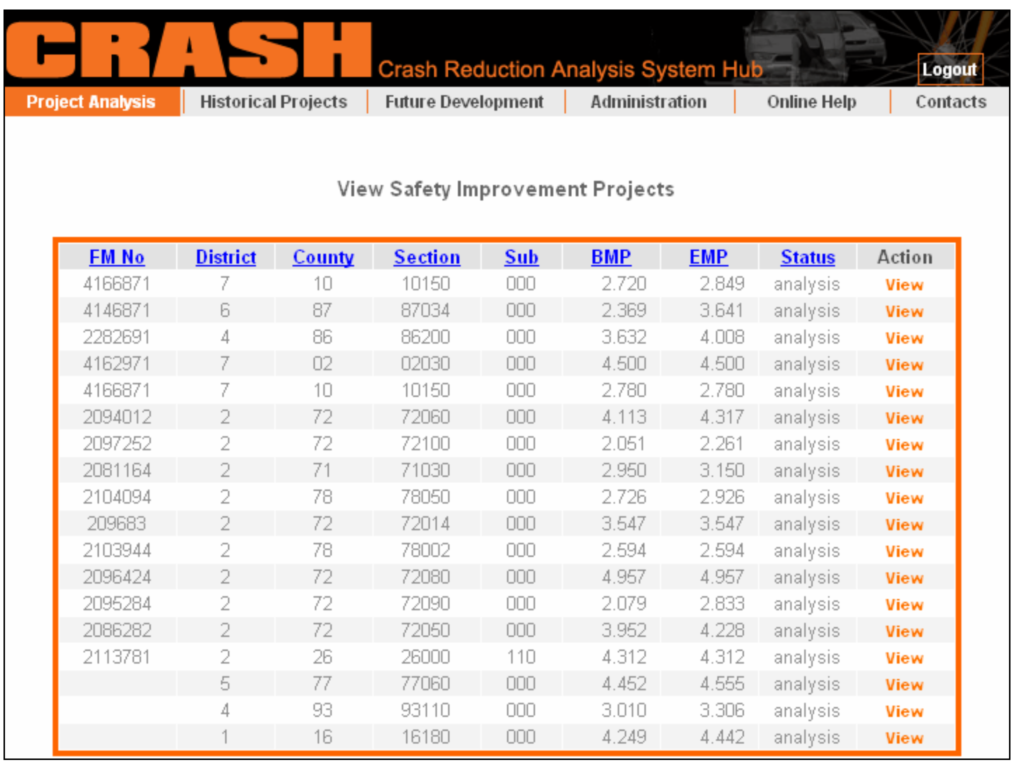
1. Analysis: The project is still in the analysis stage and may or may not be implemented.
2. Construction: The project is being constructed, but the construction has not been completed.
3. Completed: The project has been completed and the construction periods have been entered.

To view the details of a specific project, the user can click the one of the **Action** columns. Two actions, **Edit** and **Delete**, are available for the **Edit** project list and one action, **View**, is available for the **View** project list. Clicking in the **Edit** or **View** button will retrieve the project information for the selected record onto the benefit-cost analysis form. Clicking the **Delete** button will delete the record after user confirmation.



FM No	District	County	Section	Sub	BMP	EMP	Status	Action	Action
4166871	7	10	10150	000	2.720	2.849	analysis	Edit	Delete
4146871	6	87	87034	000	2.369	3.641	analysis	Edit	Delete
2282691	4	86	86200	000	3.632	4.008	analysis	Edit	Delete
4162971	7	02	02030	000	4.500	4.500	analysis	Edit	Delete
4166871	7	10	10150	000	2.780	2.780	analysis	Edit	Delete
2094012	2	72	72060	000	4.113	4.317	analysis	Edit	Delete
2097252	2	72	72100	000	2.051	2.261	analysis	Edit	Delete
2081164	2	71	71030	000	2.950	3.150	analysis	Edit	Delete
2104094	2	78	78050	000	2.726	2.926	analysis	Edit	Delete
209683	2	72	72014	000	3.547	3.547	analysis	Edit	Delete
2103944	2	78	78002	000	2.594	2.594	analysis	Edit	Delete
2096424	2	72	72080	000	4.957	4.957	analysis	Edit	Delete
2095284	2	72	72090	000	2.079	2.833	analysis	Edit	Delete
2086282	2	72	72050	000	3.952	4.228	analysis	Edit	Delete
2113781	2	26	26000	110	4.312	4.312	analysis	Edit	Delete
	5	77	77060	000	4.452	4.555	analysis	Edit	Delete
	4	93	93110	000	3.010	3.306	analysis	Edit	Delete
	1	16	16180	000	4.249	4.442	analysis	Edit	Delete

Figure 4-11. List of Projects for Editing



FM No	District	County	Section	Sub	BMP	EMP	Status	Action
4166871	7	10	10150	000	2.720	2.849	analysis	View
4146871	6	87	87034	000	2.369	3.641	analysis	View
2282691	4	86	86200	000	3.632	4.008	analysis	View
4162971	7	02	02030	000	4.500	4.500	analysis	View
4166871	7	10	10150	000	2.780	2.780	analysis	View
2094012	2	72	72060	000	4.113	4.317	analysis	View
2097252	2	72	72100	000	2.051	2.261	analysis	View
2081164	2	71	71030	000	2.950	3.150	analysis	View
2104094	2	78	78050	000	2.726	2.926	analysis	View
209683	2	72	72014	000	3.547	3.547	analysis	View
2103944	2	78	78002	000	2.594	2.594	analysis	View
2096424	2	72	72080	000	4.957	4.957	analysis	View
2095284	2	72	72090	000	2.079	2.833	analysis	View
2086282	2	72	72050	000	3.952	4.228	analysis	View
2113781	2	26	26000	110	4.312	4.312	analysis	View
	5	77	77060	000	4.452	4.555	analysis	View
	4	93	93110	000	3.010	3.306	analysis	View
	1	16	16180	000	4.249	4.442	analysis	View

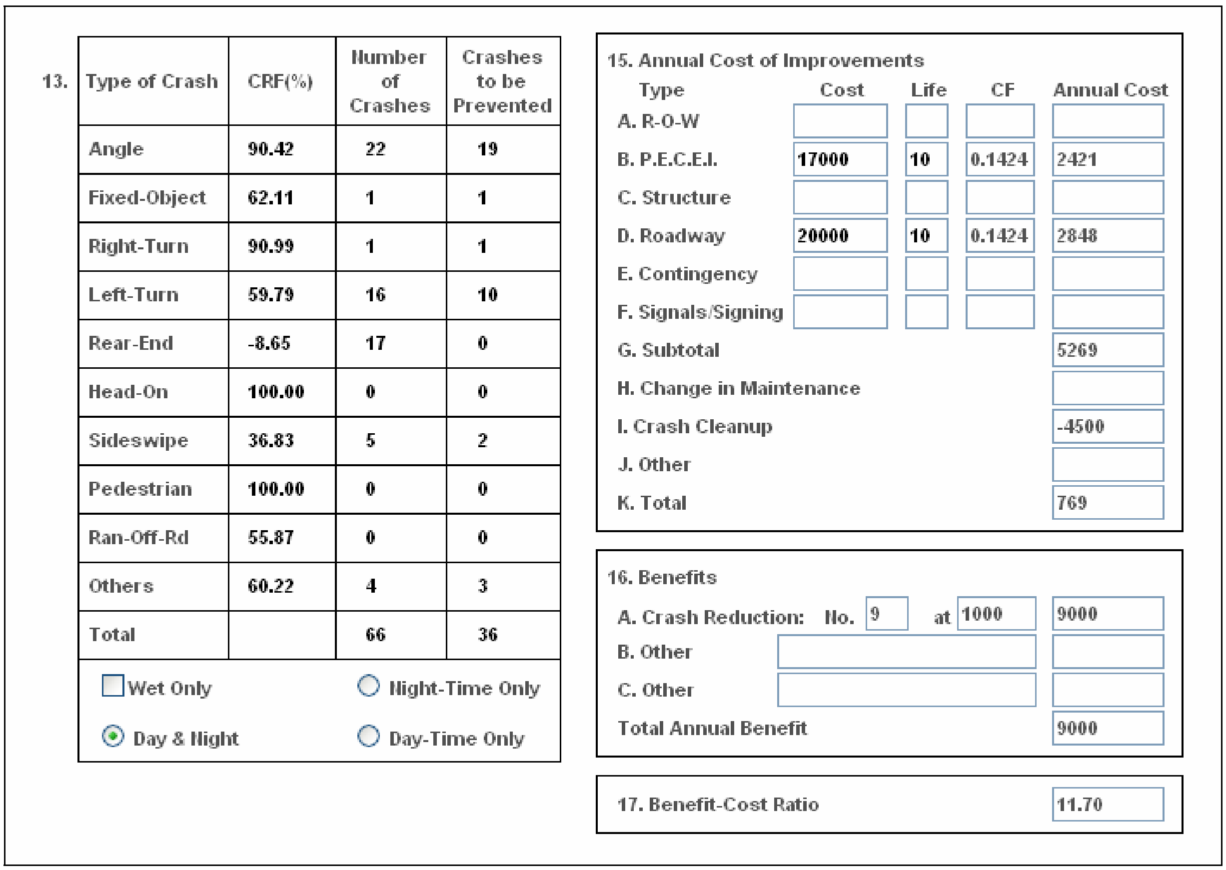
Figure 4-12. List of Projects for Viewing

4.6. Historical Projects

Historical projects are projects that have been adopted for implementation. Unlike projects under Project Analysis, historical projects are those that are either under construction or have been constructed.

4.6.1. Add Historical Projects

To add a historical project of which benefit-cost analysis has been performed, select the **Historical Projects|Add Project** menu item. This will bring up a form similar to the one for benefit-cost project analysis. Unlike for new a project, this form does not allow one to define CRFs or calculate crashes reduced (see Figure 4-13), which are done in project analysis. Another difference is that this form contains input for F.M. number and construction date (see Figure 4-14).



13. Type of Crash	CRF(%)	Number of Crashes	Crashes to be Prevented
Angle	90.42	22	19
Fixed-Object	62.11	1	1
Right-Turn	90.99	1	1
Left-Turn	59.79	16	10
Rear-End	-8.65	17	0
Head-On	100.00	0	0
Sideswipe	36.83	5	2
Pedestrian	100.00	0	0
Ran-Off-Rd	55.87	0	0
Others	60.22	4	3
Total		66	36

Wet Only — Night-Time Only
Day & Night — Day-Time Only

15. Annual Cost of Improvements

Type	Cost	Life	CF	Annual Cost
A. R-O-W				
B. P.E.C.E.I.	17000	10	0.1424	2421
C. Structure				
D. Roadway	20000	10	0.1424	2848
E. Contingency				
F. Signals/Signing				
G. Subtotal				5269
H. Change in Maintenance				
I. Crash Cleanup				-4500
J. Other				
K. Total				769

16. Benefits

A. Crash Reduction:	No. 9 at 1000	9000
B. Other		
C. Other		
Total Annual Benefit		9000

17. Benefit-Cost Ratio 11.70

Figure 4-13. Pre-calculated Number of Crashes Prevented

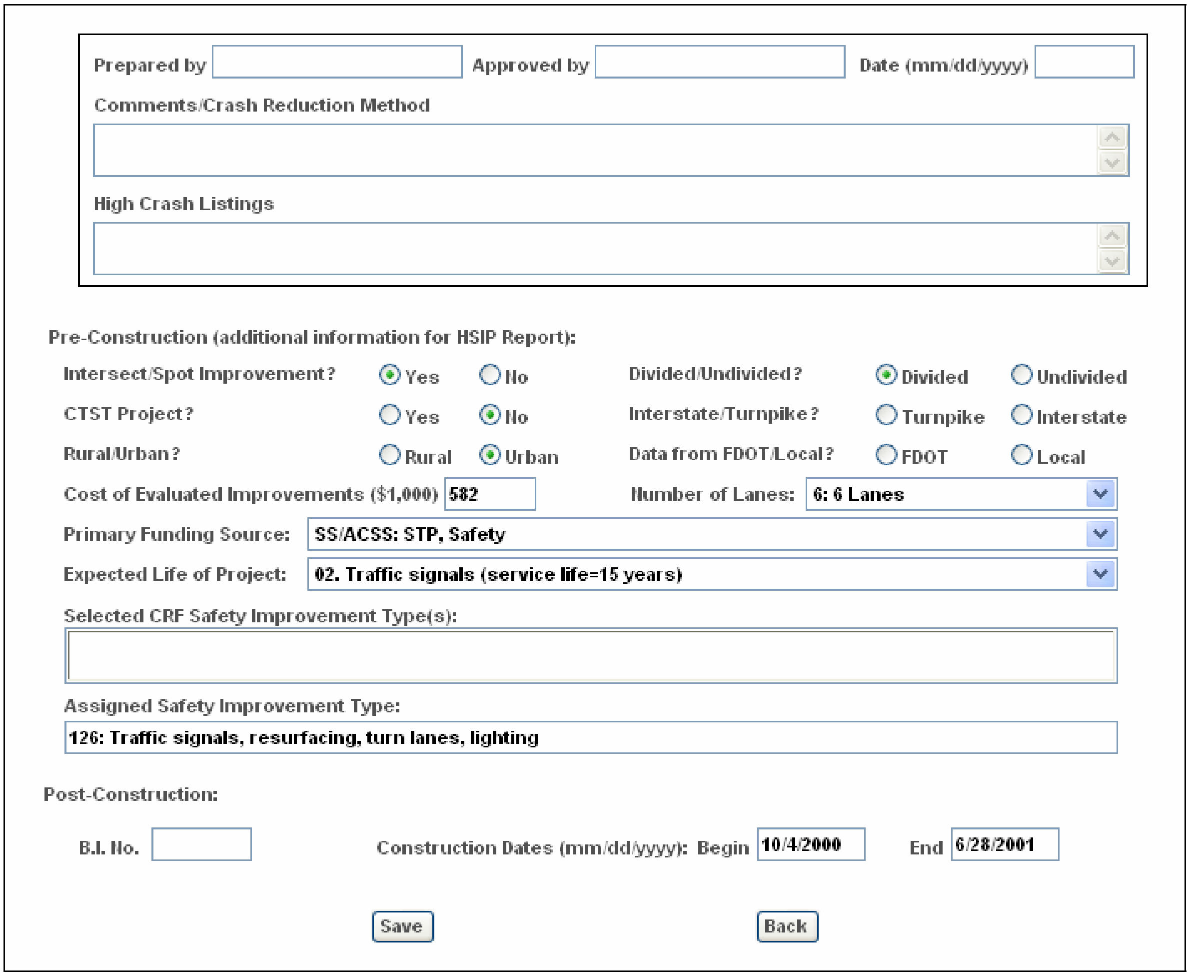


Figure 4-14. Construction Period Information for Historical Projects

4.6.2. Edit and View Historical Projects

These two functions are similar to the ones described in section 4.5.3. The only difference is that the form for historical projects contains construction date but the project analysis form does not. See section 4.5.3 for additional details.

4.6.3. Generate HSIP Report

This function is to generate the Highway Safety Improvement Programs (HSIP) annual report for selected projects. The function is accessed through the **Historical Projects|Generate HSIP Report** menu item. Figure 4-15 shows the screen for applying a set of filters to identify desirable projects. Once the filters are specified, the user can click the **Submit** button to start generating statistics for the report. Figure 4-16 shows a sample HSIP report. Click the **Print** button at the bottom of the screen to print the report.

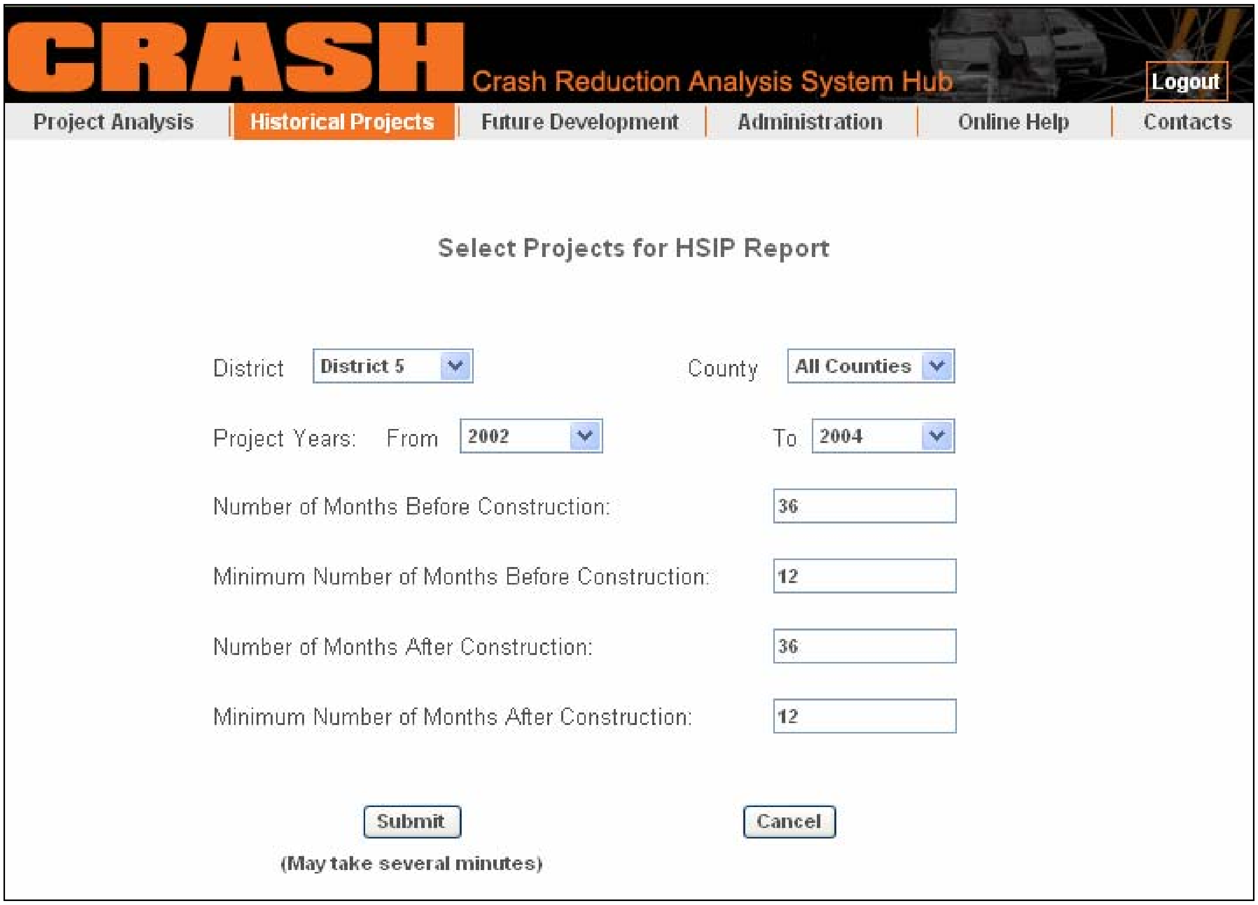


Figure 4-15. Filters for Project Selection for HSIP Report

STATE Florida F L

FIPS CODE (Alpha)

THE ANNUAL REPORT ON
HIGHWAY SAFETY IMPROVEMENT PROGRAMS

THE ANNUAL REPORT ON
EVALUATION DATA FOR COMPLETED SAFETY IMPROVEMENTS

Page 1 of 1

FM NUMBER	PRIMARY FUNDING SOURCE	SAFETY IMPROVEMENT TYPE	COST OF EVALUATED IMPROVEMENTS	CRASH BASED	NUMBER OF CRASHES										EVALUATION STATUS	VOLUME		RURAL or URBAN	NUMBER of LANES	DIVIDED or UNDIVIDED
					BEFORE					AFTER						Before AADT	After AADT			
					Mos.	Fat	Inj.	PDO	TOTAL	Mos.	Fat	Inj.	PDO	TOTAL						
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)	(21)
4066271	SS	40	$250,000	Y	36	0	44	42	86	24	0	0	0	0	P	21331	0	U	4	D
4066061	SS	108	$629,000	Y	36	0	13	1	14	24	0	10	6	16	P	23393	23500	R	4	D
4064121	SS	114	$33,000	Y	36	0	0	0	0	24	0	0	0	0	P	0	0	R	2	U
406705	SS	11	$463,000	Y	36	1	6	2	9	24	0	0	0	0	P	7722	0			
406662	SS	108	$563,000	Y	36	0	65	27	92	24	1	19	15	35	P	24799	27571			
406411	SS	40	$259,000	Y	36	0	18	14	32	12	0	3	4	7	P	29094	34429			
404312	SS	14	$1,055,000	Y											P					
404024	SS	40	$302,000	Y	36	0	20	9	29	12	0	5	0	5	P	25431	25000			
409049	SH	12	$391,000	Y	36	1	5	2	8	12	0	3	1	4	P	8912	7650			
406641	SH	12	$478,000	Y	36	1	53	29	83	24	0	19	11	30	P	40837	39367	R	4	D

Figure 4-16. HSIP Annual Report

4.6.4. Perform Before-and-After Analysis

CRASH can perform a before-and-after analysis for any selected projects. For example, one can select improvement projects from a particular district for a certain period of time to quickly evaluate if the crash rates have significantly improved due to the projects. Figure 4-17 includes a number of filters to allow the user to select the desired projects for analysis. Once the filters are specified, the user can click the **Submit** button to start the automated analysis process. Because of the intensive data retrieval and calculations involved, the process may take up to several minutes, depending on the size of projects selected. By default, all projects in the database will be included. The output summary statistics are presented in the following four tables:

1. The **Project Summary** table lists all the projects used in the calculation (see Figure 4-18) of CRFs for a specific improvement type.

2. The **Before Construction Period** table shows the crash statistics associated with the "before-construction" period of each project, including crashes, mean ADT, study period, and total exposure associated with each improvement project (see Figure 4-19).

3. The **After Construction Period** table is similar to the **Before Construction Period** table, but includes data for projects after the construction periods (see Figure 4-20).

4. The **Crash Summary** table shows the crash summary statistics for all projects, including crashes, crash rates, crash reduction factors, Poisson test statistics, and whether the Poisson test is significant (see Figure 4-21). The Poisson test is based on a 95% level of confidence.

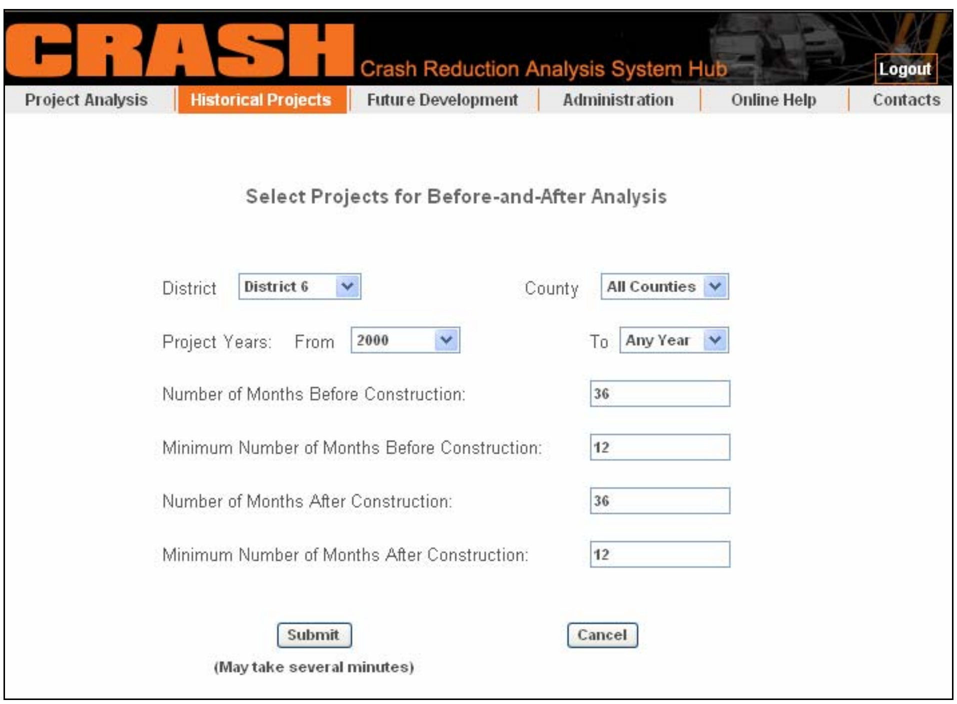
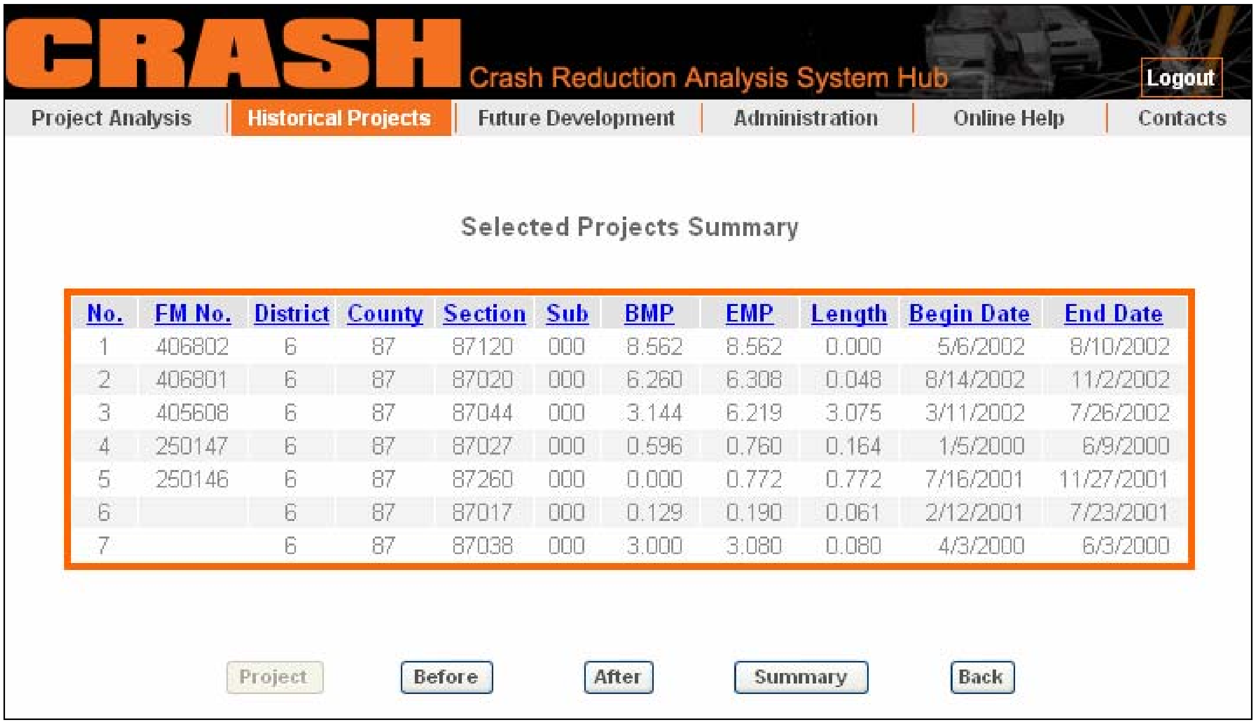
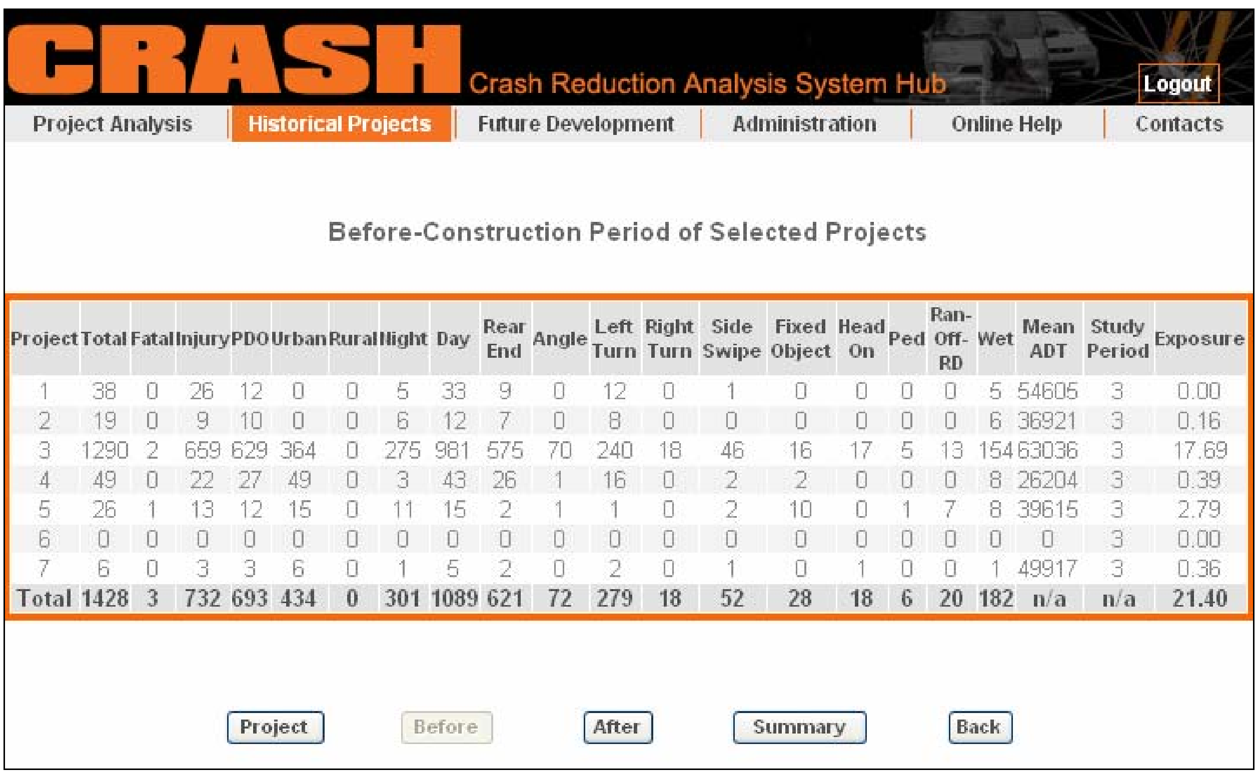


Figure 4-17. Filters for Project Selection for Before-and-After Analysis



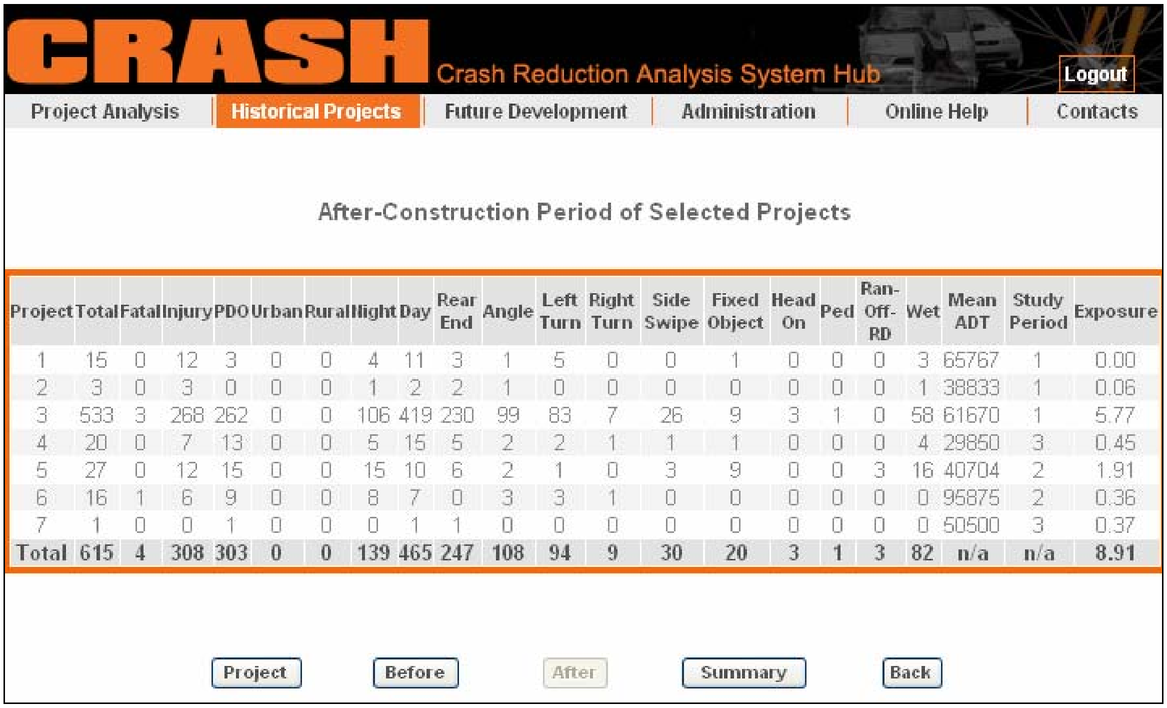
No.	FM No.	District	County	Section	Sub	BMP	EMP	Length	Begin Date	End Date
1	406802	6	87	87120	000	8.562	8.562	0.000	5/6/2002	8/10/2002
2	406801	6	87	87020	000	6.260	6.308	0.048	8/14/2002	11/2/2002
3	405608	6	87	87044	000	3.144	6.219	3.075	3/11/2002	7/26/2002
4	250147	6	87	87027	000	0.596	0.760	0.164	1/5/2000	6/9/2000
5	250146	6	87	87260	000	0.000	0.772	0.772	7/16/2001	11/27/2001
6		6	87	87017	000	0.129	0.190	0.061	2/12/2001	7/23/2001
7		6	87	87038	000	3.000	3.080	0.080	4/3/2000	6/3/2000

Figure 4-18. Project List for a Before-and-After Analysis



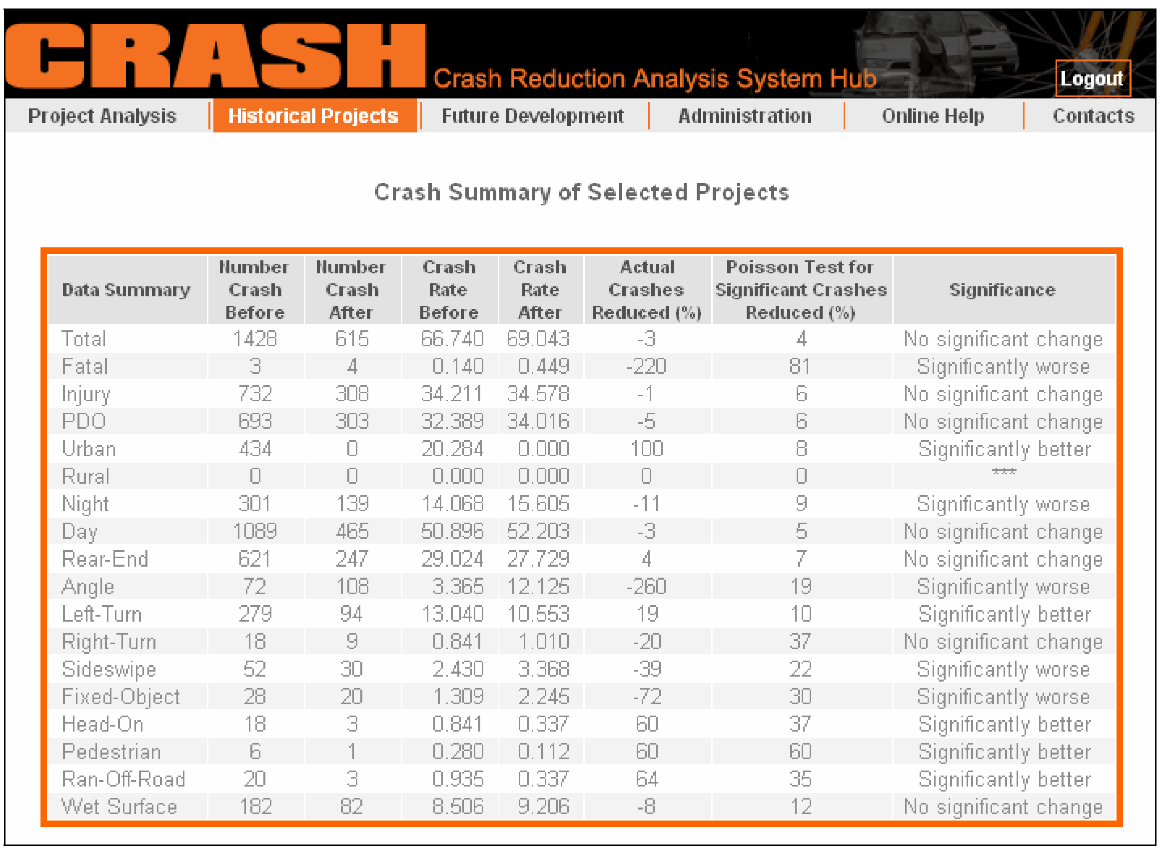
Project	Total	Fatal	Injury	PDO	Urban	Rural	Night	Day	Rear End	Angle	Left Turn	Right Turn	Side Swipe	Fixed Object	Head On	Ped	Ran-Off-RD	Wet	Mean ADT	Study Period	Exposure
1	38	0	26	12	0	0	5	33	9	0	12	0	1	0	0	0	0	5	54605	3	0.00
2	19	0	9	10	0	0	6	12	7	0	8	0	0	0	0	0	0	6	36921	3	0.16
3	1290	2	659	629	364	0	275	981	575	70	240	18	46	16	17	5	13	154	63036	3	17.69
4	49	0	22	27	49	0	3	43	26	1	16	0	2	2	0	0	0	8	26204	3	0.39
5	26	1	13	12	15	0	11	15	2	1	1	0	2	10	0	1	7	8	39615	3	2.79
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
7	6	0	3	3	6	0	1	5	2	0	2	0	1	0	1	0	0	1	49917	3	0.36
Total	**1428**	**3**	**732**	**693**	**434**	**0**	**301**	**1089**	**621**	**72**	**279**	**18**	**52**	**28**	**18**	**6**	**20**	**182**	**n/a**	**n/a**	**21.40**

Figure 4-19. Before Statistics for a Before-and-After Analysis



Project	Total	Fatal	Injury	PDO	Urban	Rural	Night	Day	Rear End	Angle	Left Turn	Right Turn	Side Swipe	Fixed Object	Head On	Ped	Ran-Off-RD	Wet	Mean ADT	Study Period	Exposure
1	15	0	12	3	0	0	4	11	3	1	5	0	0	1	0	0	0	3	65767	1	0.00
2	3	0	3	0	0	0	1	2	2	1	0	0	0	0	0	0	0	1	38833	1	0.06
3	533	3	268	262	0	0	106	419	230	99	83	7	26	9	3	1	0	58	61670	1	5.77
4	20	0	7	13	0	0	5	15	5	2	2	1	1	1	0	0	0	4	29850	3	0.45
5	27	0	12	15	0	0	15	10	6	2	1	0	3	9	0	0	3	16	40704	2	1.91
6	16	1	6	9	0	0	8	7	0	3	3	1	0	0	0	0	0	0	95875	2	0.36
7	1	0	0	1	0	0	0	1	1	0	0	0	0	0	0	0	0	0	50500	3	0.37
Total	**615**	**4**	**308**	**303**	**0**	**0**	**139**	**465**	**247**	**108**	**94**	**9**	**30**	**20**	**3**	**1**	**3**	**82**	**n/a**	**n/a**	**8.91**

Figure 4-20. After Statistics for a Before-and-After Analysis



Data Summary	Number Crash Before	Number Crash After	Crash Rate Before	Crash Rate After	Actual Crashes Reduced (%)	Poisson Test for Significant Crashes Reduced (%)	Significance
Total	1428	615	66.740	69.043	-3	4	No significant change
Fatal	3	4	0.140	0.449	-220	81	Significantly worse
Injury	732	308	34.211	34.578	-1	6	No significant change
PDO	693	303	32.389	34.016	-5	6	No significant change
Urban	434	0	20.284	0.000	100	8	Significantly better
Rural	0	0	0.000	0.000	0	0	***
Night	301	139	14.068	15.605	-11	9	Significantly worse
Day	1089	465	50.896	52.203	-3	5	No significant change
Rear-End	621	247	29.024	27.729	4	7	No significant change
Angle	72	108	3.365	12.125	-260	19	Significantly worse
Left-Turn	279	94	13.040	10.553	19	10	Significantly better
Right-Turn	18	9	0.841	1.010	-20	37	No significant change
Sideswipe	52	30	2.430	3.368	-39	22	Significantly worse
Fixed-Object	28	20	1.309	2.245	-72	30	Significantly worse
Head-On	18	3	0.841	0.337	60	37	Significantly better
Pedestrian	6	1	0.280	0.112	60	60	Significantly better
Ran-Off-Road	20	3	0.935	0.337	64	35	Significantly better
Wet Surface	182	82	8.506	9.206	-8	12	No significant change

Figure 4-21. Summary for a Before-and-After Analysis

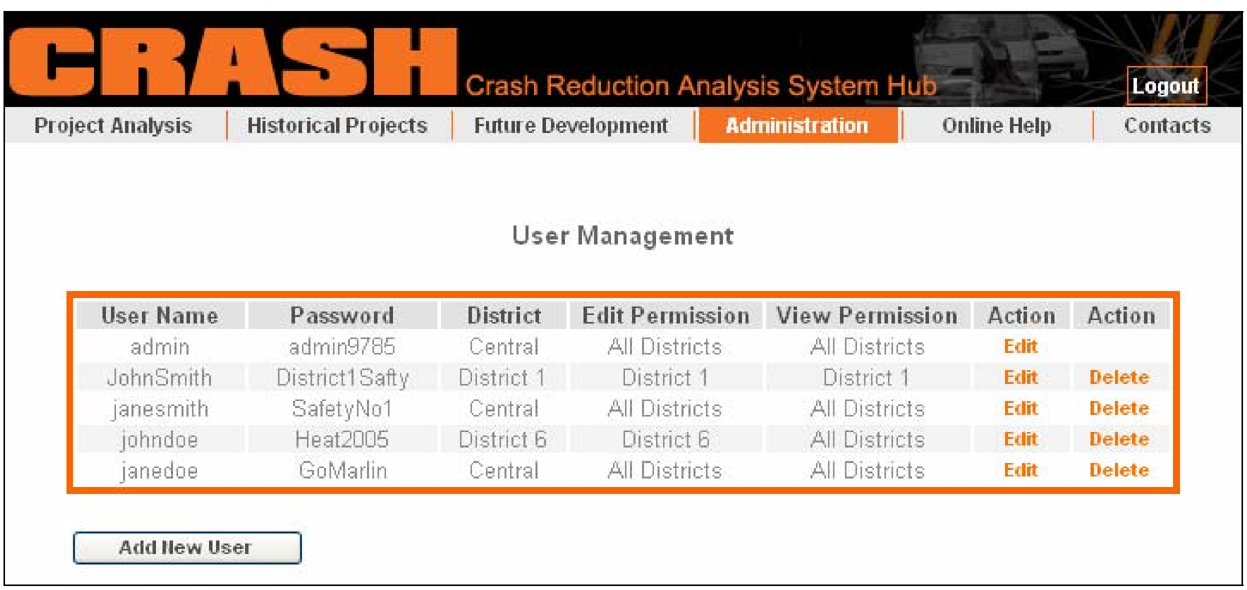
4.7. Administration

This limited-access component allows the system administrator or a designated person to perform the following tasks:

1. To manage user account and assign access privileges.
2. To view CRF summary statistics for specific improvement types (access not limited)
3. To update CRFs
4. To maintain safety improvement types
5. To assign new safety improvement types to projects
6. To append new crash records

4.7.1. User Management

The **User Management** page is accessed from the **Administration|User Management** menu item. It allows the System Administrator to assign set up accounts for new users, edit existing accounts, including deletion of accounts, and grant user privileges in terms of permission to view or edit projects for specific jurisdictions. Figure 4-22 shows the main screen of the function, which lists all the existing accounts. To add a new user, click the **Add New User** button at the bottom. This will bring up the screen in Figure 4-23, which allows a new user name and password to be specified. Both the user name and the password are not case sensitive and up to 20 alphanumeric characters may be specified for each. A new user can be either from the Central Office or from a specific district. He or she can be given privilege to edit and/or view projects from either their own district or all districts. Figures 24 and 25 show the screens with similar fields, but for editing and deleting an existing user account, respectively.



User Name	Password	District	Edit Permission	View Permission	Action	Action
admin	admin9785	Central	All Districts	All Districts	Edit	
JohnSmith	District1Safty	District 1	District 1	District 1	Edit	Delete
janesmith	SafetyNo1	Central	All Districts	All Districts	Edit	Delete
johndoe	Heat2005	District 6	District 6	All Districts	Edit	Delete
janedoe	GoMarlin	Central	All Districts	All Districts	Edit	Delete

Figure 4-22. User Management Main Screen

Figure 4-23. Assign New User

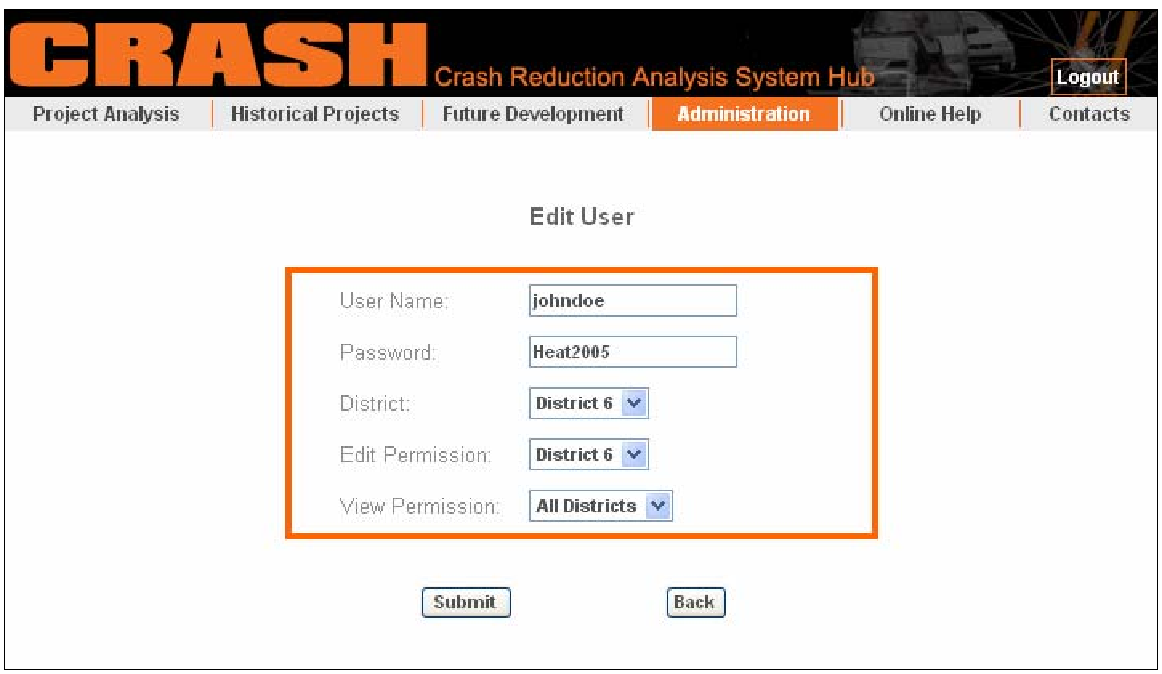


Figure 4-24. Edit User Account Information

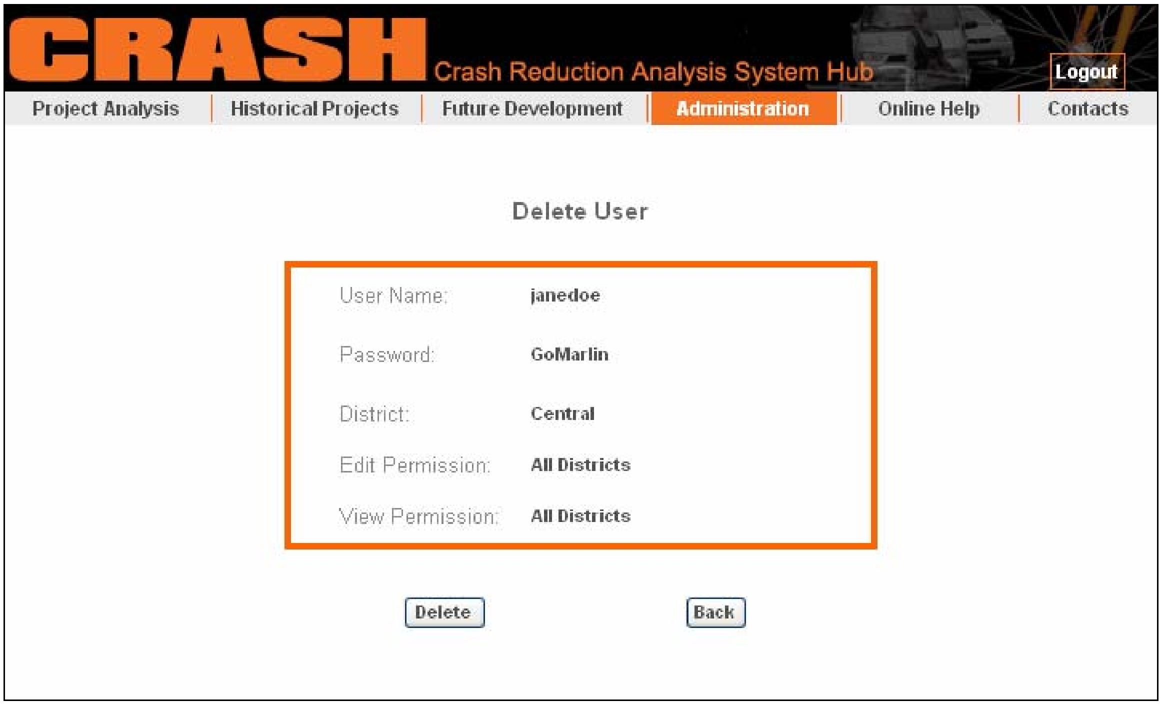


Figure 4-25. Delete a User

4.7.2. View CRF Summary Statistics

This function can be accessed from the **Administration|View CRFs** menu item. Selecting this menu item will pop up the screen shown in Figure 4-26, which allows the user to select either to view an Excel summary table listing all up-to-date CRFs from Florida by clicking the link, or to view the detailed calculations of a specific improvement type by selecting from a list of available improvement types and then clicking **View**. In the Excel summary table, the table title will show the date the last time the CRFs were updated (see next section). The output for a specific improvement type includes summary statistics presented in the following four tables:

1. The **Project Summary** table lists all the projects used in the calculation (see Figure 4-27) of CRFs for a specific improvement type.

2. The **Before Construction Period** table shows the crash statistics associated with the "before-construction" period of each project, including crashes, mean ADT, study period, and total exposure associated with each improvement project (see Figure 4-28).

3. The **After Construction Period** table is similar to the **Before Construction Period** table, but includes data for projects after the construction periods (see Figure 4-29).

4. The **Crash Summary** table shows the crash summary statistics for all projects, including crashes, crash rates, crash reduction factors, Poisson test statistics, and whether the Poisson test is significant (see Figure 4-30). The Poisson test is based on a 95% level of confidence.

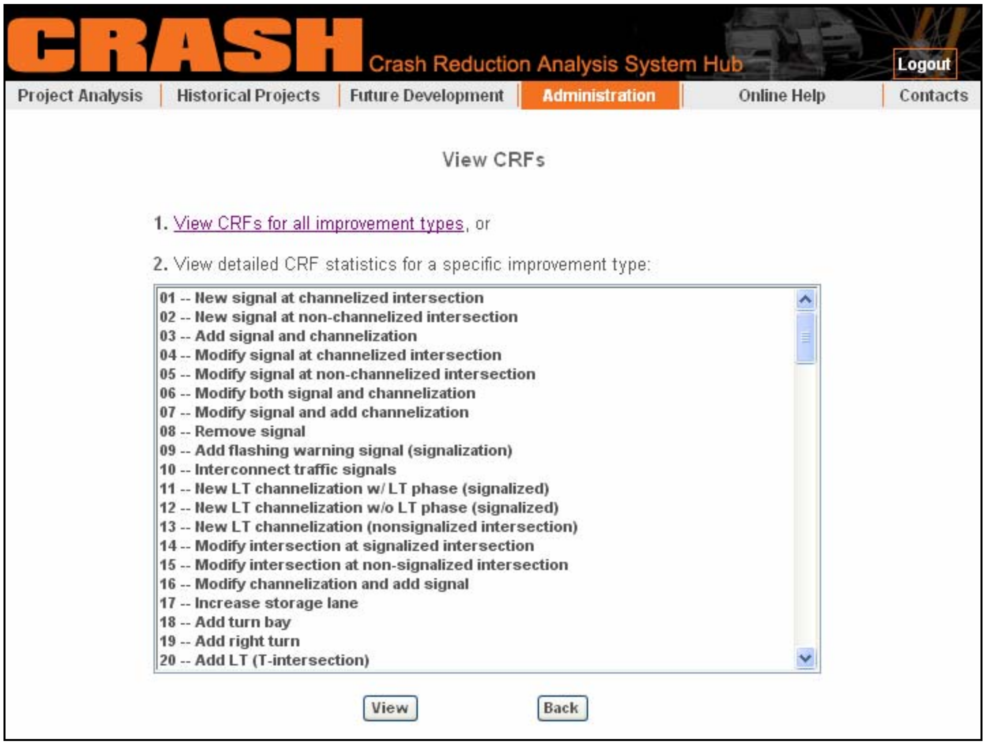
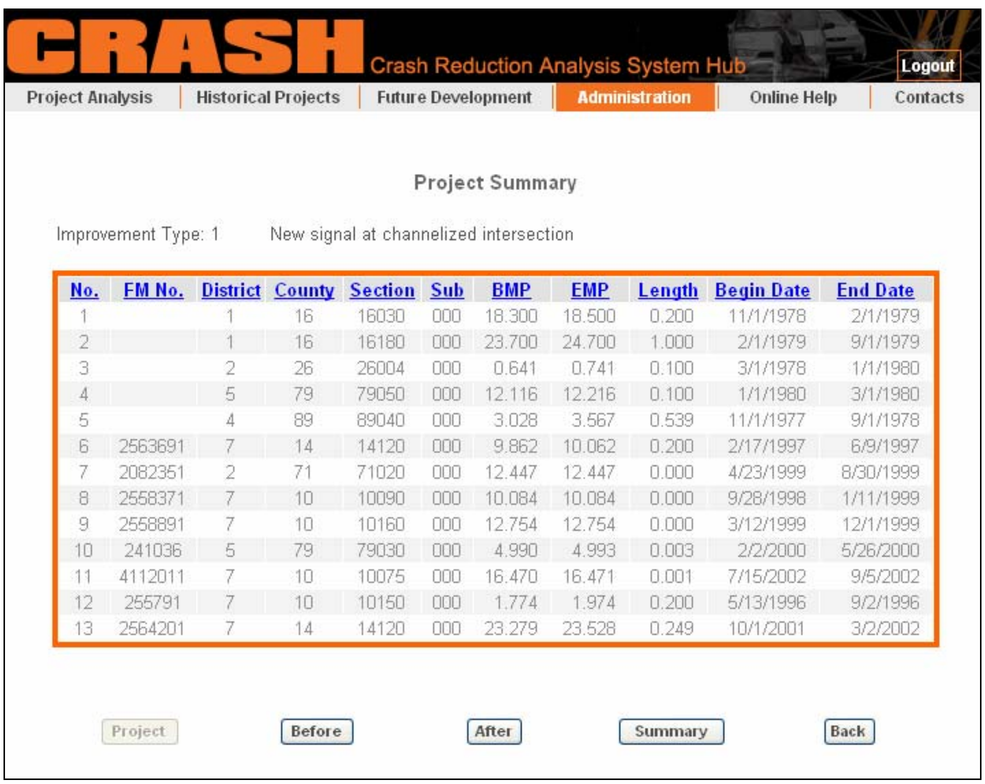
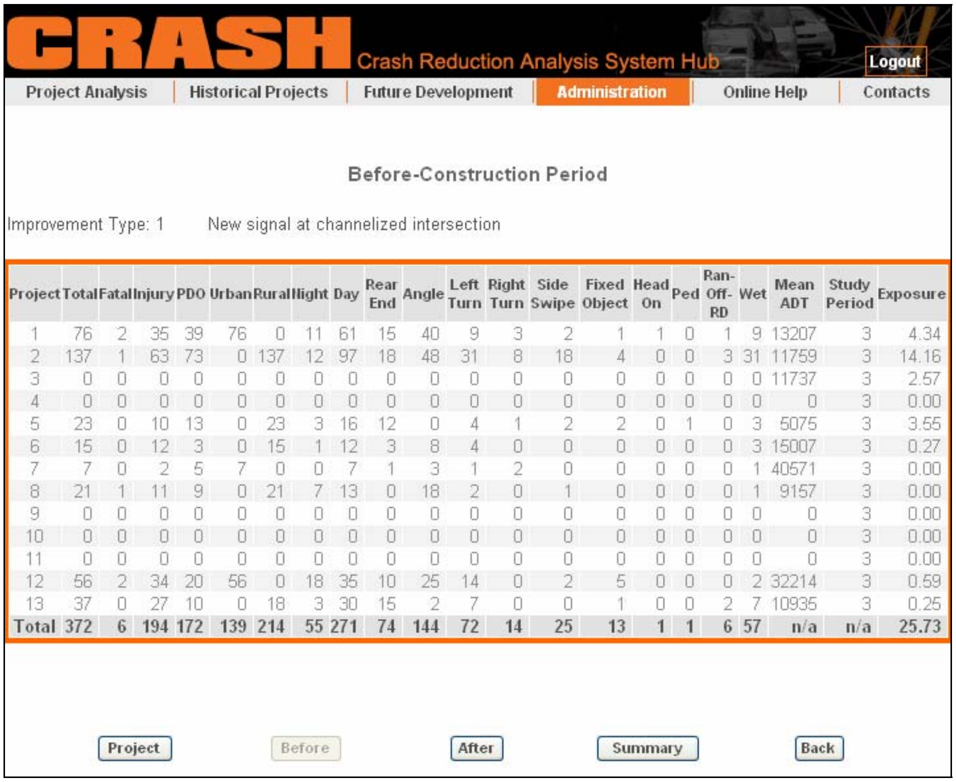


Figure 4-26. Select to View CRF Summary Statistics



No.	FM No.	District	County	Section	Sub	BMP	EMP	Length	Begin Date	End Date
1		1	16	16030	000	18.300	18.500	0.200	11/1/1978	2/1/1979
2		1	16	16180	000	23.700	24.700	1.000	2/1/1979	9/1/1979
3		2	26	26004	000	0.641	0.741	0.100	3/1/1978	1/1/1980
4		5	79	79050	000	12.116	12.216	0.100	1/1/1980	3/1/1980
5		4	89	89040	000	3.028	3.567	0.539	11/1/1977	9/1/1978
6	2563691	7	14	14120	000	9.862	10.062	0.200	2/17/1997	6/9/1997
7	2082351	2	71	71020	000	12.447	12.447	0.000	4/23/1999	8/30/1999
8	2558371	7	10	10090	000	10.084	10.084	0.000	9/28/1998	1/11/1999
9	2558891	7	10	10160	000	12.754	12.754	0.000	3/12/1999	12/1/1999
10	241036	5	79	79030	000	4.990	4.993	0.003	2/2/2000	5/26/2000
11	4112011	7	10	10075	000	16.470	16.471	0.001	7/15/2002	9/5/2002
12	255791	7	10	10150	000	1.774	1.974	0.200	5/13/1996	9/2/1996
13	2564201	7	14	14120	000	23.279	23.528	0.249	10/1/2001	3/2/2002

Figure 4-27. Project Summary Table

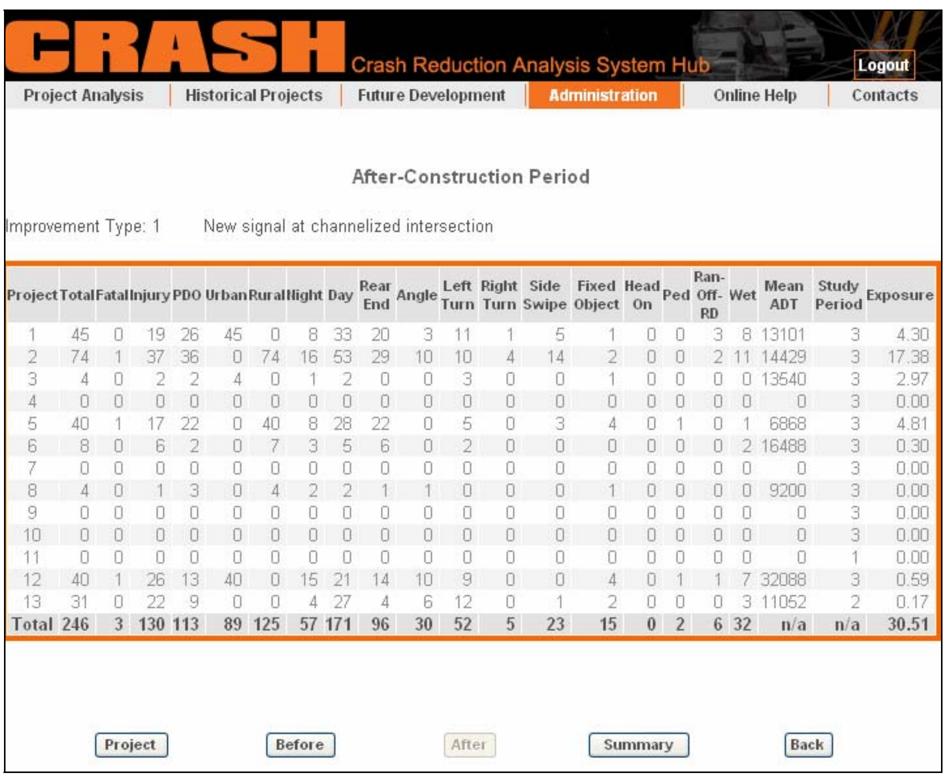


Before-Construction Period

Improvement Type: 1 New signal at channelized intersection

Project	Total	Fatal	Injury	PDO	Urban	Rural	Night	Day	Rear End	Angle	Left Turn	Right Turn	Side Swipe	Fixed Object	Head On	Ped	Ran-Off-RD	Wet	Mean ADT	Study Period	Exposure
1	76	2	35	39	76	0	11	61	15	40	9	3	2	1	1	0	1	9	13207	3	4.34
2	137	1	63	73	0	137	12	97	18	48	31	8	18	4	0	0	3	31	11759	3	14.16
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11737	3	2.57
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
5	23	0	10	13	0	23	3	16	12	0	4	1	2	2	0	1	0	3	5075	3	3.55
6	15	0	12	3	0	15	1	12	3	8	4	0	0	0	0	0	0	3	15007	3	0.27
7	7	0	2	5	7	0	0	7	1	3	1	2	0	0	0	0	0	1	40571	3	0.00
8	21	1	11	9	0	21	7	13	0	18	2	0	1	0	0	0	0	1	9157	3	0.00
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
12	56	2	34	20	56	0	18	35	10	25	14	0	2	5	0	0	0	2	32214	3	0.59
13	37	0	27	10	0	18	3	30	15	2	7	0	0	1	0	0	2	7	10935	3	0.25
Total	372	6	194	172	139	214	55	271	74	144	72	14	25	13	1	1	6	57	n/a	n/a	25.73

Figure 4-28. Crash Summary Table for Before-Construction Period

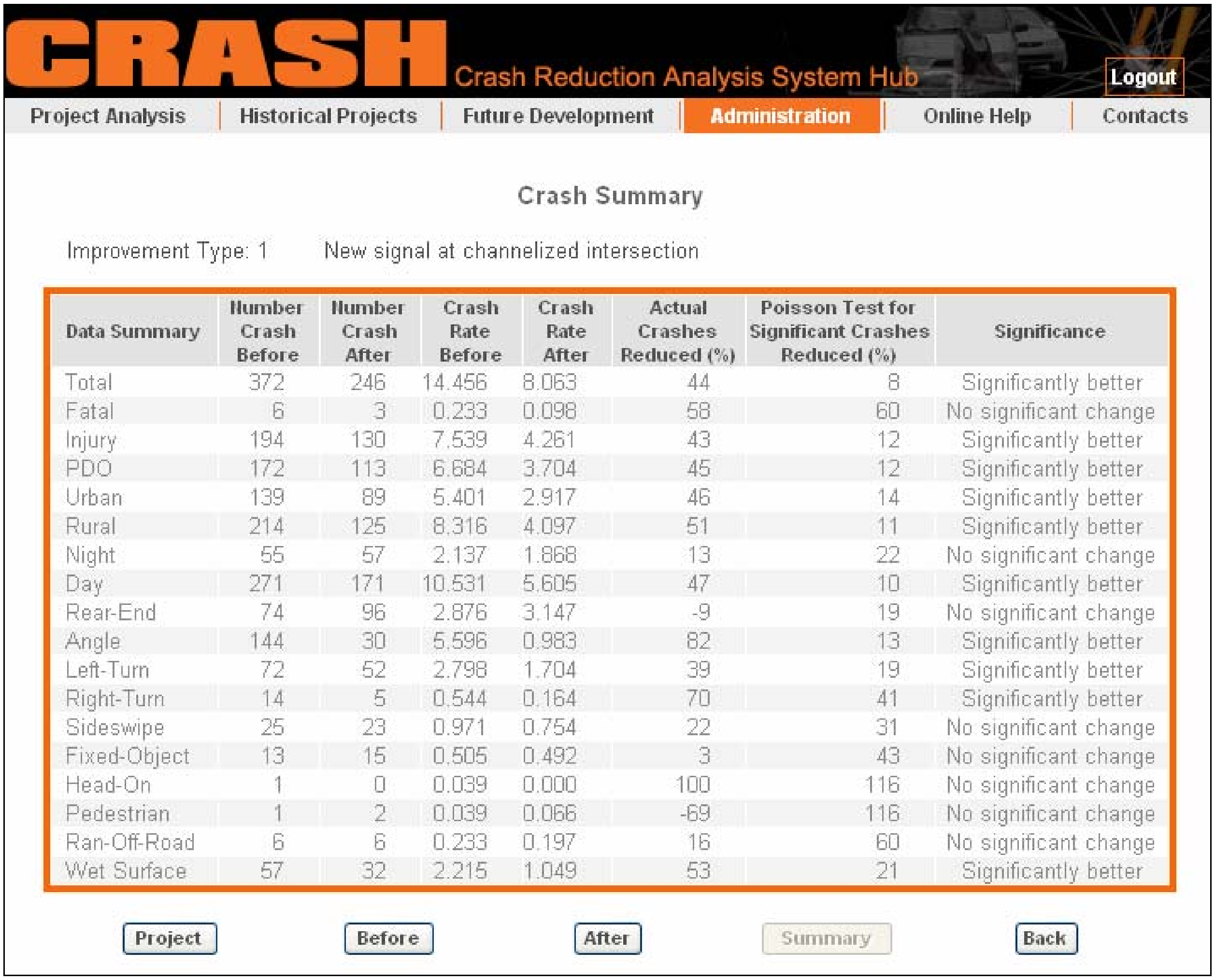


After-Construction Period

Improvement Type: 1 New signal at channelized intersection

Project	Total	Fatal	Injury	PDO	Urban	Rural	Night	Day	Rear End	Angle	Left Turn	Right Turn	Side Swipe	Fixed Object	Head On	Ped	Ran-Off-RD	Wet	Mean ADT	Study Period	Exposure
1	45	0	19	26	45	0	8	33	20	3	11	1	5	1	0	0	3	8	13101	3	4.30
2	74	1	37	36	0	74	16	53	29	10	10	4	14	2	0	0	2	11	14429	3	17.38
3	4	0	2	2	4	0	1	2	0	0	3	0	0	1	0	0	0	0	13540	3	2.97
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
5	40	1	17	22	0	40	8	28	22	0	5	0	3	4	0	1	0	1	6868	3	4.81
6	8	0	6	2	0	7	3	5	6	0	2	0	0	0	0	0	0	2	16488	3	0.30
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
8	4	0	1	3	0	4	2	2	1	1	0	0	0	1	0	0	0	0	9200	3	0.00
9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0.00
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0.00
12	40	1	26	13	40	0	15	21	14	10	9	0	0	4	0	1	1	7	32088	3	0.59
13	31	0	22	9	0	0	4	27	4	6	12	0	1	2	0	0	0	3	11052	2	0.17
Total	246	3	130	113	89	125	57	171	96	30	52	5	23	15	0	2	6	32	n/a	n/a	30.51

Figure 4-29. Crash Summary Table for After-Construction Period



Data Summary	Number Crash Before	Number Crash After	Crash Rate Before	Crash Rate After	Actual Crashes Reduced (%)	Poisson Test for Significant Crashes Reduced (%)	Significance
Total	372	246	14.456	8.063	44	8	Significantly better
Fatal	6	3	0.233	0.098	58	60	No significant change
Injury	194	130	7.539	4.261	43	12	Significantly better
PDO	172	113	6.684	3.704	45	12	Significantly better
Urban	139	89	5.401	2.917	46	14	Significantly better
Rural	214	125	8.316	4.097	51	11	Significantly better
Night	55	57	2.137	1.868	13	22	No significant change
Day	271	171	10.531	5.605	47	10	Significantly better
Rear-End	74	96	2.876	3.147	-9	19	No significant change
Angle	144	30	5.596	0.983	82	13	Significantly better
Left-Turn	72	52	2.798	1.704	39	19	Significantly better
Right-Turn	14	5	0.544	0.164	70	41	Significantly better
Sideswipe	25	23	0.971	0.754	22	31	No significant change
Fixed-Object	13	15	0.505	0.492	3	43	No significant change
Head-On	1	0	0.039	0.000	100	116	No significant change
Pedestrian	1	2	0.039	0.066	-69	116	No significant change
Ran-Off-Road	6	6	0.233	0.197	16	60	No significant change
Wet Surface	57	32	2.215	1.049	53	21	Significantly better

Figure 4-30. Crash Summary Table

4.7.3. Update CRFs

This function, accessible from the **Administration|Update CRFs** menu item, is to update the existing CRFs with data from new projects. It is performed by either the system administrator or a designated person. **The method implemented in this version of CRASH is based strictly on the simple before-and-after study method (refer to chapter 2 for more details on this method)**. Figure 4-31 shows the screen for specifying the number of months the user wishes to include for the before and after construction period. The user can also specify the desired minimum number of months before and after project construction to be included in the calculation. Thus, projects that have not yet met the minimum number of months will not be included in the calculation. The user must specify the years for which the improvement projects are to be included. This allows the user to exclude projects from a certain period. For example, if the user wants to include only projects that have been completed since 1990, the user would enter 1990 in the **From** year field.

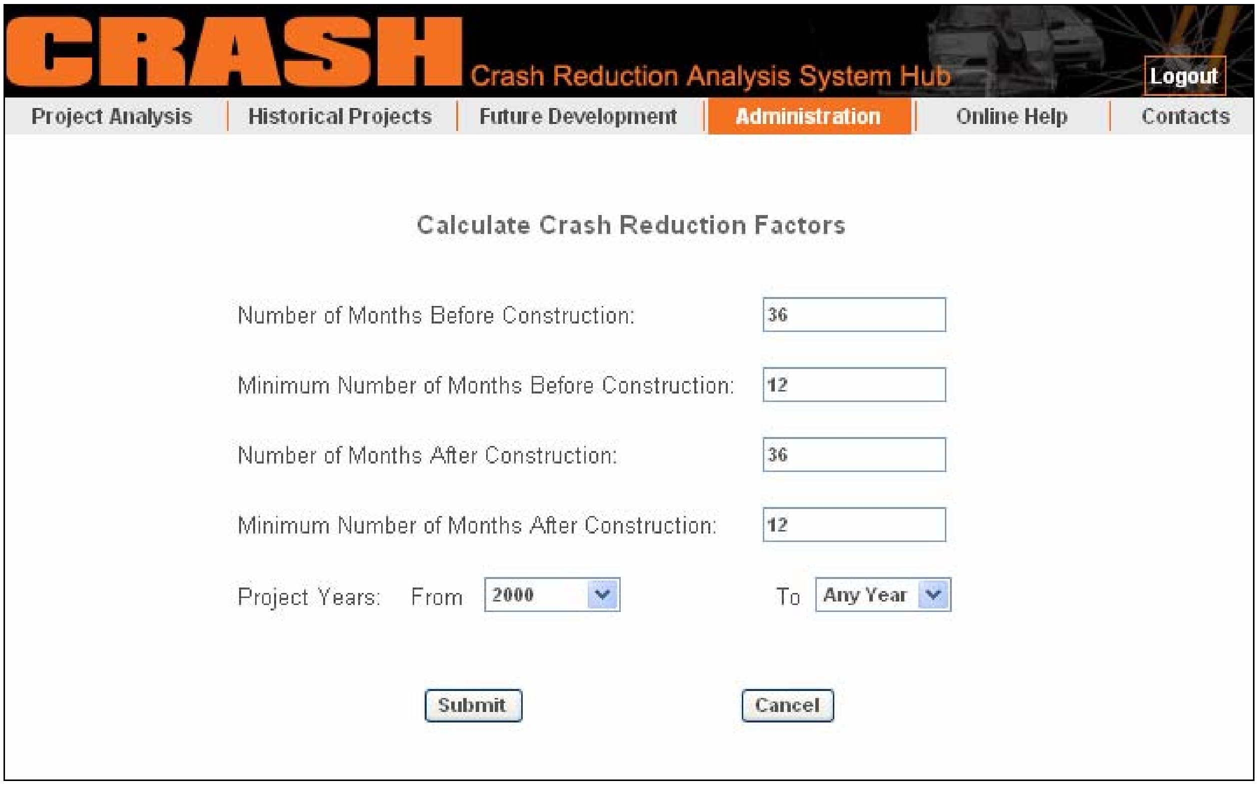


Figure 4-31. Screen for Selecting Project Time Periods for CRF Calculation

4.7.4. Maintain Improvement Types

The maintenance of improvement types involves the following three tasks:

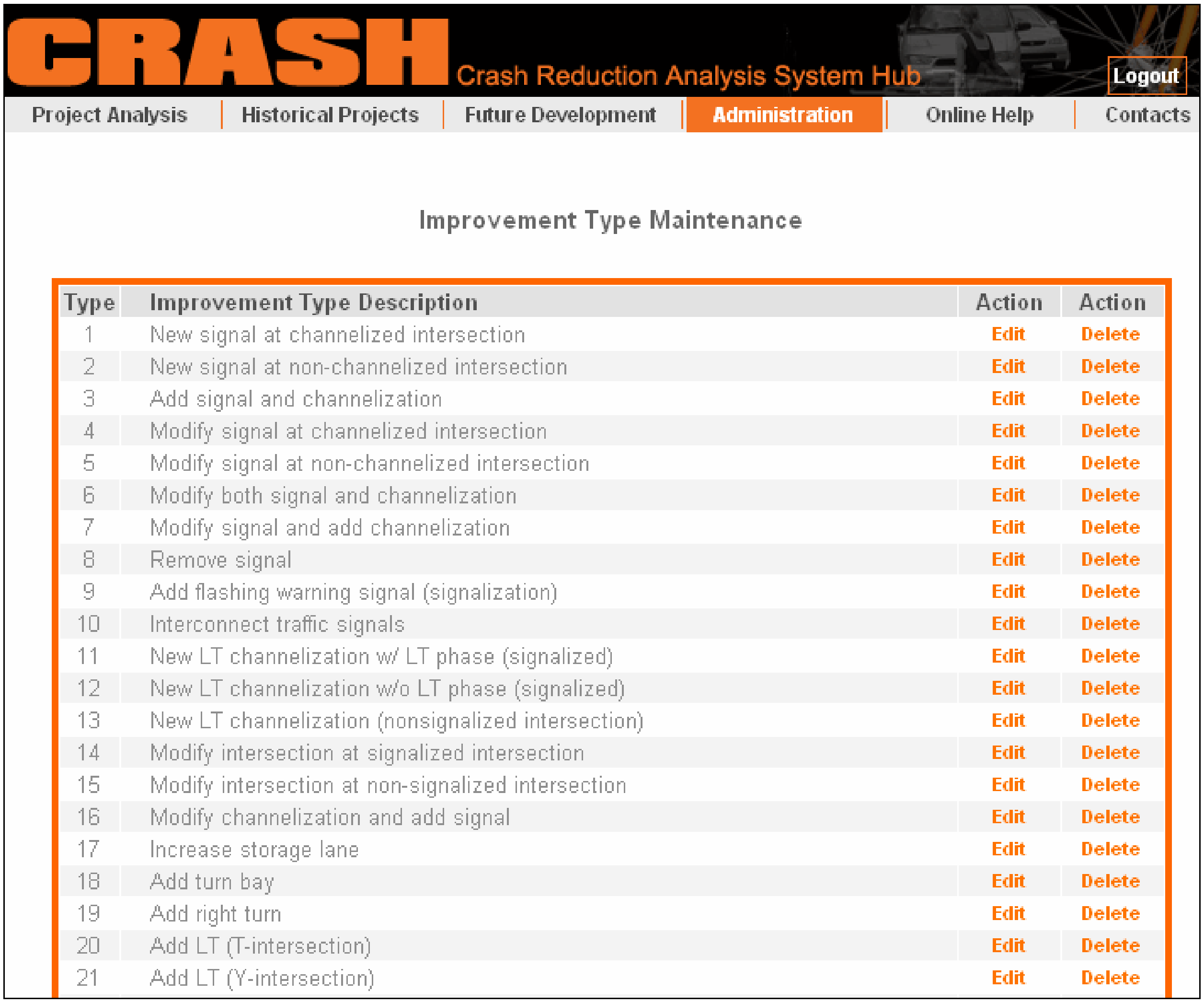
1. Add a new improvement type
2. Edit an existing improvement type
3. Delete an existing improvement type

To perform these tasks, select the **Administration|Maintain Types** menu item. This will bring up the screen shown in Figure 4-32, which lists all existing improvement types defined in the database.

To create a new improvement type, click the **Add New Type** button at the bottom of the screen (see Figure 4-32) to bring up the screen shown in Figure 4-33. By default the screen will list the next available improvement type number. The user may overwrite this with another number that is not already used. Once the name for a new improvement type is specified, click the **Submit** button and the new improvement type will be added to the existing list.

To edit an existing improvement type, click the corresponding **Edit** link to bring up the screen shown in Figure 4-34. Only the name of an improvement type can be changed. Make all the necessary changes and then click the **Submit** button to execute the change.

To delete an existing improvement type, click the **Delete** link of the corresponding improvement type on the list in Figure 4-32 to bring up the screen shown in Figure 4-35. When an existing type is deleted, all projects, if any, that have been assigned the improvement type will be reassigned the “0” improvement type, which means the projects have not been assigned an improvement type.



Type	Improvement Type Description	Action	Action
1	New signal at channelized intersection	Edit	Delete
2	New signal at non-channelized intersection	Edit	Delete
3	Add signal and channelization	Edit	Delete
4	Modify signal at channelized intersection	Edit	Delete
5	Modify signal at non-channelized intersection	Edit	Delete
6	Modify both signal and channelization	Edit	Delete
7	Modify signal and add channelization	Edit	Delete
8	Remove signal	Edit	Delete
9	Add flashing warning signal (signalization)	Edit	Delete
10	Interconnect traffic signals	Edit	Delete
11	New LT channelization w/ LT phase (signalized)	Edit	Delete
12	New LT channelization w/o LT phase (signalized)	Edit	Delete
13	New LT channelization (nonsignalized intersection)	Edit	Delete
14	Modify intersection at signalized intersection	Edit	Delete
15	Modify intersection at non-signalized intersection	Edit	Delete
16	Modify channelization and add signal	Edit	Delete
17	Increase storage lane	Edit	Delete
18	Add turn bay	Edit	Delete
19	Add right turn	Edit	Delete
20	Add LT (T-intersection)	Edit	Delete
21	Add LT (Y-intersection)	Edit	Delete

Figure 4-32. Main Screen for Maintenance of Improvement Types

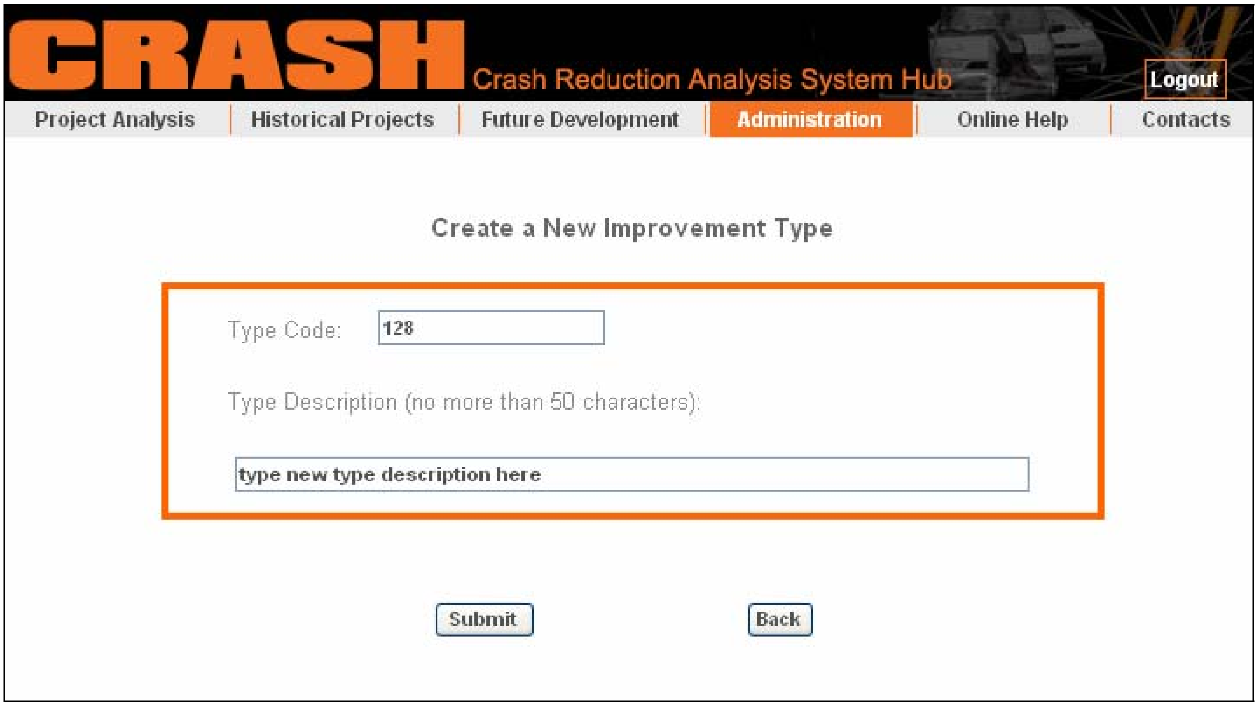


Figure 4-33. Screen for Creating a New Improvement Type

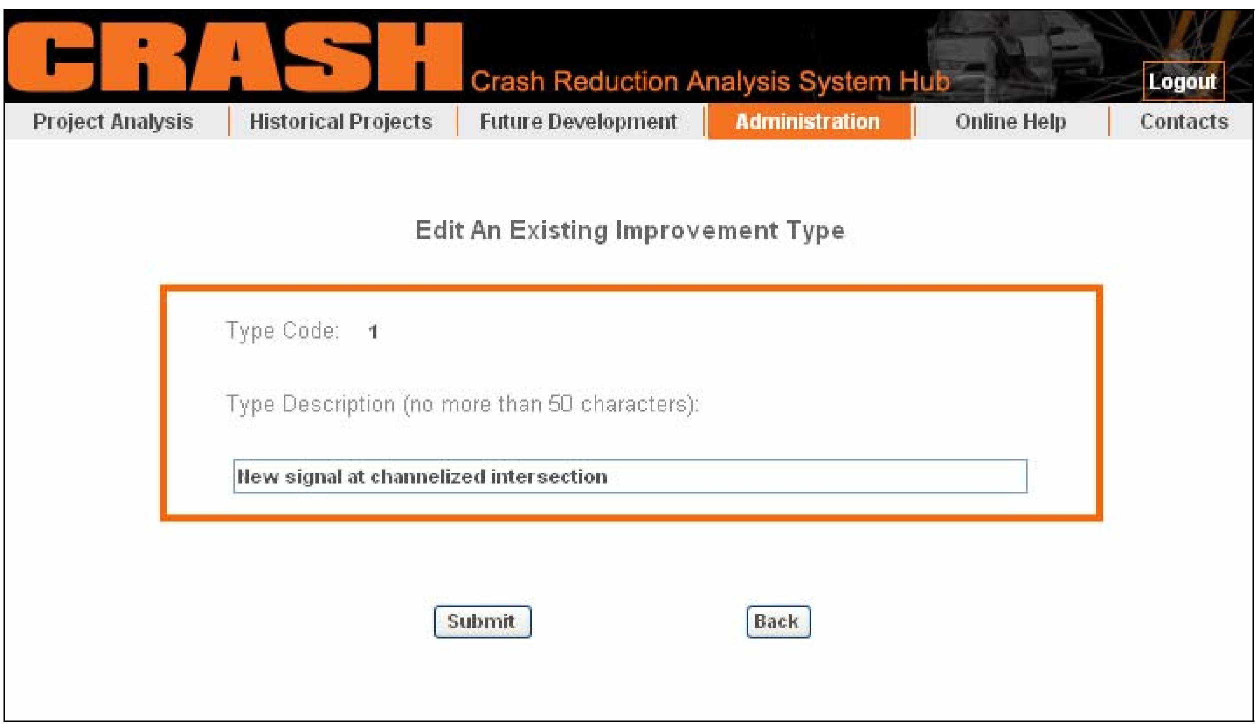


Figure 4-34. Screen for Modifying an Existing Improvement Type

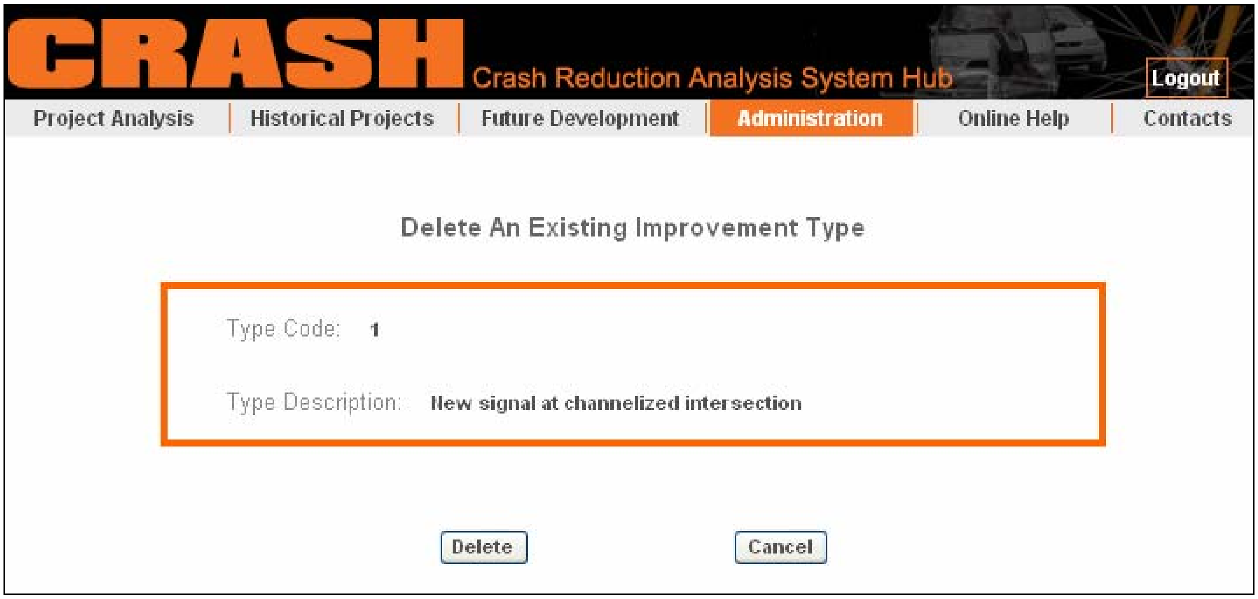


Figure 4-35. Screen for Deleting an Existing Improvement Type

4.7.5. Assign Improvement Types

Determining the appropriate improvement type is the task of a person who is experienced in safety improvement projects. The manager uses the project description for a project and then assigns an appropriate improvement type to it. For CRF development purposes, only one improvement type may be assigned, even tough a project may involve multiple improvements.

To assign an improvement type:

1. Select the **Administration|Assign Types** menu item to bring up the screen in Figure 4-36
2. Use any combination of the filters shown in the screen to limit the desirable list of projects to be assigned a new improvement type of or changed to another improvement type. For convenience, the user can select only projects that have not been assigned an improvement type by selecting the second radio button on the screen. Once the filters are specified, click the **Submit** button to retrieve the desired projects.
3. From the list of projects, identify the project that needs to be assigned an improvement type by clicking the **Assign** link that corresponds to the project. This will bring up the screen shown in Figure 4-37. Click an improvement type from the list box.
4. Click the **Assign** button to bring up the screen shown in Figure 4-38.
5. Click the **View** button to review the complete project information.

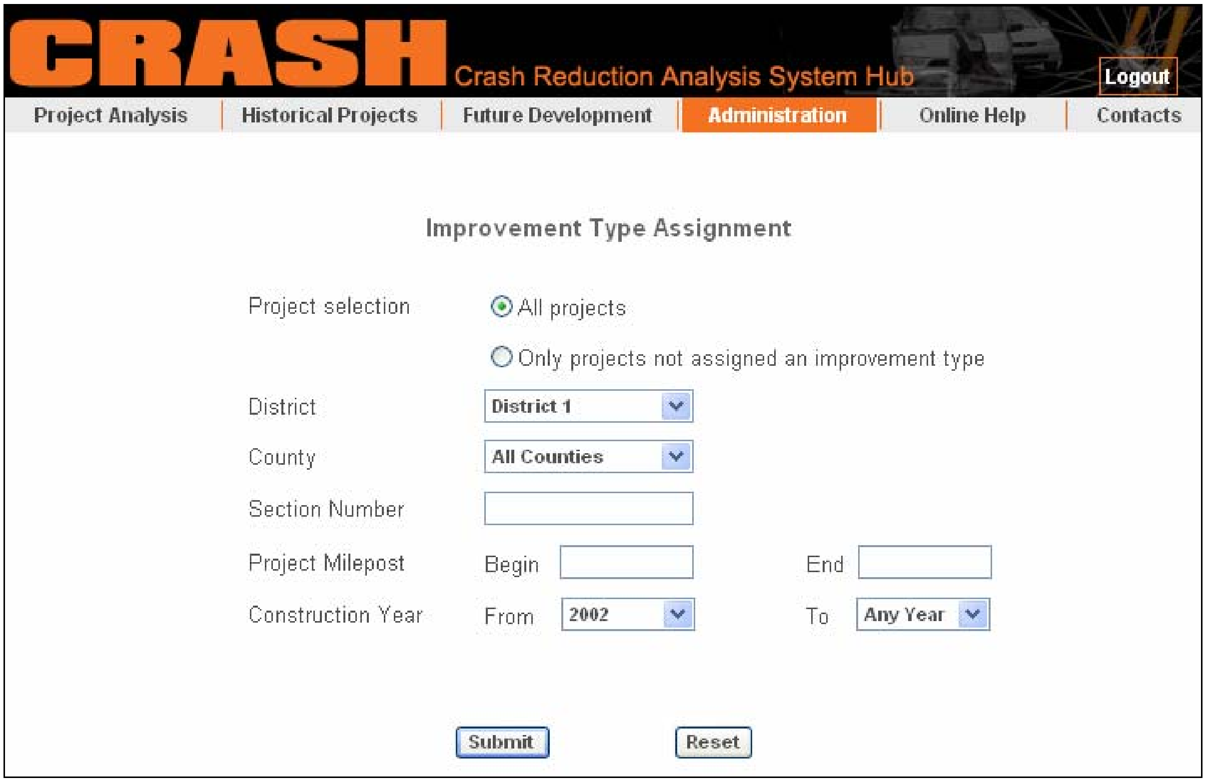
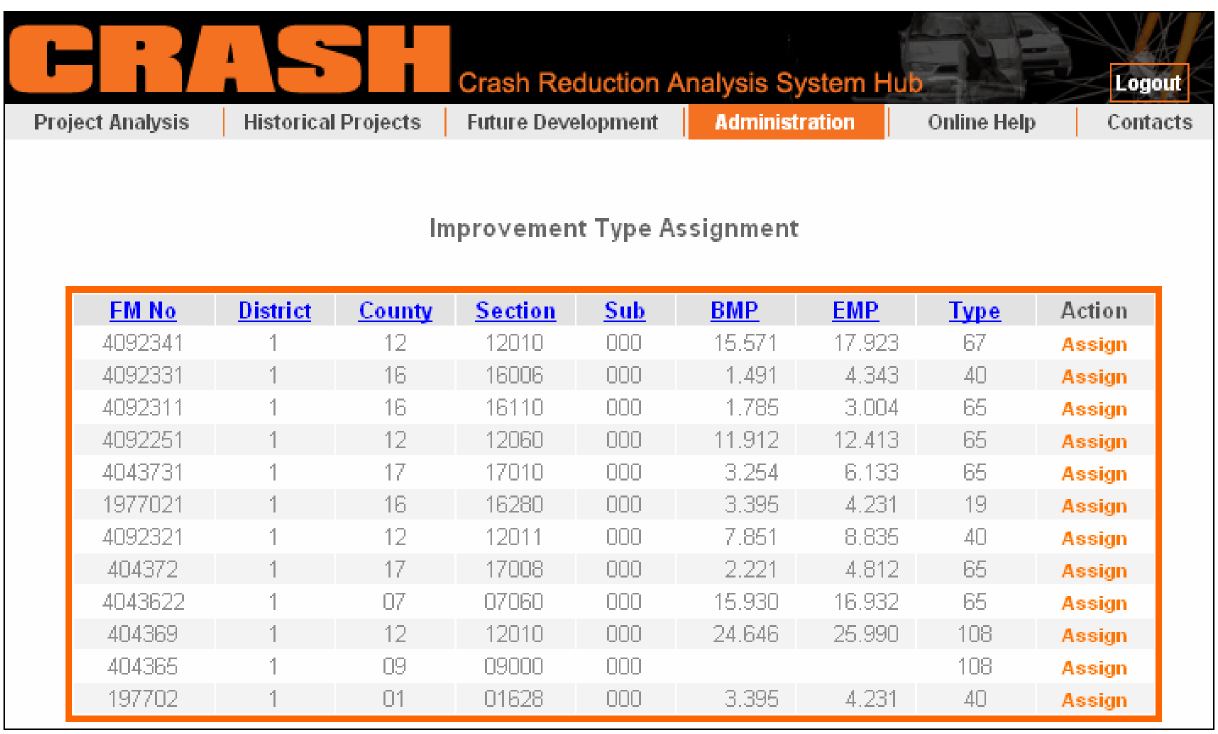


Figure 4-36. Screen for Selecting Project to Assign an Improvement Type



FM No	District	County	Section	Sub	BMP	EMP	Type	Action
4092341	1	12	12010	000	15.571	17.923	67	Assign
4092331	1	16	16006	000	1.491	4.343	40	Assign
4092311	1	16	16110	000	1.785	3.004	65	Assign
4092251	1	12	12060	000	11.912	12.413	65	Assign
4043731	1	17	17010	000	3.254	6.133	65	Assign
1977021	1	16	16280	000	3.395	4.231	19	Assign
4092321	1	12	12011	000	7.851	8.835	40	Assign
404372	1	17	17008	000	2.221	4.812	65	Assign
4043622	1	07	07060	000	15.930	16.932	65	Assign
404369	1	12	12010	000	24.646	25.990	108	Assign
404365	1	09	09000	000			108	Assign
197702	1	01	01628	000	3.395	4.231	40	Assign

Figure 4-37. Identified List of Projects for Improvement Type Assignment

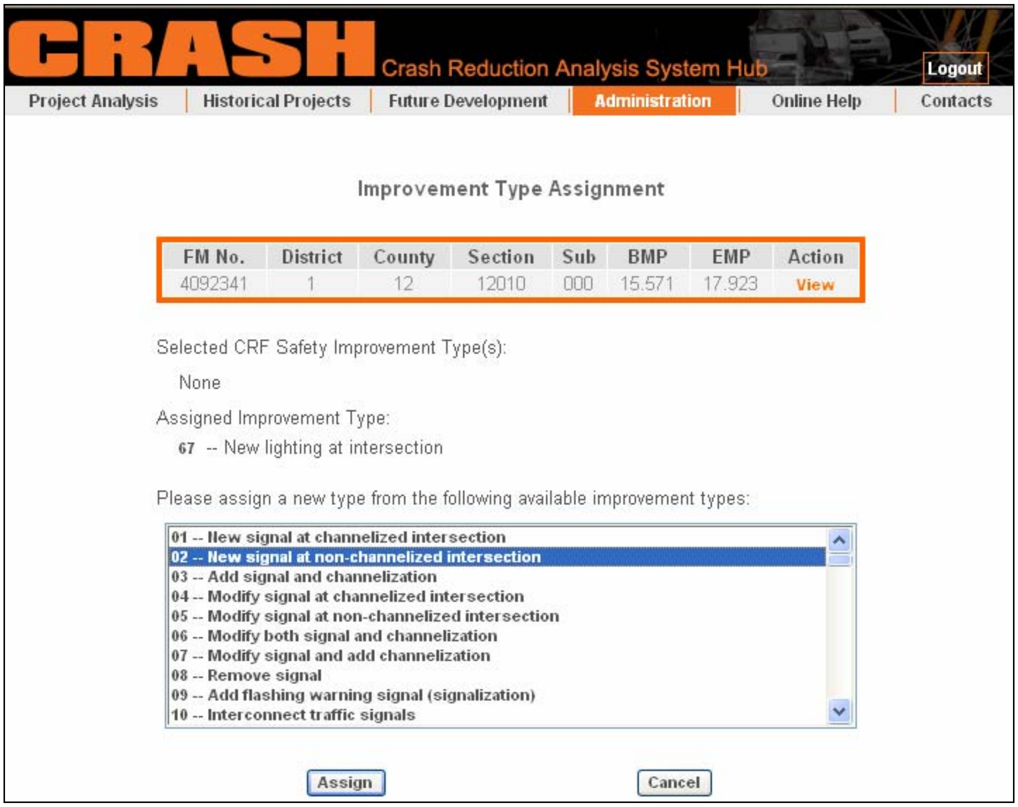


Figure 4-38. Screen for Selecting an Improvement Type to Assign

4.7.6. Append New Crash Records

CRASH includes a function to allow crash records to be appended to its crash record database. It assumes that the file being imported consists of the following 38 variables (in the same listed order) in the comma-delimited format:

1. Crash Report Number
2. Crash Date
3. Time of Crash
4. DOT County Number
5. Section Number
6. Subsection Number
7. Located Mile-point
8. Nearest Node Number
9. Located Route Id (lowest-numbered "SR" route)
10. DOT Site Location
11. Side of Road (for 1st harmful event)
12. Lane of Accident (for 1st harmful event)
13. Road Surface Condition (crash report form)
14. Lighting Condition (crash report form)

15. Weather Condition (crash report form)
16. Traffic Control (1st value from crash report form)
17. Road Conditions at Time of Crash (1st value from crash report form)
18. Crash Rate Class Category (CAR code)
19. Average Daily Traffic (RCI)
20. Crash-Level Alcohol Involved Code (crash report form)
21. 1st Harmful Event for At-Fault Vehicle (crash report form)
22. Vehicle Type for At-Fault Vehicle (crash report form)
23. Vehicle Use Code for At-Fault Vehicle (crash report form)
24. First Point of Impact for At-Fault Vehicle (crash report form)
25. Vehicle Movement Code for At-Fault Vehicle (crash report form)
26. Direction of Travel for At-Fault Vehicle (crash report form)
27. 1st Contributing Cause Driver/ Pedestrian for At-Fault Section (crash report form)
28. Driver/ Pedestrian Age for At-Fault Section (based on driver/ped birth date from crash report form)
29. Vehicle Type for Next Vehicle (crash report form)
30. Vehicle Use Code for Next Vehicle (crash report form)
31. 1st Point of Impact for Next Vehicle (crash report form)
32. Vehicle Movement Code for Next Vehicle (crash report form)
33. Direction of Travel for Next Vehicle (crash report form)
34. Contributing Cause Driver/ Pedestrian for Next Section (crash report form)
35. Driver/ Pedestrian Age for Next Section (based on driver/ped birth date from crash report form)
36. Total Number of Vehicles in Crash
37. Total Number of Traffic Fatalities in Crash (Traffic Fatality is person with Injury Severity value of "5")
38. Total Number of Injuries in Crash (Injury is person with Injury Severity value of "2", "3" or "4")

Figure 4-39 shows the screen for importing new crash records. It can be accessed from the **Administration|Append New Records** menu item. The first column of the screen shows the list of variables in the database as listed above. The second column lists the crash data years and the corresponding number of crash records stored already stored in the system crash database for each year.

To import data for a new crash year, type in the file path and name as shown in Figure 4-38. Alternatively, one can click the **Browse** button to navigate to the file folder where the desired input file resides. After a file is specified, click the **Append** button to start appending crash records to the database. CRASH will first detect if the file is of the right format. CRASH will proceed with the data importation only if the format the specified file is of the correct format.

To avoid duplicated records, CRASH will check the Crash Report Number (first field), which is unique, of each record to determine if it is an existing record in the database. If so, the duplicated records will be listed altogether in a box and the user will be asked whether to replace them with the existing records. As soon as the appending process is completed, the list of crash record statistics on the screen will be updated. The user may select to append multiple years of records at once (not recommended, however), or appending the crash records for a single year in multiple appends (e.g., one for each district).

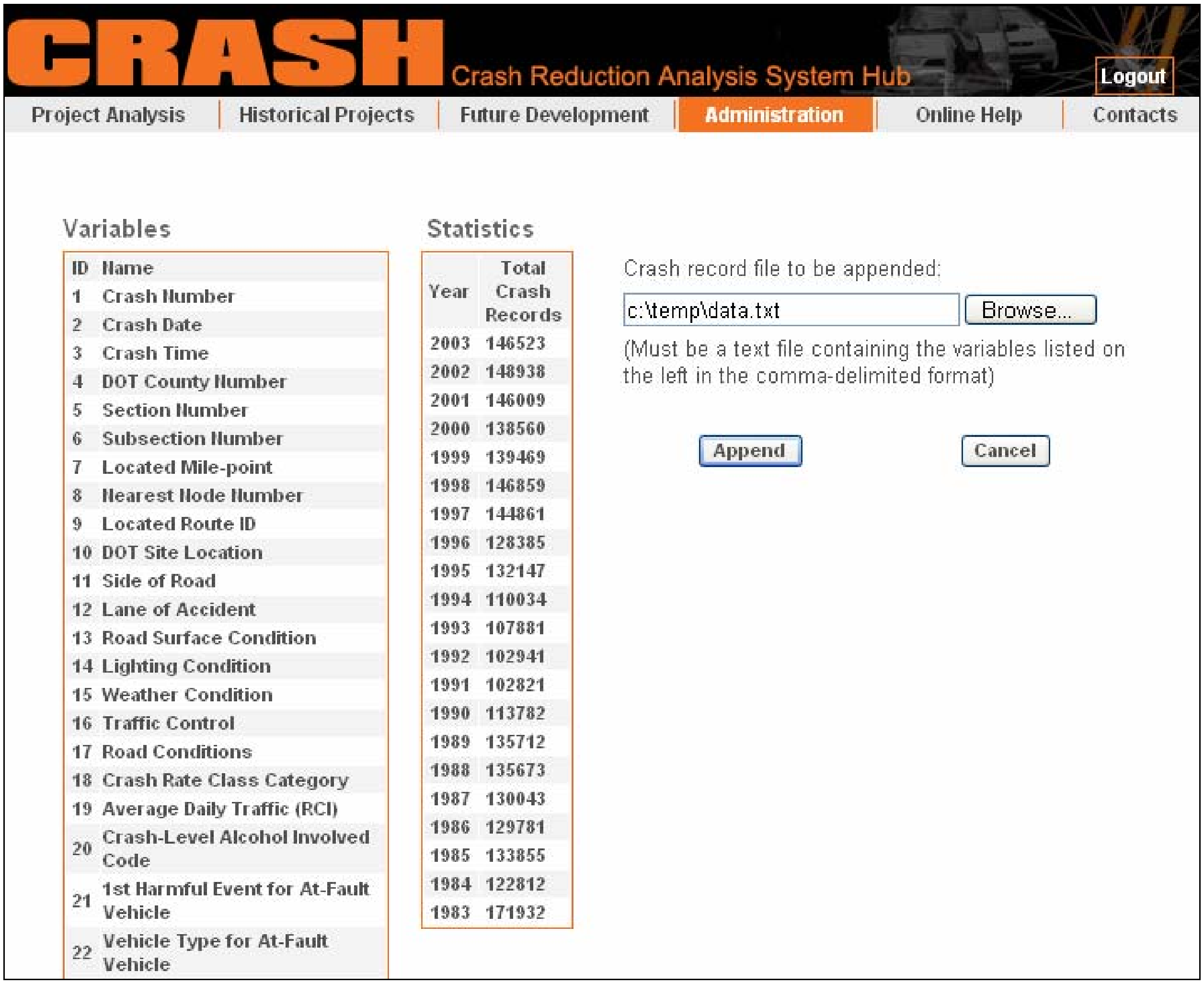


Figure 4-39. Screen for Appending New Crash Records

CHAPTER 5
FUTURE DEVELOPMENT

5.1. Introduction

The method used in calculating CRFs in Florida has been based on the commonly used before-and-after approach. This approach is easy to implement and has been used widely by state DOTs. However, as pointed out in Section 2.3.2, this approach is also known to suffer from a now widely recognized problem known as the regression-to-the-mean (RTM)—a statistical phenomenon that occurs whenever a non-random sample is selected from a population. This selection bias tends to cause crash reduction to be overestimated.

As discussed in section 2.3.3, the Empirical Bayes (EB) method has been introduced by researchers as a means to addressing the RTM problem. The idea behind this method in mitigating the RTM effect is to predict the number of crashes expected to occur during the after period had the countermeasure not been implemented. For this prediction, the EB method requires the information from both the study site and the reference sites. The information from the reference sites is estimated based on a safety performance function (SPF), which is simply a mathematical relationship that links crash occurrence to traffic and geometric characteristics for a particular roadway type.

Two levels of SPFs can be found in the literature (Midwest Research Institute *et al*. 2002; FHWA 1999). The first is the "full" SPF, which predicts crashes as a function of traffic volumes and roadway design conditions. This level of SPFs is no different from the many existing crash prediction models that were developed using various regression methods. The regression coefficients from full SPFs have been used to derive CRFs. However, it has been found that, while such regression models are good predictors of overall crash experience, the individual coefficients are not always good predictors of the incremental effects of particular roadway design variables. Consequently, a second level of SPFs, referred to as the "traffic" SPFs, has been introduced. Unlike full SPFs, traffic SPFs express crash occurrence as a function of traffic volumes only. To predict the number of crashes at a site, the crashes predicted by traffic SPF is adjusted by accident modification factors (AMFs), as follows:

$$N = N_b \; x \; AMF_1 \; x \; AMF_2 \; , \; ..., \; x \; AMF_n \tag{5-1}$$

where

N	=	the predicted number of crashes.
N_b	=	the base or nominal number of crashes predicted by a "traffic" SPF.
AMF_1, AMF_2,..., $AMF_{\underline{n}}$	=	accident modification factors for each of the n roadway conditions.

Thus, AMFs are multiplicative factors that are used to adjust the base crash frequency (as predicted by a "traffic" SPF) due to the effects of individual roadway design features such as lane width, shoulder width, etc. Each AMF is formulated so that the base condition is represented by an AMF of 1.00. Conditions in which the crash experience is higher than the base condition will have an AMF greater than 1.00 and conditions in which the crash experience is lower than the base condition will have an AMF less than 1.00. A review of existing work on AMFs and SPFs is given in the next two sections, respectively.

5.2. Accident Modification Factors

Existing literature on AMFs has been particularly limited. The main literature on AMFs was found in the *Prediction of the Expected Safety Performance of Rural Two-Lane Highways* (FHWA, 1999). The specific AMFs developed in this report were developed based on three sources of data: (1) results from before-and-after studies, (2) coefficients or parameter values from regression models, and (3) expert judgment. Results from before-and-after studies were believed to be the most reliable source of data; however, when before-and-after studies were not available, the experts also adopted the coefficients or parameters derived from regression models (FHWA, 1999). The following formula explains the basic AMF derivation:

$$AMF = \frac{Crash\ Rate\ for\ a\ Non\text{-}nominal\ or\ Non\text{-}base\ Condition}{Crash\ Rate\ for\ a\ Nominal\ or\ Base\ Condition} \tag{5-2}$$

For two-lane roadways, the group of experts selected a set of geometric and traffic control features as candidates to develop AMFs. The following features were included: (1) lane width, (2) shoulder type and width, (3) horizontal curves, (4) grades, (5) driveway density, (6) passing lanes, (7) two-way left-turn lanes, and (8) roadside design. AMFs for these features are discussed in the following subsections.

5.2.1. Lane Width

In developing AMFs based on lane width, the group of experts assumed that the base value is a lane width of 12 ft, and it was assigned an AMF of 1.00. Figure 5-1 depicts the recommended AMFs for lane width ranging from 9 to 12 ft. These AMFs were derived based on the results obtained from Zegeer *et al.* (1994) for roadways with high ADTs (i.e., greater than 2,000 veh/day), and the results from Griffin and Mark (1987) for roadways with low ADTs (i.e., less than 400 veh/day). The transition curves between the high and low ADTs were derived based on the judgment of the group of experts. It was recommended that AMFs be estimated separately for each lane if there was a difference in the lane width between the two lanes of travel.

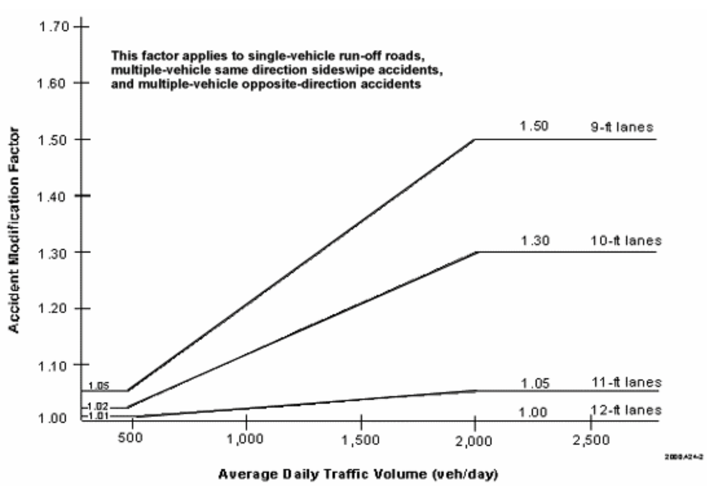


Figure 5-1. AMFs for Lane Width (FHWA, 1999)

5.2.2. Shoulder Type and Width

Figure 5-2 illustrates the recommended AMF values for shoulder widths that range from 0 to 8 ft. Table 5-1 presents the recommended AMFs for different shoulder types. Paved shoulders of 6 ft were used as the base condition and were assigned a value of 1.00. The AMFs presented were derived using results from Zegeer *et al.* (1981) for roadways with high ADT (i.e., ADT greater than 2,000 veh/day) and low ADT (i.e., ADT less than 400 veh/day). As in the case of lane width, the transition curves between the high and low ADT values were derived based on the judgment of the group of experts. These AMFs were recommended for run-off-the-road and opposite-direction crashes only. Again, it was recommended that the AMF for each lane be estimated separately if there was a difference in the shoulder type and width between two lanes of travel.

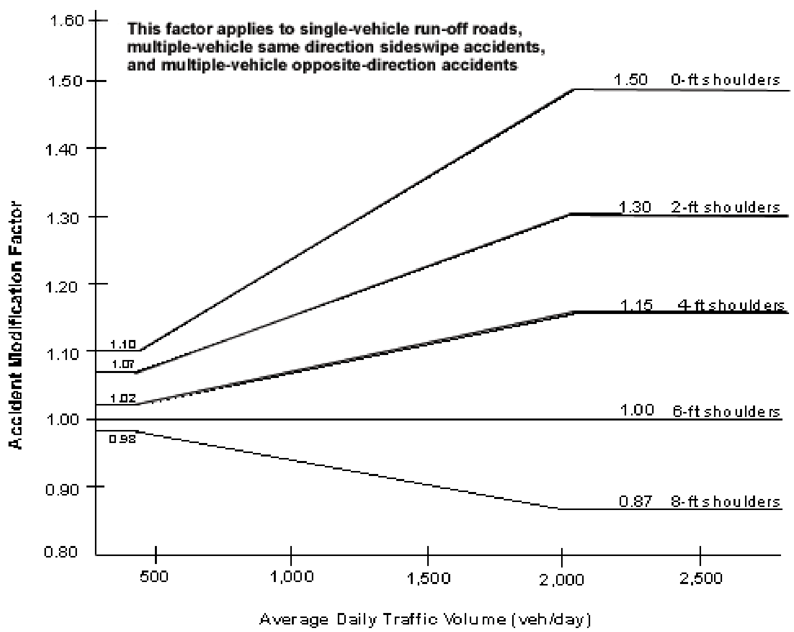


Figure 5-2. AMFs for Shoulder Width (FHWA, 1999)

Table 5-1. AMFs for Shoulder Types (FHWA, 1999)

Shoulder Type	Shoulder Width (ft)							
	0	1	2	3	4	6	8	10
Paved	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Gravel	1.00	1.00	1.01	1.01	1.01	1.02	1.02	1.03
Composite	1.00	1.01	1.02	1.02	1.03	1.04	1.06	1.07
Turf	1.00	1.01	1.03	1.05	1.08	1.11	1.11	1.14

5.2.3. Horizontal Curves

The AMF for horizontal curves was developed based on a regression model from Zegeer *et al.* (1992), as follows:

$$AMF = \frac{1.55L_e + \frac{80.2}{R} - 0.12S}{1.55L_e} \tag{5-3}$$

where
L_e = Length of the horizontal curve,
R = Radius of curvature, and
S = 1.0 for spiral transition, or 0.0 for non-spiral transition.

Tangent roadway section was used as the base to compare the accident experience of curved alignment segments against tangent segments. For superelevation of a horizontal curve, a default maximum superelevation (i.e., e-max) of 0.06 was taken as the base value. Table 5-2 gives the suggested AMFs for superelevation for all types of crashes.

Table 5-2. AMFs for Superelevation (FHWA, 1999)

Superelevation Deficiency	AMF
0.02	1.06
0.03	1.09
0.04	1.12
0.05	1.15

5.2.4. Grades

For AMFs for grades, level terrain roadways with 0% grade were treated as the base condition and was assigned an AMF of 1.00. Table 5-3 contains the recommended AMFs for various grades, which are recommended for all types of crashes. The values in Table 5-3 were derived based on a study conducted by Miaou (1996) on two-lane roadways.

Table 5-3. AMFs for Grade of Roadway Sections (FHWA, 1999)

Grade (%)				
0	**2**	**4**	**6**	**8**
1.00	1.03	1.07	1.10	1.14

5.2.5. Driveway Density

For driveway density, a density of five driveways per mile was used as the base condition. The following formula developed in a study by Muskaug (1985) was used:

$$AMF = \frac{0.2 + \left[0.05 - 0.005 ln(AADT)\right] DD}{0.2 + \left[0.05 - 0.005 ln(AADT)\right]} \tag{5-4}$$

where

AADT = Average annual daily traffic (veh/day); and

DD = Driveway density.

5.2.6. Passing Lanes

Based on the work of Harwood and St. John (1984) and Rinde and Netteblad (1977), the AMFs for passing or climbing lanes added in one direction was 0.75 for two-lane sections and 0.65 for four-lane sections. The base case was defined for sections without a passing lane.

5.2.7. Two-Way Left-Turn Lanes

The AMFs for the installation of left-turn lanes were taken from the work of Hauer (1999) and is calculated from the following equation:

$$AMF = 1 - 0.7 Pd \times Plt \tag{5-5}$$

where

Pd = Proportion of crashes related to the driveway, and

Plt = Proportion of crashes susceptible to be corrected by implementing a two-way-left-turn lane as a proportion of the crashes related to the driveway.

5.2.8. Roadside Design

The AMFs for roadside design were based on a hazard scale developed by Zegeer *et al*. (1988) and were estimated using the following equation, which is valid for all types of crashes:

$$AMF = \frac{exp(-0.6869 + 0.668 RHR)}{exp(-0.4865)} \tag{5-6}$$

where RHR is the roadside hazard rating. A hazard scale of three was used as the base condition.

5.3. Safety Performance Functions

As mentioned, a safety performance function (SPF) is simply a mathematical relationship that links crash occurrence to traffic and geometric characteristics for a particular roadway type. The relationship often takes the form of negative binomial regression relationships to predict crash frequencies from traffic volumes and roadway characteristics. SPFs serve two purposes. First, for an existing facility, a SPF provides an estimate of the prevailing crash frequency, that crash frequency which can be changed by some a planned or possible investment. Second, for a planned facility, the SPF provides an estimate of what the expected crash frequency on it might be.

While it is generally true that an estimate of crash frequency based on many variables fitting the detailed features of a site is likely to better fit the features of some site than an estimate based on fewer variables, Hauer and Persaud (1997) gave the following four reasons why multivariate or full SPF does not currently inspire confidence in use:

1. There are the missing variables.
2. The variables always reveal correlations.
3. One always has to choose a certain mathematical form for the equation in multivariate modeling.
4. The comparison of sites "with" and "without" some features cannot produce a prediction for the result of change if one cannot randomly decide which site will have the feature of interest and which will not.

The review below focuses on simple SPFs (or "traffic" SPFs) instead of multivariate SPFs (or "full" SPFs).

5.3.1. Two-lane Rural Roads

Persaud (1992) developed the following equation using 1988-1989 data for rural two-lane roads in Ontario:

$$\text{Crashes/(km-year)} = A \times (\text{AADT}/1000)^{b} \qquad (5\text{-}7)$$

This equation is for crashes occurring on two-lane highway segments and does not include intersection crashes. For overall crashes, it was found that A = 0.0025 and b = 0.733. For "Fatal and Injury" crashes, A = 0.00054 and b = 0.783. These parameters are based on lanes that are more than 6.1 m and shoulder less than 1.8 m. Table 5-4 shows the parameter values.

Table 5-4. Parameter Values

	Total Crashes				Fatal and Injury Crashes			
Lane Width	<6.1 m	<6.1 m	>6.1 m	>6.1 m	<6.1 m	<6.1 m	>6.1 m	>6.1 m
Shoulder Width	<1.8 m	>1.8 m	>1.8 m	<1.8 m	<1.8 m	>1.8 m	>1.8 m	<1.8 m
b	0.733	0.892	0.892	0.733	0.783	0.971	0.971	0.783
A	0.00287	0.00096	0.00069	0.0025	0.00067	0.00018	0.00012	0.00054

Using data on two-lane rural roads in New York State in the period 1971987, Hauer (1994) developed the following function to estimate total crashes excluding crashes at intersections:

$$\text{Crashes/(km-year)} = 0.00244\text{x}\text{AADT}^{0.776} \qquad (5\text{-}8)$$

5.3.2. Two-lane Urban Roads

Using 1988-1989 data for urban two lane roads in Ontario, Persaud (1992) developed the following function:

$$\text{Crashes/(km-year)} = 0.00369*(\text{AADT})^{0.72} \quad (5\text{-}9)$$

This function is for crashes occurring on urban two-lane highway segments and does not include intersection crashes.

5.3.3. Multilane Roads without Full Access Control

Using 1988-1989 data for multilane roads that did not have full access control in Ontario, Persaud (1992) developed the following function:

$$\text{Crashes/km/yr} = a(\text{AADT})^{b} \quad (5\text{-}10)$$

The estimates for the parameters a and b for different crash types, area types, and roadway types are given in Table 5-5.

Table 5-5. Parameters for the Ontario safety performance functions

Crash Type	Area Type	Divided or Undivided	Parameter estimates Crashes/km/yr = a (AADT)^b	
			a	b
Total	Urban	Divided or Undivided	0.0000524	1.146
Total	Rural	Divided	0.0084885	0.618
Total	Rural	Undivided	0.0000560	1.129
Fatal + Injury	Urban	Divided or Undivided	0.0001045	0.980
Fatal + Injury	Rural	Divided	0.0013000	0.687
Fatal + Injury	Rural	Undivided	0.0000078	1.219

5.3.4. Freeways

Based on the 1988-1989 data from Ontario, Persaud (1992) developed the following function for freeway crashes:

$$\text{Crashed /km/yr} = a(\text{AADT})^{b} \quad (5\text{-}11)$$

The estimated parameters a and b for different crash types and number of lanes are given in Table 5-6.

Table 5-6. Parameters for the Ontario safety performance functions

Crash Type	Lanes	Parameter Estimates	
		a	***B***
Total	4	0.0000474	1.155
Total	>4	0.0000978	1.113
Fatal + Injury	4	0.0000206	1.136
Fatal + Injury	>4	0.0000122	1.212

Huang *et al.* (1991) developed the following two functions based on data from California freeways:

$$\text{Total Crashes} = 0.65 + 0.666 \times \text{Million Vehicle Miles} \quad (5\text{-}12)$$

$$\text{Fatal + Injury Crashes} = 0.166 + 0.263 \times \text{Million Vehicle Miles} \quad (5\text{-}13)$$

Comparison made between Ontario and California functions gave comparable results for the rural four-lane functions for total crashes.

5.3.5. Intersections

Lau *et al.* (1989) used 1986-1988 data for signalized intersections from California to develop safety performance functions for all intersections. Separate models were developed for fatal, injury, and PDO crashes. Three levels of estimation were used depending on the available information of an intersection. At the first level, if only the entering traffic of an intersection is known, the following functions are used:

$$\text{Fatal Crashes/year} = 0.018 \quad (5\text{-}14)$$

$$\text{Injury Crashes/year} = 0.61856 + 0.16911 \times \text{Million Entering Vehicles} \quad (5\text{-}15)$$

$$\text{PDO Crashes/year} = 4.6029 + 0.5142 \times \text{Million Entering Vehicles} \quad (5\text{-}16)$$

If further information is available about an intersection, such as design, control, proportion of cross street traffic, and environmental features, level II estimates are used. At level II, intersections are classified by group and a “group constant” is added to the value computed by previous functions. Groups are separated by fatal, injury, and PDO crashes and defined by the intersection characteristics such as intersection type, traffic control type, number of lanes by approach, design speeds, etc. The third level is used when the individual crash history of an intersection is available, in addition to the information required in levels I and II. The third level is based on the Empirical Bayes procedure and the results represent future safety estimates of existing intersections.

To illustrate, Lau *et al.* used a four-legged urban intersection with AADT of 49,000 and 10,000 for main and side streets, respectively. All approaches were two-lane and served with a multiphase, pre-timed signal controller with permitted left turns. The design speed was 50-54 mph. Based on this information, it was classified under a certain group that determined the additive correction value. Table 5-7 shows a summary of the predictions made by the models.

Table 5-7. Number of Crashes Per Year for Level I, II, and III

Predictions				Observed Values (1979–1985)
Level	**I**	**II**	**III**	
Injury	4.26	4.99	5.74	5.86
PDO	15.68	16.60	17.94	17.97
Fatal	0.018	0.057	0.141	0.29

A number of other functions specific to area type and traffic control can be found in literature and they are described the following subsections.

5.3.5.1 Unsignalized Rural Intersections

One of the early studies in trying to relate crashes to traffic volumes was conducted by McDonald (1953). He used data from intersections of divided highways to develop the following function:

$$\text{Crashes/year} = 0.000783(\text{AADT}_{\text{major road}})^{0.455}(\text{AADT}_{\text{minor road}})^{0.633} \tag{5-17}$$

Using the HSIS data from years 1985 to 1987 for 125 rural unsignalized intersections in Minnesota, Bonneson and McCoy (1993) developed the following function of the same form:

$$\text{Crashes/year} = 0.000379(\text{AADT}_{\text{major road}})^{0.256}(\text{AADT}_{\text{minor road}})^{0.831} \tag{5-18}$$

Belanger (1995) again used the same functional form with data from 149 unsignalized intersections in Quebec to develop the following function:

$$\text{Crashes/year} = 0.00204(\text{AADT}_{\text{major road}})^{0.42}(\text{AADT}_{\text{minor road}})^{0.51} \tag{5-19}$$

5.3.5.2 Signalized Rural Intersections

In an early study by Wedd (1955) data from 96 signalized intersections on high speed rural state roadways in California were used. In this study, crashes on the minor road approaches were not included. The function found was as follows:

$$\text{Crashes/year} = 0.00703(\text{AADT}_{\text{major road}})^{0.51}(\text{AADT}_{\text{minor road}})^{0.29} \tag{5-20}$$

Using the HSIS data for rural signalized intersections, Bonneson *et al.* (1993) developed the following function:

$$\text{Crashes/year} = 0.00703(\text{AADT}_{\text{major road}})^{0.7213}(\text{AADT}_{\text{minor road}})^{0.3663} \tag{5-21}$$

Hanna *et al.* (1976) reported the crash rates given in Table 5-8 for 76 signalized intersections in 42 rural municipalities in Virginia. Table 5-8 shows crashes/100 million entering vehicles at signalized intersections in rural municipalities.

Table 5-8. Crashes/100 Million Entering Vehicles (Hanna et al., 1976)

Geometry	Crash Rate
Four-Legged Intersections	147
T Intersections	82
Y Intersections	140

Hanna *et al.* also found that the crash rates did not remain constant but tend to diminish with AADT, as is shown in Table 5-9.

Table 5-9. Crash rate varies with AADT (Hanna *et al.*, 1976)

AADT	Crashes/100 Million Entering Vehicles
<10,000	133
10,000 – 15,000	126
15,000 – 20,000	109
>20,000	126

5.3.5.3 Unsignalized Urban Intersections

Table 5-10 gave the crash rates developed by McGee *et al.* (1989) using data from unsignalized urban intersection in Seattle, Milwaukee, Rapid City and Madison.

Table 5-10. Crash Rate (Crashes/Million Entering Vehicles)

Major Street ADT	Minor Street ADT						
	100	300	500	700	900	1250	2000
250	2.19	2.09	2.01	1.99	2.03	1.72	1.22
750	1.06	1.44	1.53	1.57	1.58	1.49	1.14
1250	0.73	1.15	1.25	1.31	1.34	1.36	1.09
1750	0.64	0.92	1.12	1.26	1.19	1.17	0.91
2500	0.53	0.73	0.90	1.02	1.04	0.99	0.88
3500	0.43	0.57	0.69	0.80	0.83	0.81	0.75

5.3.5.4 Signalized Urban Intersections

Using data on signalized intersection of one-way streets in Philadelphia, Persaud *et al.* (1995) developed the parameter values given in Table 5-11 for different crash types based on the following popular functional form:

$$\text{Crashes/year} = a(AADT_{\text{major road}})^{b}(AADT_{\text{minor road}})^{c} \qquad (5\text{-}22)$$

Table 5-11. Parameters for a, b, and c

Parameters	Right-angle and turn crashes	Rear-end crashes	Pedestrian crashes
a	0.0002037	0.0002099	0.0009039
b	0.5941	0.6758	0.5150
c	0.354	0	0

5.4. Recommendations for Future Development

The implementation of the EB method to account for the RTM bias is important but non-trivial. In April 2001, the Federal Highway Administration (FHWA) entered into a major contract to develop an EB-based system known as *SafetyAnalyst* (http://www.safetyanalyst.org/index.htm). This system is aimed at providing the state and local highway agencies with a comprehensive set of tools to improve their programming of site-specific highway safety improvements. This national system will have default SPFs and AMFs developed from studies throughout the U.S. and Canada. The users will have the option to replace these default values with localized SPFs and AMFs to better represent the local crash experience.

To take advantage of the new capability from *SafetyAnalyst* to improve its safety improvement programs, the Department will need to have a system that helps to prepare the data needed to go into the system and to perform regression analysis to develop Florida specific SPFs and AMFs. To this end, the CRASH system can serve as a platform for FDOT to support applications of the *SafetyAnalyst* system. It is recommended that the FDOT continue the current effort of CRASH development by developing a project that aims to meet the following objectives:

1. Evaluate *SafetyAnalyst* in terms of data needs, system functionality, and other requirements.
2. Based on findings from the evaluation, develop Florida specific Safety Performance Functions (SPFs) and Accident Modification Factors (AMFs).
3. Develop a process that allows SPFs and AMFs to be developed and updated in the most automated manner possible.
4. Develop an automated process that converts Florida's crash data into the format needed in *SafetyAnalyst*.
5. Conduct a workshop to train the district officials in the use of *SafetyAnalyst*.

CHAPTER 6
SUMMARY AND FUTURE WORKS

Crash Reduction Factors (CRFs) are used to estimate the expected reduction in crashes that will occur during a given period as a result of implementing a proposed countermeasure. This estimate is needed to perform an economic evaluation of a potential countermeasure. This report documents an effort by the Florida Department of Transportation (FDOT) to update its CRFs and to develop a computer system to systematically maintain safety improvement projects implemented by its district offices to facilitate regular CRF updates.

As part of this study, a review of the current methods of developing CRFs was performed. In addition, a state-of-the-practice survey of the state Departments of Transportation (DOTs) was conducted. Before-and-after and cross-sectional methods were found to be the two existing methods for developing CRFs, with the before-and-after method being more widely used. Three existing before-and-after methods were reviewed: (1) the simple before-and-after study method, (2) the before-and-after study with comparison group method, and (3) the before-and-after study with Empirical Bayes (EB) method.

The method used in calculating CRFs in Florida has been based on the commonly used simple before-and-after approach. This approach is easy to implement and has been used widely by state DOTs. However, this approach is also known to suffer a widely recognized problem known as the regression-to-the-mean (RTM)—a statistical phenomenon that occurs when a non-random sample is selected from a population. This selection bias is a direct result of the general practice to select high-crash locations for safety improvements. When data from these locations are used to derive CRFs, the resultant CRFs will tend to overestimate the crash reduction for a treatment site.

In addition to the RTM problem, the simple before-and-after study method is also vulnerable to other known problems, including crash migration, maturation, and external causal factors. The before-and-after study with comparison group method is considered a better approach than the simple method due to its ability to account for the effects of maturation and external causal factors. However, the accuracy of this method is highly dependent on the availability of comparison sites and the similarity between the comparison and treatment sites.

The Empirical Bayes (EB) method has been introduced by researchers as a means to addressing the RTM problem, although it is also more difficult to implement. The idea behind this method in mitigating the RTM effect is to predict the number of crashes expected to occur during the after period had the countermeasure not been implemented. For this prediction, the EB method requires the information from both the treatment site and the reference sites. The information from the reference sites is estimated based on a safety performance function (SPF), which is simply a mathematical relationship that links crash occurrence to traffic and geometric characteristics for a particular roadway type.

Two levels of SPFs were found in the literature. The "full" SPF predicts crashes as a function of traffic volumes and roadway design conditions. The regression coefficients from full SPFs can be used to derive CRFs. While such regression models have been found to be good predictors of the overall crash experience, the individual coefficients often do not adequately predict the incremental effects of particular roadway design variables. Consequently, a second level of SPFs, referred to as the "traffic" SPFs, has been suggested. A traffic SPF relates crash occurrence to only the traffic volumes. To predict the number of crashes at a site, the crashes predicted by traffic SPF is adjusted by a number of so-called accident modification factors (AMFs), which are multiplicative factors that are used to adjust the base crash frequency (as predicted by a "traffic" SPF) due to the effects of individual roadway design features such as lane width, shoulder width, etc.

The implementation of the EB method to account for the RTM bias is important but non-trivial. In 2001, the Federal Highway Administration (FHWA) entered into a major contract to develop an EB-based system known as *SafetyAnalyst* (http://www.safetyanalyst.org/index.htm). This system is aimed at providing the state and local highway agencies with a comprehensive set of tools to improve their programming of site-specific highway safety improvements. This national system will have default SPFs and AMFs developed from studies throughout the U.S. and Canada. States will have the option to replace these default values with localized SPFs and AMFs to better represent the local crash experience.

To take advantage of the new capability from *SafetyAnalyst* to improve its safety improvement programs, it is recommended that the FDOT develop a system that can help to prepare the data needed to go into the system and to perform regression analysis to develop and update Florida specific SPFs and AMFs. The goal will be to develop an information infrastructure that supports Florida's use of the *SafetyAnalyst* national model, which is an EB-based system that is designed to address the RTM problem associated with the simple before-and-after method currently used by most state DOTs, including FDOT.

The development of the Crash Reduction Analysis System Hub (CRASH) system in this study provides a good start for the longer-term effort to improve Florida's safety improvement programs. It also provides a platform for FDOT to support applications of the *SafetyAnalyst* system. Developed as a web-based application that runs on FDOT's Intranet system, CRASH is able to perform the following tasks in a highly automated manner:

1. Recording and maintaining improvement projects,
2. Updating CRFs based on the latest available improvement project and crash data, and
3. Applying calculated CRFs in the benefit-cost analyses of specific projects.

In addition, the system provides various functions for data retrieval and exportation for different analysis and reporting purposes.

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Appendix A:

Request for Information Letter and Status Summary

FLORIDA INTERNATIONAL UNIVERSITY

Hope, Knowledge, and Opportunity

February 21, 2002

Mr. Kurt Smith
State Traffic Engineer
Alaska Department of Transportation & Public Facilities
3231 Channel Drive
Juneau, Alaska 99801-7898

Re: Request for Information on Highway Safety Improvement Procedures and Crash Reduction Factors

Dear Mr. Smith:

The Florida International University is conducting a study for the Florida Department of Transportation (FDOT) to update crash reduction factors for use in calculating the benefit to cost ratios for highway safety improvements in Florida. One of the project tasks is to provide a summary of the current highway safety evaluation procedures and crash reduction factors used by other state transportation agencies.

We would like to ask you to provide us a copy of the procedures used by your agency for the determination of the benefit/cost ratios (or other measure if B/C ratios are not used) for potential highway safety improvements. Of particular interest are the crash reduction factors or procedures used by your agency. We would also appreciate any other documents and supporting information such as a manual, handbook, or report that you use. This information will be assimilated together with information received from the other states to determine the state-of-the-art in the area of pre-implementation evaluation of highway safety improvements.

Your cooperation in this matter will be greatly appreciated. We will provide you with a summary of the findings of our request for information if you so indicate. If you have any questions, please do not hesitate to call me at (305) 345-3116 or email gan@eng.fiu.edu. We appreciate your assistance.

Sincerely,

Albert Gan, Ph.D.
Principal Investigator

DEPARTMENT OF CIVIL & ENVIRONMENTAL ENGINEERING
Center for Engineering and Applied Science
University Park Campus, EAS 3680 • Miami, Florida 33199
telephone (305) 348-2824 • fax (305) 348-2802
www.eng.fiu.edu/ce/

Appendix B

State-by-State Crash Reduction Factors

State: Alaska
Source: Alaska Department of Transportation and Public Facilities

Improvement	Reduction Factor (%)
INSPECTION AND TRAFFIC CONTROL	
New turning pockets Rear-ends and sideswipes involving turning cars making the target movement (This does not include adding lanes to existing turning pockets)	90
Acceleration lane for right turning traffic from side street Multi-car crashes involving through traffic vehicles making the target movement	75
Improve sight distance Multi-car crashes involving cars on the limited sight distance approach	75
Install stop ahead or yield signs Crashes caused by failure to stop or yield on the target approach	25
Intersection illumination Night crashes	50
New traffic signal Angle crashes Rear-end crashes (expected to be increase)	 60 +25
Protected left turn movement at existing signalized intersection Angle crashes involving the target left turn movement	80
Rumble strips on approaches to intersections Non ice/snow crashes on the target approach caused by cars failing to stop	90
Active advance warning flashers Rear-end and angle crashes involving vehicles on the target approach	Factor needs to be derived from crash data
Replace signal or stop-controlled 4-leg intersection with a single-lane roundabout All intersection crashes	75
Replace signal or stop-controlled 3-leg intersection with a single-lane roundabout All intersection crashes	50
STRUCTURES	
Replace or widen narrow bridge Head-on, sideswipes, collisions with fixed objects on bridge or approaches	50
Construct interchange All intersection crashes	60
ROADWAY AND ROADSIDE	
Widen shoulder Run off road, head on, opposite-direction sideswipe, and same direction sideswipe crashes within the widened segment	Use formula from Appendix C, page 249 of TRB Special Report 214
Widen travel lanes to reconstruction manual standard Run off road, head on, opposite-direction sideswipe, and same direction	Use formula from Appendix C, page 249 of TRB Special Report 214
Install median barrier Crashes within the median or resulting from vehicles crossing the median in which there are major or fatal injuries	90
Install raised median Crossover collisions Pedestrian crashes	 75 25
Rumble strips on shoulders (45 MPH and above) Non ice/snow run off the road crashes	50
Flattening of horizontal curves All non-intersection crashes within the realigned segment	Use factor from table D-7 of TRB Special Report 241
Flattening of crest vertical curves All non-intersection crashes within the realigned segment	Use factor from table D-7 of TRB Special Report 241

Improvement	Reduction Factor (%)	
Relocate utility poles Collisions with the poles to be relocated if poles are moved outside of clear zone: If poles are not moved outside of clear zone-prorate (0 movement = 0 reduction, Clear zone = 90% reduction)	90 Pro-rate	
Flatten or regrade side slopes All run off the road crashes (Source: Appendix C, page 253, of TRB Special Report 214, Designing safer roads, 1997. Reductions are based on no existing recovery distance. Assume a reduction of 50 % for 30 ft, and no increase beyond 30 in)	Recovery Distance 5 10 15 20	Crash Reduction 13 25 35 44
Install shoulder guardrail Single car run off the road crashes that would have been contained by rail	50	
Remove obstacles Collisions with the obstacle to be removed	100	
Install impact attenuators on rigid objects Fatal and major injury collisions with the object to be shielded	90	
New curve warning signs and delineators All non-intersections crashes within the target curve	20	
Signs, markings, delineators at narrow bridges All crashes on the bridge and within 300 ft of bridge termini	50	
Install new continuous illumination Night crashes on segments to receive lighting (Exclude crashes at intersections that currently have street lights)	20	
PEDESTRIAN AND BICLYCLE SAFETY		
Construct sidewalk Crashes between vehicles and pedestrian walking on shoulder	75	
Construct pedestrian and bicycle overpass/underpass Crashes between vehicles and bikes or pedestrians at the crossing the overpass or underpass will replace	100	
RAILROAD-HIGHWAY CROSSINGS		
Upgrade from rail road signs to flashers Crashes involving trains and highway vehicles	75	
Upgrade from rail road signs to gates Crashes involving trains and highway vehicles	90	
Upgrade from rail road flashers to gates Crashes involving trains and highway vehicles	90	
Construct rail road grade separation Crashes involving trains and highway vehicles	100	
Install rail road crossing illumination Crashes involving trains and highway vehicles	25	
Improve rail road crossing sight distance Crashes involving trains and highway vehicles	25	
Improve rail road crossing surface Crashes caused by trucks high-centering, vehicles bouncing over the tracks, or bicyclists or motorcyclists getting their wheels caught by the track	90	
Install new rail road pavement markings Crashes involving trains and highway vehicles	25	

State: Arizona
Source: Arizona Department of Transportation

Improvement	Reduction Factor (%)				
	All	Fatal	Injury	Fatal and Injury	PDO
ROADWAY IMPROVEMENTS					
LANE ADDITION					
All crashes	25	39	23	23	27
Rear-end	32	67	28	28	35
Run-off-road	44	55	44	45	44
Side swipe/same direction	30	100	36	37	28
Side swipe/opposite, and head-on	53	100	39	70	59
LANE WIDENING					
All crashes	56	58	57	57	54
Run-off-road	49	100	35	41	54
Side swipe/same direction	52	0	43	43	54
Side swipe/ opposite, and head-on	70	0	100	100	25
SHOULDER WIDENING					
All crashes	57	48	59	58	57
Run-off-road	60	25	57	54	65
Side swipe/same direction	41	100	75	78	28
Sideswipe/ opposite, and head-on	75	33	80	72	83
Pedestrian	71	86	57	71	0
TWO-WAY LEFT-TURN LANE					
All crashes	30	40	20	20	35
Rear-end	36	0	38	38	34
Left-turn	33	100	0	2	48
Run-off-road	37	100	(3)	0	49
Pedestrian	19	0	19	18	50
Sideswipe/ opposite and head-on	36	0	50	50	27
REALIGNMENT					
All crashes	48	33	56	55	42
Run-off-road	66	33	71	69	62
Rear-end	37	0	42	42	34
Sideswipe/ opposite and head-on	85	67	89	83	87
Sideswipe/same direction	54	0	57	57	53
SHOULDER GROOVING					
All crashes	18	15	18	18	17
Run-off-road	27	12	27	26	26
OVERLAY					
All crashes	9	2	4	4	13
Rear-end	19	25	18	18	20
Run-off-road	13	(16)	11	10	15
Wet pavement	39	61	25	27	43
TRUCK ESCAPE RAMP					
All crashes	18	(75)	28	20	16
Deficient brakes	(14)	(100)	0	(100)	20
Rear-end	33	0	71	71	(100)
BRAKE CHECK AREA					
All crashes	45	100	55	58	50
Deficient brakes	100		100	100	0

ROADSIDE IMPROVEMENTS					
NEW GUARDRAIL					
All crashes	19	47	12	15	21
Run-off-road	30	56	23	26	34
UPGRADED/EXTENDED GUARDRAIL					
All crashes	15	9	13	13	16
Run-off-road	26	10	27	25	26
DRAINAGE STRUCTURE EXTENSIONS					
All crashes	36	18	34	33	38
Run-off-road	44	27	36	36	50
SLOPE FLATTENING					
All crashes	(4)	30	(15)	(12)	2
Run-off-road	10	30	18	19	(2)
VEGETATION/OBSTACLE REMOVAL					
All crashes	61	0	59	58	64
Run off road	71	100	76	77	76
NEW/UPGRADED MEDIAN BARRIER					
All crashes	36	60	26	28	39
Run-off-road	35	50	11	13	46
Sideswipe/opposite, and head-on	0	0	0		0
IMPACT ATTENUATORS 15					
All crashes	41	(100)	55	50	36
Run-off-road	45	0	30	30	58
OBJECT MARKERS					
All crashes	16	41	17	19	14
Run-off-road	29	60	24	29	29
DELINEATION					
All crashes	11	8	19	18	4
Run-off-road	34	14	43	40	24
Nighttime	25	14	41	38	10
Sideswipe/opposite, and head-on	67	100	25	63	71
ANIMAL FENCING					
All Crashes	(12)	0	(17)	(15)	(9)
Animal	66	0	91	91	61
ANIMAL REFLECTORS					
All crashes	10	0	6	6	11
Nighttime animal	25	0	0	0	25
SNOW FENCING					
All crashes	71	0	83	83	64
Snowy pavement	58	0	67	67	56
ROCKFALL CONTAINMENT					
All crashes	14	0	0	0	25
Strike rocks	100	0	0	0	100
ILLUMINATION					
All crashes	19	0	8	8	23
Nighttime	30	100	35	42	23
INTERSECTIONS AND INTERCHANGES					
NEW SIGNAL					
All crashes	(17)	(14)	(20)	(20)	(15)
Angle	42	60	39	40	45
NEW SIGNAL AND GEOEMTRIC REVAMP					
All crashes	21	57	28	30	13
Angle	68	56	73	72	73

Sideswipe/same direction	53	0	100	100	42
Pedestrian	33	100	0	33	0
REVAMPED SIGNAL					
All crashes	9	0	3	3	13
Angle	32	100	37	37	27
Left-turn	0	0	(44)	(44)	26
Pedestrian	57	0	50	50	100
REVAMPED SIGNAL AND GEOMETRIC REVAMP					
All crashes	40	50	33	34	43
Rea-end	48	100	45	45	5O
Left-turn	18	50	24	25	11
Angle	19	0	21	20	19
Improper turn	80	0	83	83	79
Sideswipe/same direction	48	0	17	17	52
Pedestrian	(14)	100	(60)	(33)	100
LEFT-TURN PHASING					
All crashes	15	33	6	6	21
Left-turn	35	50	4	6	52
TURN LANES					
All crashes	6	100	(1)	3	9
Rear-end	(8)	100	(40)	(31)	3
Angle	13	100	14	17	6
Left-turn	24	100	33	38	12
Sideswipe/same direction	59	0	75	75	54
Improper turn	54	0	25	25	67
INTERSECTIONS AND INTERCHANGES					
GEOMETRIC REVAMP					
All crashes	43	0	71	71	20
Angle	17	0	58	58	(27)
Run-off-road	67	0	80	80	50
Rear-end	60	0	100	100	33
Improper turn	100	0	100	100	100
Left-turn	67	0	50	50	100
Sideswipe/same direction	67	0	100	100	50
ILLUMINATION					
All crashes	(48)	0	(14)	(14)	(73)
Nighttime	18	0	29	29	8
SIGHT DISTANCE IMPROVEMENT					
All crashes	7	0	6	5	8
Angle	21	75	3	7	31
Rear-end	10	0	17	17	4
Left-turn	13	0	21	21	3
Improper turn	30	0	30	30	29
CHANNELIZATION PAVEMENT MARKINGS					
All crashes	0	100	(4)	(2)	1
Left-turn	19	0	9	9	24
Angle	(33)	100	(50)	(36)	(31)
Improper turn	17	0	60	60	(14)
Pedestrian	80	0	100	100	(100)
Sideswipe/same direction	25	0	0	0	33
CHANNELIZATION SIGNING					
All crashes	14	(100)	(2)	(7)	27
Left-turn	36	(100)	36	27	45

Angle	14	0	(50)	(50)	63
Sideswipe/same direction	67	0	100	100	33
Improper turn	100	0	100	100	100
CROSS ROAD/SIDE ROAD SIGNING					
All crashes	33	100	56	59	15
Rear-end	27	0	38	38	(75)
Angle	29	100	25	50	20
Improper turn	64	0	86	86	43
Left-turn	86	0	75	75	100
STOP SIGNS					
All crashes	19	0	20	20	18
Angle	8	0	0	0	17
Rear-end	48	0	67	67	38
Left-turn	22	0	14	14	27
YIELD SIGNS					
All crashes	(37)	0	25	25	(89)
Angle	43	0	33	33	50
SIGNAL REMOVAL					
All crashes	100	0	100	100	100
Rear-end	100	0	100	100	100
TRAFFIC CONTROL DEVICES					
EDGELINE MARKINGS					
All crashes	30	(100)	63	52	15
Run-off-road	30	0	60	56	10
RAISED PAVEMENT MARKINGS					
All crashes	11	16	11	12	11
Nighttime	16	35	10	12	18
Run-off-road	33	13	37	37	31
Sideswipe/same direction	13	100	6	7	14
Sideswipe/opposite, and head-on	12	40	(15)	(4)	38
RUMBLE STRIPS					
All crashes	53	83	65	73	29
Run-off-road	54	75	56	60	38
Sideswipe/opposite, and head-on	80	100	100	100	67
NEW CURVE SIGNING					
All crashes	14	55	20	24	3
Run-off-road	17	57	14	27	1
Sideswipe/opposite, and head-on	29	57	17	49	3
Sideswipe/same direction	75	100	100	100	71
UPGRADED CURVE SIGNING					
All crashes	21	6	23	22	21
Run-off-road	21	0	25	23	18
Sideswipe/opposite, and head-on	26	50	11	14	34
Rear-end	48	0	38	38	76
Sideswipe/same direction	100	100	100	100	100
ICY PAVEMENT SIGNING					
All crashes	(15)	67	(24)	(13)	(17)
Icy pavement	(22)	100	(52)	(42)	(16)
SLIPPERY WHEN WET SIGNING					
All crashes	7	(81)	10	6	8
Wet pavement	31	0	29	28	33
NARROW BRIDGE SIGNING					
All crashes	47	0	86	86	13

Run-off-road	50	0	100	100	0
Sideswipe/opposite, and head-on	20	0	100	100	(33)
WATCH FOR ROCKS SIGNING					
All crashes	13	0	13	12	14
Strike rocks	64	0	88	88	56
ANIMAL WARNING SIGNING					
All crashes	10	(15)	8	6	13
Strike animals	18	83	2	12	19
INTERSTATE SIGNING					
All crashes	7	8	10	10	25
SIDEWALKS					
All crashes	(15)	100	(70)	(58)	7
Hit pedestrian	89	100	88	89	0
PEDESTRIAN OVERPASS					
All crashes	(33)	0	0	0	(62)
Hit pedestrian	67	0	50	67	0
PEDESTRIAN SIGNING					
All crashes	4	4	8	8	1
Hit pedestrian	15	22	17	17	(33)
STRUCTURES					
BRIDGE WIDENING					
All crashes	36	50	38	38	32
Run-off-road	44	50	27	29	62
Sideswipe/same direction	57	0	100	100	0
BRIDGE REPLACEMENT					
All crashes	62	100	36	40	70
Run-off-road	52	100	0	17	65
Rear-end	100	0	100	100	100
Sideswipe/opposite, and head-on	100	0	0	0	100
Sideswipe/same direction	100	0	100	100	0
NEW BRIDGE					
All crashes	11	0	38	36	(15)
Wet pavement	50	0	50	50	50
BRIDGE BARRIER UPGRADE					
All crashes	25	(100)	50	41	14
Run-off-road	42	0	46	46	40
RAILROAD-HIGHWAY CROSSINGS					
NEW FLASHING LIGHTS					
All crashes	43	0	0	0	60
Hit train	0	0	0	0	0
UPGRADED FLASHING LIGHTS					
All crashes	43	0	29	29	57
Hit train	38	0	0	0	60
NEW GATES TO REPLACE X-BUCKS					
All crashes	59	90	73	76	44
Hit train	96	100	95	26	95
NEW GATES TO SUPPLEMENT FLASHING LIGHTS					
All crashes	62	100	71	73	53
Hit train	80	100	100	100	60
SURFACE IMPROVEMENT					
All crashes	7	(100)	0	22)	20
Hit train	20	(100)	50	50)	67
Run-off-road	25	0	33	33	20

SIGNING					
All crashes	100	0	100	100	100
Hit train	100	0	100	100	0
Run-off-road	100	0	100	100	100
PAVEMENT MARKINGS					
All Crashes	48	(100)	43	42	51
Hit train	56	(100)	50	43	62
Rear-end	58	0	52	52	62
Run-off-road	22	0	8	8	30

Note: Underlined numbers represent statistically significant rate reductions. Numbers in parentheses represent rate increases

State: California
Source: Caltrans Highway Safety Improvement Program

Improvement	Reduction Factor (%)
New signals	20
Modified signals	20(1)
Flashing beacons	20
New left turn channelization	
A. Signalized Intersections	
1. Without left-turn phase	15 (2)
2. With left-turn phase	35 (2)
B. Non-signalized Intersection	35 (2)
C. Two-Way Left-Turn Lanes	25 (2)
New safety lighting	15 (3)
Curve correction	50 (2)
Rumble strip	50 (4)
Superelevation correction	50 (5)
Truck escape ramp	75 (6)
Shoulder widening on narrow 2-lane roads (24 feet wide or less)	
A. Widening (ADT less than 400)	15 (2)
B. Widening (ADT 400 to 1499)	30 (2)
C. Widening (ADT 1500 to 3000)	30 (2)
Truck climbing lane for 2-lane roads	30 (2)

Notes:
(1) Calculate the appropriate reduction factor. Not to exceed 20% for all intersection types.
(2) Of all accidents.
(3) Of night accidents.
(4) Of drift off the road accidents. (Sleepy, under influence). Inattention
(5) Of run off the road accidents.
(6) Of run-away truck accidents.

State: Idaho
Source: Missouri Department of Transportation and Idaho Department of Transportation

Description	Reduction Factor (%)	
I. SIGNS		
A. Warning		
1. Intersections		
a. Urban	30	
b. Rural	40	
2. Sections		
a. Urban	15	
b. Rural	20	
3. Curves	30	
B. Regulatory		
1. Intersections	50	
2. Other	25	
C. Guidance	15	
D. Other		
1. Variable message signs	10	
2. Upgrade signing	15	
II. SIGNALS		
A. New installations	30	
B. Modernize modify or upgrade	26	
C. Warning signals or flashing beacons		
1. Intersections		
A. Red-yellow	30	
B. 4-way red	64	
C. Advance	25	
2. Curves	30	
3. Pedestrian signal	15	50P
D. Signal phasing		
1. Add protected left-turn phase	25	85L
2. Add permissive left-turn phase	10	40L
3. Improve timing	10	
4. Add pedestrian phase	30	60P
5. Increase clearance interval	30	
E. Other	20	
1. Pretimed to actuated	10	
2. 12-inch lens		
Ill. DELINEATION		
A. Post delineators	20	
B. Raised pavement markers	5	20Wn 10Dn
A. Add centerline	30	
B. Add edgeline	15	
C. Add no passing stripe	40	
D. Transverse striping	15	
E. Lane use/ pavement arrows	30	
F. Continuous left-turn lane	32	
V. CHANNELIZATION		
A. General intersection	40	
B. Left-turn	30	
1. Signalized intersection	15	
A. Left-turn phase		

B. No left-turn phase		
2. Non-signalized intersection		
A. With curb	60	
B. Painted	25	
VI.CONSTRUCTION/RECONSTRUCTION		
A. Lane addition		
1. Left-turn lane		
A. Without signal	25	
B. With signal	30	
C. Two-way left-turn lane	31	37I+F
2. Acceleration /Deceleration lane	10	
3. Passing lane	20	
4. Shoulder	20	
5. Climbing lane	10	
B. Lane/shoulder widening	20	
C. Alignment		
1. Change horizontal alignment	30	
2. Change vertical alignment	45	
3. Change horizontal and vertical alignment	52	57I+F
D. Curve reconstruction	50	
E. Bridges and minor structures		
1. Widen bridge	22	
2. Replace bridge	40	
3. Widen minor structure	22	
4. Replace minor structure	23	
F. Intersections / interchanges		
1. Construct interchange	50	
2. Reconstruct interchange	40	
G. Other		
1. Improve sight distance	32	
2. Correct/improve superelevation	40	
3. Close median openings	30	
4. Increase intersection turn radii	15	
5. Frontage road	40	
6. Ramp modification	25	
7. Fatten side Slopes	34	
8. Construct pedestrian crossover	95P	
VII. PAVEMENT TREATMENT		
A. Resurfacing	20	40W
B. Skid resistance		
1. Deslicking	20	40W
2. Pavement grooving	15	55W
3. Seal coat	19W	
C. Rumble strips	49DOR	
VIII. SAFETY BARRIERS		
A median barriers	38I &F	
B. Crash cushion	32F	33I
C. Guardrail		
1. Metal	55F	28I
2. Concrete	55F	28I
IX. SAFETY LIGHTING		
A. General	25	50N
B. Intersections	25	55N

C. Sections	25	50N
D. Rail road crossings	30	60N
E. Interchanges	25	30N
X. BREAKAWAY POLES & POSTS		
A. Breakaway signs	60F	30I
B. Breakaway utility poles	40F	30I
X1. RAILROAD CROSSINGS		
A. Flashing beacons	77T	
B. Automatic gates	87T	
C. Rail road. Pavement markings	10	
D. Rail road. Warning signals /flashing beacons	80	
X11. REMOVE/RELOCATE FIXED OBJECTS		
A. Remove fixed objects	20	50F 19I
B. Relocate fixed objects	0	40F 15I
XIII OTHER		
A. Fencing	90D	
B. Eliminate parking	30	
C. Prohibit turning movements	40	
D. Truck escape ramps	-	

Legend:

P: pedestrian crashes	Den: dry and night crashes	I: injury crashes	D: animal crashes
L: left turn crashes	W: wet pavements crashes	N: nighttime crashes	I+F: Injury and fatal crashes
Wn: Wet and Night crashes	F: fatal crashes	T: train crashes	DOR: Drift-off-road crashes

State: Iowa
Source: Iowa Department of Transportation

Improvement	Reduction Factor %
INTERSECTIONS	
Add signals	20
Upgrade signals	15
Channelize/add turning lanes	25
Improve sight distance	35
Upgrade signs / Markings	36
New Signs Markings (None previously)	83
Illuminate	20
Add acceleration/deceleration lane	25
Rumble strips (applies only to crashes involving stop)	Angle crashes: 44; Pedestrian crashes: 44
Reconstruct approach angle	35
Add beacons	25
CURVES	
Vertical realignment	57
Horizontal realignment	38
Horizontal / vertical realignment correct superelevation	73
Pavement markings / delineate	15
BRIDGES	
Widen	48
Guardrail	24
Impact attenuator	35
Replace	50
Eliminate	75
CULVERTS	
Lengthen	48
Guardrail or grate	24
Remove headwall and delineate (outside shoulder line)	35
RAILROAD CROSSINGS	
Add signals	50
Upgrade warning devices	27
Illuminate	62
Replace with grade separation	39
Eliminate	75
HIGH FILLS	
Guardrail	16
Delineate	10
Flatten foreslopes	25
Add lanes	5
Widen shoulder	22
Widen pavement / shoulder	8
Flatten foreslopes	28
Widen Shoulder / Flatten foreslop	8
FRICTION IMPROVEMENT	
Overlay	27
P.C. grooving, diamond profiling, texturing	14
Signing	5
Edgeline markings	4
Horizontal realignment	25
Vertical realignment	30
Horizontal/vertical realignment/ correct superelevation	45
Roadway lighting	6
Relocate driveways	5
Flatten entrance slopes	5

State: Kentucky
Source: Kentucky Transportation Center

Improvement	Reduction Factor (%)
TRAFFIC SIGNS	
WARNING SIGNS	
Warning signs - general	25
Curve warning	
Run-off-road crashes	30
Intersection-related warning (side road, stop ahead, etc.)	30
Railroad crossing	
Train accidents	30
Pavement condition	
Surface condition-related crash	20
School zone	15
Regulatory signs	
Stop sign (two-way)	35
All-way stop	55
Yield	45
Guide signs	
Guide sign - general	15
Variable message sign	15
TRAFFIC SIGNALS	
Install signal	25
Angle crash	65
Signal upgrade -general	20
12-inch lens	10
Backplates	
Right angle crashes	20
Optically programmed signal lenses	15
Remove unwarranted signal	50
Signal phasing	
Signal phasing - general	25
Add exclusive left turn phase	25
Left turn crashes	70
Add protected/permissive left turn phase	10
Left turn crashes	40
Improve timing	10
Add pedestrian phase	25
Pedestrian crashes	55
Add All-Red interval/increase Yellow Time	15
Right-angle crashes	30
Interconnect traffic signals	15
Flashing beacon	
Flashing beacon - general	30
Install flashing beacon at intersection	30
Intersection advance warning flasher	25
General advance warning flasher	35
Railroad crossings	
Railroad crossings - general	
Train crashes	70
Flashing lights	
Train crashes	65

Flashing lights and automatic gates	
Train crashes	75
Automatic gates	
Train crashes	75
ROADWAY DELINEATION/PAVEMENT MARKINGS	
General	15
Edgeline markings	15
Run off road	30
Centerline markings	35
Wide markings	
Night crashes	25
No passing zone	
Passing crashes	40
Crosswalk	
Pedestrian crashes	25
Raised pavement markers	10
Night crashes	20
Wet night	25
Post delineators	
Night accidents	30
Railroad	
Train accidents	15
LIGHTING	
General	25
Night crashes	50
Roadway segment	25
Night crashes	45
Intersection	30
Night crashes	50
Interchange	25
Night crashes	50
Railroad crossing	30
Train crashes at night	60
CHANNELIZATION	
General intersection	25
Left Turn Lane - with signal	25
Left turn related	45
Left Turn Lane - without signal	35
Left turn related	50
Right turn lane	25
Right turn related	50
Increase turn lane length	15
PAVEMENT TREATMENT	
General	25
Wet pavement	50
Resurfacing	25
Wet pavement	45
Pavement grooving	25
Wet pavement	60
Rumble strips	25
Shoulder grooving	25
ROADSIDE IMPROVEMENT (APPURTENANCES/CLEAR ZONE)	
Install guardrail	5

Fatal crashes	65
Injury crashes	40
Install median barrier	5
Fatal crashes	65
Injury crashes	40
General guardrail upgrade	5
Fatal crashes	50
Injury crashes	35
Impact attenuator	5
Fatal crashes	75
Injury crashes	50
Remove fixed objects	30
Fatal crashes	50
Injury crashes	30
Relocate fixed objects	25
Fatal crashes	40
Injury crashes	25
Flatten side slopes	30
Convert hardware to breakaway	5
Fatal crashes	60
Injury crashes	30
Upgrade bridge railing	5
Fatal crashes	60
Injury crashes	30
Gore improvements	25
CONSTRUCTION/RECONSTRUCTION	
Realignment	
Horizontal realignment/curve reconstruction	40
Vertical realignment	40
Modify horizontal and vertical realignment	50
Realign intersection	40
Modify superelevation	40
Sight distance improvement	30
Pavement widening	
Widen pavement	25
Widen shoulder	20
4 feet or less	20
Over 4 feet	35
Shoulder stabilization/shoulder drop-off	25
Pave shoulder	15
Additional lanes	
Add passing/climbing lane	20
Add acceleration/deceleration lane	10
Add left turn lane	25
Left-turn related crashes	50
Add right-turn lane	25
Right-turn related crashes	50
Add two way left turn lane	30
Median	
Add mountable median	15
Add Non-mountable median	25
Bridge	
Widen bridge	45

Replace bridge	45
Bridge deck repair	15
Intersection	
Increase turning radii	15
Sight distance improvements	30
Freeway	
Construct interchange	55
Modify entrance/exit ramp	25
Frontage road	40
Glare screen	
Night crashes	15
Pedestrian crashes	
Construct pedestrian grade separation	
Pedestrian crashes	90
Add sidewalk	
Pedestrian crashes	65
Other	
Drainage improvements	20
Wet pavement	40
Install animal fencing	
Animal related	90
REGULATIONS	
Eliminate parking	
Parking related	35
Prohibit turns	
Turning crashes	45
Modify speed limits	20
Two-way to one-way operation	30

State: Minnesota
Source: Minnesota Department of Transportation

Improvement	Reduction Factors (%)							
	RE	**SS**	**LT**	**RA**	**ROR**	**HO/ SS**	**Ped**	**Other**
Over head flasher	-47 +21	+100 0	+250 +150	-25 +14	-44 -44	-100 -29	+100 0	-100 -14
Temporal signal	+63 +66	-50 +400	+13 -11	-39 -73	+200 +100	0 -83	+700 0	-75 +88
New signal no channel	+33 -17	0 +150	+433 +270	+67 +35	+67 -56	0 +3	-50 0	-100 -50
New signal + channel	+1 -17	+60 +10	-42 -7	-55 -61	-28 -2	-63 -48	0 -38	-20 -32
New signal with channelization implementation	+121 +32	-54 0	+23 -24	-67 -63	-35 +1	+20 -27	+43 -100	+117 -61
Advance warning flashers	+82 -16	-33 -83	-67 -79	-73 -62	-40 -54	-67 0	+100 0	+100 -71
Signal revision	-14 -25	-59 -35	-53 -35	-33 -33	+2 +75	-15 -58	-10 0	+11 -36
Signal rebuilt	-22 -32	-50 -28	-27 -21	-29 -32	-37 -52	-47 -61	+32 -33	+16 -15
Signal phase change	+4 -17	+23 +10	-55 -63	-30 -46	-62 -28	-75 +33	-14 +200	-24 -55
Signal coordination	-15 -20	-51 -31	-24 -15	-21 -40	-32 -23	+26 -34	+68 +100	-15 -30
Rumble strips	-50 +24	-100 0	-33 -60	-54 -47	+100 -50	-75 -100	0 0	0 -100
Capacity	-33 -22	-25 -13	-37 -19	-32 -29	-9 -35	-31 +19	-71 0	0 -41
Double left-turn lane	-29 -32	-50 +89	-47 -71	-20 -8	-8 -13	-75 +33	-50 0	+25 -23
2 Way Left-turn lane	-32 -38	-32 -37	-17 -38	-31 -23	-90 -16	-67 -64	+100 0	-67 -11
T-intersection turn and bypass lane	-18 -21	0 -30	-36 -28	-24 -53	0 -40	+33 -13	+100 0	-100 -56
Internal turn and bypass lane	-14 -14	+33 -8	-35 -33	-16 -44	-25 -25	-13 0	+100 0	-100 -33
Channelization	-33 +8	+50 -28	+33 +6	+5 +21	+67 +8	-25 -50	-100 0	-82 -68
Add lanes	-53 -53	-35 -64	-71 -67	-15 -46	-26 -50	-97 -50	0 0	-74 -30
Mill and bit overlay	-6 -10	-25 -14	-11 -6	-16 -22	+9 +3	-12 -16	+48 -100	-13 -17
Skid correction	-12 -21	-12 -27	-41 -34	-11 -31	-28 -29	-19 -30	-3 0	-11 -50
Maintenance and Bit Overlay	-21 +15	+18 -29	-37 -13	-16 -23	-19 -30	-31 +18	-33 -42	-24 +45
Mill concrete surface	-1 +10	-57 0	-57 -57	-42 -52	-41 +54	-38 +100	+22 0	-46 +10
Sight distance correction	+300 +400	0 +100	0 +100	+17 -70	-100 -100	-100 0	0 0	0 -100

Shoulder bus lanes	+23 -3	-27 -8	-42 -57	-34 -31	+17 -27	-50 -86	+78 0	+146 +58
Detached left-turn lane	-11 -56	0 0	-50 +50	-58 -54	0 -50	-100 -100	0 0	+200 0

Legend:

Top Factor = Fatal and personal injury
Bottom Factor = Property damage only
(Before crashes adjusted for growth in ADT)

RE: Rear-end
SS: Sideswipe
LF: Left turn
RA: Right angle

ROR: Ran off road
HO/SS: Head on/Sideswipe opposite direction
Ped: Pedestrian

State: Missouri
Source: Missouri Department of Transportation

Improvement	Reduction Factor (%)														
	All	**F/I**	**PDO**	**HO**	**RE**	**RA**	**SS**	**LT**	**RT**	**FO**	**Ped**	**ROR**	**WP**	**N**	**T**
CHANNELIZATION															
Channelization intersection	25							45							
Provide left-turn lane (with signal)	25							50							
With no left-turn phase	15														
Existing left-turn phase	35														
Provide left-turn lane (without signal)	35														
Painted lane	32				75										
Protected lane with curb or raised bars	67		62		93										
Provide right-turn lane	25								50						
Increase turn lane length	15														
Install two-way left-turn lane in median	35	20	35		36			33				37			
Two-lane to three-lane	32	59			46		46	46							
Four-lane to five-lane	28	42			40		40	40							
Add mountable median	15														
Add non mountable median	25														
CONSTRUCTION/ RECONSTRUCTION															
REALIGNMENT															
Construct a more gradual horizontal curve	40														
From 20 to 10 degrees	48														
From 15 to 5 degrees	63														
From 10 to 5 degrees	45														
Improve vertical curve	40														
Improve horizontal and vertical curve	50														
Improve sight distance it intersection	40														
SEPARATING DEVICES															
Close median opening				100	50	100	50	100							
Install median barrier	5	F: 65 I: 40										35			
Install a 1 to 12 ft. Median		F: 75 I: 2	-28*												
Install a 13 to 30 ft Median		F: 85 I: 5	-30*												
Install concrete median barrier		F: 90 I: 10	-10*												
Install/improve curbing										50					
Replace active warning															
Devices with bridge or tunnel	95		88												
PAVEMENT WIDENING															
Widen pavement	25														
Widen shoulder (paved)															

Widen shoulder (paved) Widen 2 ft										16		16			
Widen 4 ft										29		29			
Widen 6 ft										40		40			
Widen 8 ft										49		49			
Widen shoulder (unpaved)															
Widen 2 ft										13		13			
Widen 4 ft										25		25			
Widen 6 ft										34		34			
Widen 8 ft										43		43			
Pave shoulder	15														
Stabilize shoulder	25														
Widen lane															
Add 1 ft to both sides				12			12					12			
Add 2 ft to both sides				23			23					23			
Add 3 ft to both sides				32			32					32			
Add 4 ft to both sides				40			40					40			
ADDITIONAL LANES															
Add passing/climbing lane	25	30													
Add acceleration /deceleration Lane	10														
Add lanes	25	F: 39 I: 23	27	53	32		30					44			
BRIDGES															
Widen bridge (general)	45														
From 18 to 24 ft	68														
From 20 to 24 ft	56														
From 22 to 24 ft.	36														
From 18 to 30 ft.	93														
From 20 to 30 ft.	90														
From 22 to 30 ft.	86														
Replace two-lane bridge	45														
Repair bridge deck	15														
INTERSECTION															
Increase turning radii	15														
Improve sight distance	30			10		21	10	13			10				
PEDESTRIAN															
Construct pedestrian bridge or tunnel	5										90				
Install sidewalk											65				
DRAINAGE															
Provide adequate drainage	20												40		
Provide proper superelevation	40														
FREEWAY															
Construct interchange	55														
Modify entrance /exit ramp	25														
Construct frontage road	40														
Install glare screen														15	
GUARDRAIL															
Install guardrail	5	F: 65 I: 40										30			
Upgrade guardrail	5	F: 50 I: 35										26			

Install at bridge		F: 90 I: 45	-110*												
Install along ditch		26	-19*												
Install along embankment		42	-47*												
Install to shield trees		F: 65 I: 51	-90*												
Install to shield fixed objects as rocks and steel posts		31	-45*												
TRAFFIC SIGNS															
WARNING SIGNS															
Install warning signs	25														
Install warning signs in advance of intersections															
Urban	30														
Rural	40														
Install warning signs in advance of curves	30	F: 55 I: 20		29								30			
Add signs at railroad crossings															30
Install school zone signs	15														
Install pavement condition signs													20		
REGULATORY SIGNS															
Install stop sign (2-way)	35														
Change to all-way stop sign from two-way stop sign	55				13	72		20			39				
Install yield sign	45														
Install lane use signs	30				10		20								
GUIDE SIGNS															
Install guide signs	15														
Install variable message sign	15														
TRAFFIC SIGNALS															
Install signal (general)	25					65									
- From two-way stop	28	43			-46*	74		-92*							
- From two-way stop and add left-turn lane	36	53			8	74		-43*							
SIGNAL UPGRADE															
Upgrade signal	20														
Install 12-inch lenses	10														
Install visors or back-plates						20									
Install optically programmed signal lenses	15			20	10	10		10							
Upgrade pedestal mounted to mast arm: pre-timed signal															
No left-turn lane	51	52			24	69		28							
Existing left-turn lane	44	25			35	74		2							
Left-turn lane added	84	87			72	83		87							
SIGNAL PHASING															
Improve signal phasing	25														
Add exclusive left-turn phase	25							70							
Add protected/permissive Left-turn phase	10							40							
Improve timing	10														
Install/improve pedestrian signal	25										55				

Improve yellow change interval	15					30									
Add all-red interval	15					30									
Interconnect signals	15	29			20	10		38	36		10				
Install traffic actuated signal						10	20	80							
REMOVAL															
Remove unwarranted signal	50				90	-30*		-10*			-10*				
FLASHING BEACON															
Install flashing beacon	30														
Install flashing beacon at intersection	30														
Install intersection advance warning flashers	25														
Install general advance warning flashers	35														
ROAD CROSSINGS															
General railroad crossings															70
Add flashing lights at railroad crossings															65
Add automatic gates at railroad crossings															75
Add automatic gates and flashing lights															75
ILLUMINATION															
Improve street lighting	25													50	
Install/improve lighting at roadway segment	25													45	
Install/improve lighting at intersections	30													50	
Install/improve lighting at interchanges	25													50	
Install1improve lighting at railroad crossings	30													60	60
PAVEMENT TREATMENT															
De-slick pavement	13			10	40	10	10			10	10	10	65		
Groove pavement	25												60		
Resurface curve with skid-resistant overlay				86									51		
Resurface (general)	25												45		
Install rumble strips	25														
Groove shoulder	25	18	17									27			
Make surface improvements at railroad crossings	34		39												
PAVEMENT MARKINGS															
Add pavement markings	13														
Add pavement markings at railroad crossings	48	42	51		58										15
Add reflectorized raised pavement markings	10			20			20			10		10	25	20	
Add "no passing" striping				40			40								
Add centerline markings	35														
Add edgeline markings	15	15	8									30			
Add/improve pedestrian crosswalk											25				

Add wider markings														25	
REGULATIONS															
Prohibit on-street parking	35				10	10	30			40	30				
Change angle parking to parallel	59														
Set appropriate speed limit	20		35												
Prohibit left-turns	45				30			90			10				
Change two-way roadway to one-way roadway Intersection crashes Mid-block crashes	 26 43											 46 50			
Prohibit right-turn-on-red at signalized intersections					20	30	20					30			
ROADSIDE IMPROVEMENT															
Remove fixed objects	30	F: 50 I: 30													
Relocate fixed objects	25	F: 40 I: 25													
Improve gore area	25														
Modify poles /post with breakaway features	5	F: 60 I: 30													
Install impact attenuators	5	F: 75 I: 50													
Relocate utility poles to increase offset from road															
From 2 to 6 ft									50						
From 3 to 8 ft									46						
From 5 to 10 ft									36						
Flatten side-slope															
From 2:1 to 4:1	6								10		10				
From 2:1 to 5:1	9								15		15				
From 2:1 to 6:1	12								21		21				
From 3:1 to 4:1	5								8		8				
From 3:1 to 5:1	8								14		14				
From 3:1 to 6:1	11								19		19				
From 4:1 to 6:1	7								12		12				
From 5:1 to 7:1	8								14		14				
Install animal fencing	90*	91	61												
Eliminate poles by burying utility lines	40														
Install object markers	16	F: 41 I: 17	14								29				
Increase roadside clear zone Recovery distance															
Add 5 ft										13		13			
Add 8 ft										21		21			
Add 10 ft										25		25			
Add 15 ft										35		35			
Add 20 ft										44		44			
DELINEATION															
Install post-mounted delineators on horizontal curve	25														
Install chevron alignment sign on horizontal curve	35														

Install delineation at bridges	40														

Legend:

F/I: Fatal or injury	RA: Right angle	Ped: pedestrian	T: Train related
PDO: Property damage only	SS: Sideswipe	ROR: Run off road	
HO: Head-on	LT: Left turn	WP: Wet pavement	
RE: Rear-end	FO: Fixed object	N: Night	

* A crash reduction factor by a (-) sign indicates an increase should be expected for that type of crashes.

State: Montana
Source: Montana Department of Transportation

Improvement	Reduction Factor (%)
DELINEATION	
Delineation post mounted	25
Delineation horizontal curve	30
Delineation bridge ends	39
Delineation tangent section	22
SIGNING	
School Signs (signing and/or striping)	20
Curve warning arrow	23
Curve with speed plate	29
4-way stop/stop sign	53
Advisory speed plate	36
Stop ahead / rural intersection sign	
Chevron signing	50
GUARDRAIL (percent reduction for fatalities and injuries only)	
Road edge	23
At bridge ends	44
Median barrier	31
Inside curves	28
Outside Curves	63
Concrete barrier rail (inside/outside curve)	39
Convert median barrier (W-beam to barrier)	40
Modernize bridge rail and approach rail	15
Improve guardrail to standard	7
Install impact attenuation system	50
CHANNELIZATION	
Left turn channelization (non signalized intersection with painted channelization in rural area)	25
Continuous left turn lane	34
Lanes added without new median	20
Install raised median	25
Add acceleration/deceleration lanes	10
Add through lane	28
Lengthen left turn lane	40
Add right turn lane	25
Lengthen right turn lane	40
TRAFFIC SIGNALS	
4-legged intersection (without channelization)	23
New traffic signal and left turn channelization.	28
Left turn phase on signal	30
Modernize traffic signal	22
Install pedestrian signal	15
Remove signal support (from median)	10
FLASHING BEACON	
Flashing beacon at intersection (4-leg red-yellow)	34
Flashing beacon at intersection (3-leg red-yellow)	39
Flashing beacon at intersection (4-way red)	70
Advance warning at curves and intersection using flashing beacon	27
Overheight warning system	65
STRIPING	

Striping edge lines	19
22 ft pavement	37
New center and edge lines	8
No-passing zone	53
Install pavement markings (center line, shoulder, etc)	20
Install pedestrian crosswalk	25
Install center line stripe	65
RECONSTRUCTION	
Sight distance improvement	30
Horizontal realignment	34
Horizontal and vertical realignment	36
Super-elevation correction	49
Reconstruction (combinations and miscellaneous)	26
Curve reconstruction	50
Construct pedestrian overpass/underpass	95
Increase turning radius	10
STRUCTURE IMPROVEMENTS	
Replacement of bridge or other major structure	28
Widening bridge	47
LIGHTING	
New safety lighting at intersection (night crash only)	64
Breakaway sips or light supports	14
SKID TREATMEENT	
Skid treatment / overlay (all crashes)	24
FENCING	
Fencing (domestic animals)	70
Snow fence	35
WEDENING AND SLOPE FLATTENING	
Pavement widening Widen paved shoulder Construct paved shoulder (where no shoulder exists)	32
Dark crashes	62
Head-on crashes	86
Flatten side slopes	32
RUMBLE STRIPS	
Rumble strips at shoulder	18
Transverse rumble strip at stop controlled approach	28
SAFETY TREATMENT IN CLEAR ZONE	
Remove tree	30
Remove, relocate or safety treatment of objects in clear zone	55
Safety treatment of crossroad and/or parallel drainage structure	60
Extend drainage structure to clear zone	30
Widen travel way, widen shoulder, construct shoulder, flatten slopes and treat roadside obstacles	15

State: New York
Source: Traffic Engineering and Safety Division, Safety Program Management Bureau

TABLE 1A
AADT > 5000/ LANE

Description	**Reduction Factor (%)**	**Remarks**
INTERSECTION IMPROVEMENTS		
CHANNELIZATION	37	Right angle 58%, rear-end/overturn30 %, right turn 51 %
Add Left turn lane with physical separation	26	Head on /sideswipe 79%@
Add Left turn lane with painted separation	45	Reduces right angle crash by 63 %, rear-end/ overturn 39 %, left turn 35 % @
Add right turn lane with physical separation	*	
Addition of pavement markings to reduce size of intersection	*	
Other channelization	24	Right angle 47 %, rear-end/overturn 33 % @
TRAFFIC SIGNALS/ DEVICES	19	Right angle 34 %, rear-end/overturn 26 %, left turn 18 %, head on/sideswipe 36 %
Other signal improvements	15@	Reduces right angle crash. 22%@, rear-end/overturn 25 %
Install 4-way stop signs	73*	Reduction factor from reference 2
Install stop ahead signs	15+	
Install minor –leg stop control	1*	
Install yield signs	23+	
Install new flashing red/yellow signal	26@	Reduces right angle crash. 36%@
Change in operation to a flashing red/ yellow signal	*	
Installing of a new red/ yellow /green signal	20	Reduces right angle crash by 43%, rear-end/overturn 20%@
Upgrading of a red/yellow/green signal (Includes larger lenses, more /better placed heads, phase adjustment, and general signal upgrades.)	19	Reduces right angle crash by 37 % rear-end/overturn 26 %, left turn 26 %@, head on /sideswipe 52%
Add Left turn protection (change # of phases)	36	Reduces right-angle crash. 56%, rear-end/overturn 35 %, left turn 46 %.
Add pedestrian signals	13*	Reduction factor from reference 5.
Change in signal operation, from pretimed to traffic actuated	28	Reduces right-angle crash. 32 %, rear-end/sideswipe 26 %, head on/sideswipe 60 % @, left turn 30 %
COMBINATION OF CHANNELIZATION (10) AND SIGNALS/ DEVICES (11)	8	Right angle 30 %, rear-end/overturn 26 % @
Add left turn lane w/signal (physical)	19	Reduces right-angle crash 55%@, rear-end/overturn 28 %, left turn 24%@
Add left turn lane w/signal (painted)	16@	Reduces right-angle crash49%@
Add right turn lane w/signal	*	

Add left and right turning lane w/signal	14	Reduces right-angle crash42% and rear-end/sideswipe 38%@
INTERSECTION SIGHT DISTANCE IMPROVEMENT	31*	Reduction factor from reference 4
OTHER INTERSECTION WORK	*	
Prohibit parking	32*	Reduction factor from reference 5
Prohibit turns	40*	Reduction factor from reference 5
CROSS-SECTIONAL IMPROVEMENTS		
PAVEMENT WIDENING, NO LANE ADDED	59	Reduces left turn crashes 69%@
Widen travel way from 9 feet	*	
Widen travel way from 10 feet	59	Reduces left turn crash by 69%@
LANES ADDED, WITHOUT NEW MEDIAN	31	Reduces right angle crash 45%, rear-end/overturn crash 52%, head on/sideswipe 44%
Add additional lanes same alignment	31	Reduces rear-end/overturn crash 52%, head on/sideswipe 44%, right angle 45% Increases right turn crash 79%@
Add climbing lane	*	
HIGHWAY DIVIDED, NEW FLUSH MEDIAN ADDED	44	Reduces rear-end/overturn crash 41%, left turn crash 78%, head on/sideswipe 57%
Flush median added	52	Reduces left turn crash 78%
Flush median added w/refuge for Left turns	44	Reduces rear-end/overturn crash 40%, left turn 77%, head-on/sideswipe 52%@ Increases right turn crash 95%@
Widen flush median	*	
SHOULDER WIDENING OR IMPROVE MENT	*	
Shoulder stabilization	*	
Widen existing shoulder	17*	Reduction factor from reference 6, for 2-lane roads only
ADD ADDITIONAL LANES W/MEDIAN, SAME ALIGMENT	20*	Reduction factor from reference 1, general reconstruction
SKID TREATMET W/GROOVING	22@	Rear-end/ over turn 35 %, wet road reduce 54 %, ran off road 40%, fixed object 19%
Longitudinal grooving	21@	Reduce wet road crash 54%, ran off road 40%, rear-end/overturn 35 %, fixed object 19%
Transverse grooving	*	
SKID TREATMENT W/OVERLAY	20	Open-graded mix most effective. Right angle 23%@, fixed object 34% Reduces wet-road crash 50%, head-on/sideswipe 61%
Resurfacing w/skid resistant pavement	13	Reduces wet-road crash 42%, right-angle 23%
Resurfacing and superelevation	28@	Reduces wet-road crash 51%

Resurfacing w/open-grad mix	75@	Reduces wet-road crash 91%@, coll. w/fixed object 93%@, head-on/sideswipe 90%@
Resurfacing w/Verglimit	31@	Reduces icy-road crash 52%@
SIDE SLOPES	45@	Reduces coll. w/fixed object 62%
Flattering of side slopes	45@	Reduces coll. w/fixed object 62%
Flattering or clearing of side slopes	*	Refer to improvement code 271
IMPROVEMENTS AND/OR REPLACEMENT OF STRUCTURES		
WIDENING EXISTING BRIDGE OR OTHER MAJOR STRUCTURE	65*	Reduction factor from reference 4. Applicable to only collision with bridge structure crashes
REPLACEMENT OF BRIDGE OR OTHER MAJOR STRUCTURE	25*	Reduction factor from reference 7
CONTRUCTION OF NEW BRIDGE OR MAJOR STRUCTURE	19*	Reduction factor from reference 3
COSTRUCTION OR IMPROVEMENT OF MINOR STRUCTURE	*	
CONSTRUCTION OF PEDESTRIAN OVER OR UNDER CROSSING	*	
OTHER STRUCTURE WORK	*	
ALIGMENT WORK		
HORIZONTAL ALIGMENT CHANGES	41	Reduces fixed object crash 87%, ran off road 79%, head-on 64%, rear-end/overturn 24%
VERTICAL ALIGMENT CHANGES	*	
COMBINATION OF 40 AND 41	20*	Reduction factor from reference 1
	21*	Reduction factor from reference 4
SUPERELEVATION AND RESURFACING	See Code 262	
ROADSIDE APPURTENANCES		
TRAFFIC SIGNS	14@	Reduces rear-end/overturn crashes 18%, right turn 59%
Installation or upgrading of traffic signs	13@	Left turn 34%@
Replacement of standard w/large stop signs	19+	
Install/improve warning signs	*	
Install/improve curve warning signs	*	
Install/improve advance curve warning flashers	54*	Reduces night crashes 62%
Install/improve other signs (Arrow signs)	34+	Reduction factors from reference 2
Protection/removal of fixed object	17@	Rear-end/overturn 44%
Make breakaway or install breakaway signs and/or light supports	32*	Rear-end/overturn 70%@
Install clearance and/or hazard markers	*	
INSTALACION/IMPROVEMENT OF ROAD EDGE GUIDERAIL	13@	Rear-end/overturn 28%@, fixed object 14%@

Replacement or upgrading of deficient guiderail	9@	Reduces collision with guiderail 31%@, coll. w/fixed object 18%@, ran off road 32%@, rear-end/over turn 27%@
Protection or removal of fixed object in gore	*	Refer to improvement codes 605 & 702
Installing or upgrading of culvert and bridge railing	20@	Reduce collision w/bridge or culvert 38%@, rear-end/over turn 32%@
Install road edge guiderail at new location	10*@	Reduce collision with fixed object 4%*@, collision with guiderail. 51%@, ran off road 18%*@, rear-end/overturn 34%@
Removal of guiderail (w/o other improvements)	-19@	Increase coll. w/ditch/cut/bank 360%@
<u>INSTALATION OF IMPROVEMENT OF MEDIAN BARRIER</u>	20@	Right angle 53%@, rear-end/overturn 32%@, left turn 44%@, ran off road 42%@
Replace deficient median barrier	*	
Install median barrier	19@	Reduces right angle crash 54%
Install/improve median barrier near gore area	17@	Reduces ran off road crash 56%@; increases collision with guiderail 57%@, rear-end /over turn 39%@
PAVEMENT MARKINGS AND/OR DELINEATORS	9@	13%- reduction noted in reference 4
Install raised snowplowable pavement markers	*	
Centerline striping	5*	Reduction factor from reference 1
No-Passing striping	66*	Reduction factor from reference 2
Road edge restriping	38	Reduces collision with fixed object crashes 59%@, rear-end/overturn 50%
Delineation of shoulders	9*	Delineation group factor. Also see code 645
Delineation of curves	30*	For curves of radius <500 ft. reduction factor from reference 2
Thermoplastic pavement markings	35	Reduces coll. w/fixed object 80%
Thermostatic pavement markings, spot locations	22*	NYS DOT PIES
OTHER ROADSIDE APPURTENANCES		
ROADWAY LIGHTING INSTALATION	9*	Reduction factor from reference 4
Spot locations only	36@	Reduction factor from reference 2. Reduces nighttime crashes 67%@
IMPROVE DRAINAGE AND/OR DRANAIGE STRUCTURES	32@	
INSTALL FENCING	*	
INSTALL IMPACT ATTENUATORS	4*	NYS DOT PIES
INSTALL SHOULDER RUMBLE STRIPS	*	
<u>IMPROVEMENTS AT GORE</u>	31	Right angle 60%, rear-end/overturn 44%, head on/sideswipe 43%, ran off road 52%
Protection of fixed objects / improvements of positive guidance in gore area	35	Reduces rear-end/sideswipe crash. 45% ran off road 46%@, collision w/fixed object 18%@, head-on/sideswipe 36%, right-angle 62%, ran off road

		51%
Thermoplastic striping & delineation in gore area	94	Reduces rear-end/sideswipe crash 64%
Removal or protection of fixed objects in gores	7*@	Reduces rear-end/sideswipe crash. 32%, ran off road 74%@

Unless otherwise noted, crash reductions reflect crash trends at SELECTED locations improved by categorical safety funded projects. When reduction factors for low Cost Accident Counter Measures (LCAC) or reduction factors from other sources were tabulated a + appears with the reduction factor or a note appears in the remarks column.

Non-reportable crashes were not used to calculate the safety project reduction factors tabulated.
Reduction factors should only be used to ESTIMATE safety benefits for respective improvements.

* Insufficient number of locations for factor calculation or no statistically significant change in crash rate. If a factor is present the source for the factor is shown in remarks. @= State Wide Average
+ Reduction Factors updated using 1992 Low Cost Crash Counter Measure Evaluations.

State: New York
Source: Traffic Engineering and Safety Division, Safety Program Management Bureau

TABLE 1B
AADT < 5000/ LANE

Description	Reduction Factor (%)	Remarks
INTERSECTION IMPROVEMENTS		
CHANNELIZATION	35@	Right angle 48%, rear-end/overturn 30%, left turn 49%
Add Left turn lane w/physical separation	*	Head on /sideswipe 79%@
Add Left turn lane w/painted separation	50	Reduces right angle crash by 62%, rear-end/ overturn 54%, left turn 57% @
Add right turn lane w/physical separation	*	
Addition of pavement markings to reduce size of intersection	*	
Other channelization	36	Right angle 45%@, rear-end/overturn 76% @
TRAFFIC SIGNALS/ DEVICES	34	Right angle 50%, rear-end/ overturn 39%, left turn 26%, head on/sideswipe 23%, right turn 34%
Other signal improvements	23	Reduces right angle crash 30%, rear-end/overturn 39%, left turn 22%, right turn 53%
Install 4-way stop signs	73*	Reduction factor from reference 2
Install stop ahead signs	15+	
Install minor –leg stop control	1*	
Install yield signs	23+	
Install new flashing red/yellow signal	25	Reduces right angle crash 35%@
Change in operation to a flashing red/ yellow signal	*	
Installing of a new red/ yellow /green signal	38	Reduces right angle crash by 74%, Rear-end/overturn 22%@
Upgrading of a red/yellow/green signal (Includes larger lenses, more /better placed heads, phase adjustment, and general signal upgrades)	37	Reduces right angle crash by 47% Rear-end/overturn 41%, left turn 38 %@, Head on /sideswipe 32%
Add Left turn protection (change # of phases)	30@	Reduces right angle crash 54%, Rear-end/overturn 27%@, left turn 41%@
Add pedestrian signals	13*	Reduction factor from reference 5
Change in signal operation, from pretimed to traffic actuated	39	Reduces right angle crash 41%, rear-end/sideswipe 53%, head on/sideswipe 81%
COMBINATION OF CHANNELIZATION (10) & SIGNALS/ DEVICES (11)	41	Right angle 66%, rear-end/overturn 49%
Add left turn lane w/signal (physical)	51	Reduces right angle crash 68%@, Rear-end/overturn 50%, left turn 24%@
Add left turn lane w/signal (painted)	30	Reduces right angle crash64%@

Add right turn lane w/signal	*	
Add left and right turning lane w/signal	41	Reduces right angle crash70% and Rear-end/sideswipe 64%
INTERSECTION SIGHT DISTANCE IMPROVEMENT	31*	Reduction factor from reference 4
OTHER INTERSECTION WORK	41	Reduces right angle crash 69%@
Prohibit parking	32*	Reduction factor from reference 5
Prohibit turns	40*	Reduction factor from reference 5
CROSS-SECTIONAL IMPROVEMENTS		
PAVEMENT WIDENING, NO LANE ADDED	37	Reduces left turn crashes 77%
Widen travel way from 9 feet	*	
Widen travel way from 10 feet	37	Reduces left turn crashes by 77%
LANES ADDED, WITHOUT NEW MEDIAN	20@	Reduces right angle crash 35%@, rear-end/overturn crash 42%@, head on/sideswipe 38%
Add additional lanes same alignment	20@	Reduces rear-end/overturn crash 42%@, head on/sideswipe 38%@, right angle 35%@ Increases right turn crash 79%@
Add climbing lane	*	
HIGHWAY DIVIDED, NEW FLUSH MEDIAN ADDED	24	Reduces rear-end/overturn crash 44%, left turn crash 59%@, head on/sideswipe 60%
Flush median added	44@	Reduces left turn crash 72%@
Flush median added w/refuge for Left turns	24	Reduces rear-end/overturn crash 44%, left turn 58%@, head-on/sideswipe 55% Increases right turn crash 95%@
SHOULDER WIDENING OR IMPROVE MENT	*	
Shoulder stabilization	*	
Widen existing shoulder	17*	Reduction factor from reference 6, for 2-lane roads only
ADD ADDITIONAL LANES W/MEDIAN, SAME ALIGMENT	20*	Reduction factor from reference 1, general reconstruction
SKID TREATMET W/GROOVING	37	Rear-end/ overturn 54 %, wet road reduce 64 %, ran off road 41%, fixed object 36%
Longitudinal grooving	37	Reduce wet road crash 64%, ran off road 41%, rear-end/overturn54 %, fixed object 36%
Transverse grooving	*	
SKID TREATMENT W/OVERLAY	13@	Open-graded mix most effective. Right angle 23%@, fixed object 43% reduces wet-road crash 23%, head-on/sideswipe 43%
Resurfacing w/skid resistant pavement	8@	Reduces wet-road crash 35%, right angle 31%
Resurfacing and superelevation	28@	Reduces wet-road crash 51%

Resurfacing w/open-grad mix	75@	Reduces wet-road crash 91%@, crash with fixed object 93%@, head-on/sideswipe 90%@
Resurfacing w/Verglimit	31@	Reduces icy-road crash 52%@
SIDE SLOPES	43	Reduces crash with fixed object 62%
Flattering of side slopes	43	Reduces crash with fixed object 62%
Flattering or clearing of side slopes	*	Refer to improvement code 271
IMPROVEMENTS AND/OR REPLACEMENT OF STRUCTURES		
WIDENING EXISTING BRIDGE OR OTHER MAJOR STRUCTURE	65*	Reduction factor from reference 4. Applicable to only collision with bridge structure crashes
REPLACEMENT OF BRIDGE OR OTHER MAJOR STRUCTURE	25*	Reduction factor from reference 7
CONTRUCTION OF NEW BRIDGE OR MAJOR STRUCTURE	19*	Reduction factor from reference 3
COSTRUCTION OR IMPROVEMENT OF MINOR STRUCTURE	*	
CONSTRUCTION OF PEDESTRIAN OVER OR UNDER CROSSING	*	
OTHER STRUCTURE WORK	*	
ALIGMENT WORK		
HORIZONTAL ALIGMENT CHANGES	59	Reduces fixed object crash 68%, ran off road 90%, head-on 67%, rear-end/overturn 73%
VERTICAL ALIGMENT CHANGES	*	
COMBINATION OF 40 AND 41	20*	Reduction factor from reference 1
	21*	Reduction factor from reference 4
SUPERELEVATION AND RESURFACING	See Code 262	
ROADSIDE APPURTENANCES		
<u>TRAFFIC SIGNS</u>	18	Reduces rear-end/overturn crashes 21%, right turn 34%, left turn 35%
Installation or upgrading of traffic signs	28	Left turn 34%, rear-end/overturn 33%, left turn 51%
Replacement of standard w/large stop signs	19+	
Install/improve warning signs	*	
Install/improve curve warning signs	*	
Install/improve advance curve warning flashers	54*	Reduces night crashes 62%
Install/improve other signs (Arrow signs)	34+	Reduction factors from reference 2
Protection/removal of fixed object	18	Rear-end/overturn 42%
Make breakaway or install breakaway signs and/or light supports	28	Rear-end/overturn 72%
Install clearance and/or hazard markers	*	

INSTALACION/IMPROVEMENT OF ROAD EDGE GUIDERAIL	16	Rear-end/overturn 36%, fixed object 16%, right angle 17%
Replacement or upgrading of deficient guiderail	18	Reduces collision with guiderail 40%, collision with fixed object 23%@, ran off road 42%@, rear-end/overturn 41%
Protection or removal of fixed object in gore	*	Refer to improvement codes 605 and 702
Installing or upgrading of culvert and bridge railing	22	Reduces collision with bridge or culvert 37%, rear-end/overturn 41%
Install road edge guiderail at new location	10*@	Reduces collision with fixed object 4%*@, increases collision with guiderail. 67%@, ran off road 18%*@, rear-end/overturn 34%@
Removal of guiderail (w/o other improvements)	-19@	Increase collision with ditch/cut/bank 411%
INSTALATION OF IMPROVEMENT OF MEDIAN BARRIER	56	Right angle 30%, rear-end/overturn 32%@, left turn 44%@, ran off road 42%@
Replace deficient median barrier	*	
Install median barrier	19@	Reduces right angle crash 58%@
Install/improve median barrier near gore area	17@	Reduces ran off road crash 56%@; increases collision with guiderail 57%@, rear-end /overturn 39%@
PAVEMENT MARKINGS AND/OR DELINEATORS	17	13% - reduction noted in reference 4
Install raised snowplowable pavement markers	*	
Centerline striping	5*	Reduction factor from reference 1
No-Passing striping	66*	Reduction factor from reference 2
Road edge restriping	44	Reduces collision with fixed object crash 66%, rear-end/overturn 45%
Delineation of shoulders	9*	Delineation group factor also see code 645
Delineation of curves	30	For curves of radius <500 ft. reduction factor from reference 2
Thermoplastic pavement markings	14@	Reduces collision with fixed object 56%
Thermostatic pavement markings, spot locations	22*	NYS dot pies
OTHER ROADSIDE APPURTENANCES		
ROADWAY LIGHTING INSTALATION	9*	Reduction factor from reference 4
Spot locations only	36@	Reduction factor from reference 2. Reduces nighttime crashes 67%@
IMPROVE DRAINAGE AND/OR DRANAIGE STRUCTURES	32@	
INSTALL FENCING	*	
INSTALL IMPACT ATTENUATORS	4*	NYS DOT PIES
INSTALL SHOULDER RUMBLE STRIPS	*	
IMPROVEMENTS AT GORE	23	Right angle 51%, rear-end/overturn 50%, head on/sideswipe 34%, ran off road 56%

Protection of fixed objects / improvements of positive guidance in gore area	27	Reduces rear-end/sideswipe crash 53% ran off road 46%@, collision with fixed object 18%@, head-on/sideswipe 51%@, right angle 54%@, ran off road 46%
Thermoplastic striping & delineation in gore area	38	Reduces rear-end/sideswipe acc 51%
Removal or protection of fixed objects in gores	7*@	Reduces rear-end/sideswipe crash 42%, run of road 84%@

Unless otherwise noted, crash reductions reflect crash trends at SELECTED locations improved by categorical safety funded projects. When reduction factors for Low Cost Accident Counter Measures (LCAC) or reduction factors from other sources were tabulated a + appears with the reduction factor or a note appears in the remarks column.

Non-reportable crashes were not used to calculate the safety project reduction factors tabulated.
Reduction factors should only be used to ESTIMATE safety benefits for respective improvements.

* Insufficient number of locations for factor calculation or no statistically significant change in crash rate. If a factor is present the source for the factor is shown in remarks. @= State Wide Average
+ Reduction Factors updated using 1992 Low Cost Accident Counter Measure Evaluations.

State: Oklahoma
Source: Oklahoma Department of Transportation

Improvement	Reduction Factor (%)
Bridge rail upgrade**	20
Bridge rail upgrade (injury crash)***	30
Bridge rail upgrade (fatal crash)***	60
Channelization-increase turn lane length	15
Channelization-left turn lane with signal (left turn crash)***	45
Channelization-left turn lane with signal	30
Channelization-left turn lane without signal	40
Channelization-left turn lane without signal (left turn crash)***	55
Channelization-right turn lane	25
Channelization-right turn lane (right turn crash)***	50
Lighting-general (night crash)***	50
Lighting-interchange (night crash)***	50
Lighting-intersection (night crash)***	50
Lighting-rail road crossing (night crash)***	60
Lighting-segment (night crash)***	45
Marking/delineation-centerline (all)	30
Marking/delineation-edge marking (all)	15
Marking/delineation-general	15
Marking/delineation-No pass (passing crash)*	40
Marking/delineation-pedestrian crosswalk (pedestrian)***	25
Marking/delineation-post del (night)***	30
Marking/delineation-RPM (night)***	20
Marking/delineation-RPM (wet-night)***	25
Marking/delineation-RR with/Rpm (rail road crash)***	15
Marking/delineation-wide marking (night)***	25
Pavement resurfacing asphalt	25
Pavement shoulder grooving/strip	25
Roadside-new guardrail**	15
Roadside add sidewalk (pedestrian crashes)	65
Roadside attenuator **	20
Roadside median barrier	15
Roadside relocate fixed objects	25
Roadside remover fixed objects	25
Roadside upgrade guardrail	15
Roadside-flatten side slope	30
Roadside-lengthen culverts	40
Roadside-protect culvert ends	30
Roadway add glare screen (night crashes)***	15
Roadway add speed change lane	10
Roadway add two-way left-turn lane	25
Roadway improve intersection sight distance	25
Roadway improve sight distance	25
Roadway modify superelevation	40
Roadway-redesign/relocate driveways	50
Signal interconnect (underground costs)	15
Signal phasing add left (left turn crash)***	75
Signal phasing-general, add pedestrian phase (pedestrian crashes)***	50
Signal phasing-P/P left turn (left turn crashes)**	40
Signal remove unwarranted	75

Improvement	**Reduction Factor (%)**
Signal upgrade **	20
Signal upgrade –optical program **	15
Signal-flashing beacon-adv. Warn inter **	25
Signal-flashing beacon-curve	30
Signal-flashing beacon-general	25
Signal-flashing beacon-general warning	35
Signal-flashing beacon-intersection **	30
Signals-new (all crashes)***	20
Signals-new (angle crashes)***	65
Signs-changeable message	15
Signs-general	20
Signs-school zone (flashing beacon)	15
Bridge parapet	5
Signal interconnect (above ground costs)	15

* CRF (crash reduction factor) for specific crashes types
*** Some crashes types excluded by program

State: Texas
Source: Texas Department of Transportation

Description	Definition	Reduction Factor (%)	Preventable Crash
SIGN AND SIGNALS			
Install warning/guide signs	Provide advance signing for unusual or unexpected roadway features where no signing existed previously	20	Vehicle movements/manner of collision = 20-22 or 30 or roadway related = 2 or 3
Install stop signs	Provide STOP signs where none existed previously	20	Intersection related = 1 or 2
Install advance warning signals	Provide flasher units, where none existed previously in advance of the identified problem area	To be defined	Will be determined from supplied diagram
Improve advance warning signals	Bring existing flasher units into conformance with current design standards. Refer to W.C. 106 for modernization of intersection flashing beacons	To be defined	Will be determined from supplied diagram
Install intersection flashing beacon	Provide a flashing beacon at an intersection where a beacon did not exit previously	50	Intersection related = 1or 2
Modernize intersection flashing beacon	Improve an existing flashing beacon, located at an intersection, to current located at an intersection, to current design standards. Refer to W.C. 104 for non-intersection flashing beacon	10	Intersection related = 1 or 2
Install traffic signal	Provide a traffic signal where none existed previously	28	Intersection related = 1 or 2 and vehicle movements/manner of collision = 10-39or first harmful event = 1 or 5
Improve traffic signals	Modernize existing intersection signals to current design standards. Refer to W.C. 106 for modernization of intersection flashing beacons	22	Intersection related =1 or 2 and vehicle movements/manner of collision = 10-39 or first harmful event = 1 or 5
Add left turn signal phase	Provide a left turn signal phase at an existing signalized intersection with existing left turn lanes. Affected intersection approaches must be specified	25	Vehicle movements/manner of collision = 34 or 36
Install pedestrian signal	Provide a pedestrian signal at an existing signalized location where no pedestrian phase exists, but pedestrian crosswalks are existing Refer to W.C. 403 for installation of pedestrian crosswalks.	15	First harmful event = 1
Interconnect signals	Provide a communication link between two or more adjacent signals in a corridor. Specify all signalized intersections to be included in the interconnection	10	All
Overheight warning system	Install electronic devices to detect Overheight loads	65	Object struck = 43
Install delineators	Install post mounted delineators to provide guidance	30	Roadway related 2 or 3 and light condition = 3 or 4

Install school zones	Place school zones to include signing and/or pavement markings where none existed previously. Refer to W.C. 403 for pedestrian crosswalk markings	20	All
Eliminate Parking with milepoints	Completely remove existing parking on one side of the roadway in the direction of the milepoints	32	First Harmful Event = 1 or4 or vehicle movements/manner of collision = 40-44 or vehicle movements/manner of collision = 10 and travel direction 1= 1or 5 and direction of travel 2 = 2, 3 or 4 or vehicle movements/manner of collision = 10 and direction of travel 1= 2, 3, or 4 and direction of travel 2= 1 or 5
Eliminate parking opposite milepoints	Completely remove existing parking on one side of the roadway in the direction opposite the milepoints	32	First harmful even = 1 or 4 or vehicle movements/manner of collision = 40-44 or vehicle movements/manner of collision = 10 and direction of travel 1 =1 or 5 and direction of travel 2 = 6, 7 or 8 or vehicle movements/manner of collision = 10 and direction of travel 1 = 6, 7 or 8 and (direction of travel 2 = 1 or 5
Eliminate parking	Complete remove existing parking on the roadway	32	First harmful event = 1 or4 or vehicle movements/manner of collision = 40-44 or 10
Replace flashing beacon with a traffic signal	Replace an existing flashing beacon at an intersection with a traffic signal	25	Intersection related = 1 or 2 and vehicle movements/manner of collision = 10-39 or first harmful event = 1 or 5
Install overhead guide signs	Install overhead advance signing for unusual or unexpected roadway features where no signing existed previously	20	Vehicle movement/manner of collision = 20-29
Convert 2-way STOP Signs to 4-way STOP Signs	Provide 4-way STOP signs where 2-way STOP signs existed previously	15	Intersection/intersection related = 1 or 2
Install Advanced Warning Signals intersection existing signal, flashing beacon or STOP Signs	Provide flasher units for in advance of an intersection where none previously existed	10	Intersection related = 1 or 2
Install advanced warning signals (curve)	Provide flasher units in advance of a curve where none previously existed	10	Roadway related = 2 or 3 or vehicle movement/manner of collision = 20-24 or 30
Install advanced warning signals and signs (intersection - existing signal, flashing beacon or STOP Signs)	Provide flasher units and signs in advance of an intersection where none previously existed	15	Intersection related = 1 or 2
Install advanced warning signals and signs curve	Provide flasher units and signs in advance of a curve where none previously existed	15	Roadway related = 2 or 3 or vehicle movement/manner of collision = 20-24 or 30

Install advanced warning signals and/or signs intersection - uncontrolled, no existing advance Warning	Provide flasher units and/or signs in advance of an uncontrolled intersection where none previously existed	20	Intersection related 1 = or 2
Install advanced warning signals (intersection - existing warning signs)	Provide flasher units in advance of an intersection where none previously existed. Advance warning signs already exist	10	Intersection related = 1 or 2
Install advanced warning signs (intersection-existing warning signals)	Provide signs in advance of an intersection where none previously existed. Advance warning signals existing warning already exist	5	Intersection related = 1 or 2
Install advanced warning signals (curve existing warning signs)	Provide flasher units in advance of a curve where none previously existed advance warning signs already exist	10	Roadway related = 2 or 3 or vehicle movement/manner of collision = 20-24 or 30)
Install advanced warning signs (curve - existing warning signals)	Provide signs in advance of a curve where none previously existed advance-warning signals already exist.	5	Roadway related = 2 or 3 or vehicle movement/manner of collision = 20-24 or 30
Improve pedestrian signals	Bring existing pedestrian signal units into conformance with current standards	0	First harmful event = 1
ROADSIDE OBSTACLES AND BARRIERS			
Install median barrier	Construct a metal or concrete median barrier where none existed previously.	65	Vehicle movements/manner of collision = 30 or point of impact = 04, 05 or 63 and object struck = 01, 03, 20-23, 29-30, 32-36, 39-40, 42, 56, 60, 62, or 63
Convert median barrier	Remove an existing metal median barrier system and install a concrete median barrier	40	Point of impact = 04, 05, 12,16 or 63 and object struck 23, 39, 56, 62, or 63 or vehicle movements/manner of collision = 30
Install raised median	Install a roadway divider using barrier curb	25	Part of roadway No.1 involved = 1 and vehicle movements /manner of collision = 10, 14, 20-22, 24,26, 28-30, 34 or 38
Flatten side slope	Provide an embankment side slope of 6: 1 or flatter.	46	Roadway related = 3
Modernize bridge rail and approach guardrail	Improve existing substandard bridge rail and approach guardrail to current design standards. Post spacing, end treatment and length of need should be considered. For length of need, if the existing length is less than 20% of the current design length, use W.C 208, also	15	Object struck = 23, 39- 41 or 56 or bridge detail = 2 or 3

Improve guardrail to design standards	Bring existing substandard guardrail into conformance with current design standards. Post spacing, end treatment and length of need should be considered. For length of need, if the existing length is less than 20% of the current design length, consider the project under W.C 207 for installation of new guardrail or W.C 208 for installation of protection at bridge ends	7	Roadway related = 2 or 3 or object struck = 20-26, 29-36,40-42, 56-58, 60, 62, or 63
Install protection	Provide guardrail or concrete traffic barrier where none existed previously. Refer to W.C 206 for improving existing guardrail and W.C 208 for the installation of protection at bridge ends	30	Roadway related = 2 or 3 or object struck = 20-26, 29-36,40,42, 56-58, 60, 62, or 63
Install protection at bridge ends	Provide guardrail, concrete traffic barrier or other protective system at bridge ends where no protection existed previously. Refer to W.C 207 for installation of new guardrail and W.C 206 for improving existing guardrail	50	Roadway related = 2 or 3 or object struck = 20-26, 29-36,40-42, 56-58, 60, 62, or 63
Safety treat fixed objects	Remove, relocate or safety treats all fixed objects within the project limits, to include both point and continuous objects. Refer to W.C 210,211,212,213,214,215,216,217, or 218 if the project includes only one type of fixed object. Guardrail should be coded separately.	55	Roadway related = 2 or 3 or object struck = 20-26, 29-36,40-42, 56-58, 60, 62, or 63
Safety treat sign support	Replace existing sign supports with breakaway supports. Refer to W.C 217 for the installation of attenuation systems.	45	Roadway related = 2 or 3 or object struck = 20-26, 29-36,40-42, 56-58, 60, 62, or 63
Safety treat luminaire supports	Replace existing luminaire supports with breakaway supports.	35	Roadway related =2 or 3 or object struck = 20-26, 29-36,40,42, 56-58, 60, 62, or 63
Safety treat drainage structures	Provide safety end treatments to crossroad and/or parallel drainage structures.	60	Roadway related =2 or 3 or object struck = 20-26, 29-36,40,42, 56-58, 60, 62, or 63
Widen drainage structures to clear zone	Widen existing structures to provide the desirable clear zone	30	Roadway related =2 or 3 or object struck = 20-26, 29-36,40-42, 56-58, 60, 62, or 63
Remove signal supports	Redesign signals to remove the existing supports from the median	10	Point of impact = 04, 05, 12,16, or 63 and object struck = 20-26, 29-36, 40-42, 56-57,60, 62, or 63
Remove trees 4:1 or 3:1 with recovery	Remove trees from the clear zone. Consideration is given to the embankment slope rate and the clear recovery area gained after removal	10	Roadway related = 2 or 3 or object struck = 20-26, 29-36,40-42, 60, 62, or 63
Remove trees 6: 1	Remove trees from the clear zone. Consideration is given to the embankment slope rate and the clear recovery area gained after removal	50	Roadway related = 2 or 3 or object struck = 20-26, 29-36 or 40-42
Install impact attenuation system	Provide any of a variety of impact attenuators where none existed previously	60	Object struck = 20, 30, 40 or 42

Widen bridge	Provide additional width across an existing structure, either by rehabilitation or replacement. Specify existing bridge width, existing approach roadway width and roadway type (2 lane, 4 lane undivided, etc.)	55	Bridge number is not blank or bridge detail is not blank or vehicle movements/manner of collision = 20, 21, or 30 or roadway related = 2 or 3
Install curb control of access	Installation of curb for an urban low speed design highway where no previous curb existed and the accident history indicates a control of access problem	10	Intersection related = 3 or 4 and vehicle movements/manner of collision = 10-19, 20-29, 33-39,40-44 or roadway related 2 or 3 or object struck = 20, 22-23, 26, 29-36 or first harmful event = 1 or 4
Relocate luminaire supports from median	Relocate luminaire supports from median (usually narrow) and place between outside curb and R.O.W refer to work code 211 for safety treating luminaire supports	To be defined	Roadway related = 2 or 3 or object struck = 20-26, 29-36,40-42, 56-58, 60, 62, or 63
Remove or modify barrier curb	Remove or make traversable the barrier curb in front of existing guardrail or concrete traffic barrier	30	Object struck = 21, 23, 39, 41or 56 or vehicle movements/manner of collision =30
RESURFACING AND ROADWAY LIGHTING			
Resurfacing with milepoints	Provide a new roadway surface to increase pavement skid numbers on the lane(s) in the direction of travel of the milepoints	42	Surface condition = 2 and direction of travel 1 = 1 or direction of travel 2 = 1
Resurfacing opposite milepoints	Provide a new roadway surface to increase pavement skid numbers on the lane(s) in the direction of travel opposite the milepoints	42	Surface condition = 2 and direction of travel 1 = 5 or direction of travel 2 = 5
Resurfacing	Provide a new roadway surface to increase pavement skid numbers on all the lanes	42	Surface condition = 2
Safety lighting	Provide roadway lighting, either partial or continuous, where either none existed previously or major improvements are being made. Refer to W.C 305 for intersection lighting	25	Light condition = 3 or 4
Safety lighting at intersection	Install lighting at an intersection where either none existed previously or major improvements are proposed. Refer to W.C 304 for general lighting	75	Light condition = 3 or 4
PAVEMENT MARKINGS			
Install pavement markings	Place complete pavement markings, excluding crosswalks, in accordance with the TMUTCD where either no markings or nonstandard markings exist. Refer to W.C 402 for edge marking, W.C 403 for pedestrian crosswalks. W.C 404 for centerline striping.	20	Roadway related = 2 or 3 or vehicle movements/manner of collision = 21 or 30 or first harmful event = 3
Install edge marking	Place edge lines where none existed previously.	25	Roadway related = 2 or 3
Install pedestrian crosswalk	Place pedestrian crosswalk markings where none existed previously. Refer to W.C 114 for school zones, and W.C 110 for pedestrian signal.	10	First harmful event = 1

Install centerline striping	Provide centerline striping where either no markings or nonstandard markings existed previously. Refer to W.C 401for complete pavement markings.	65	Vehicle movements/manner of collision = 30
Install traffic buttons	Place raised non-reflectorized traffic buttons for improved visibility in daylight wet surface conditions. Buttons will be installed where no buttons existed previously. Refer to W.C 406 for installation of reflectorized pavement markers.	30	Surface condition =2 and light condition = 1 or vehicle movements/manner of collision = 21 or 30
Install raised reflective pavement markers	Place raised reflective pavement markers for improved visibility at night and in wet surface conditions. Markers will be installed where none existed previously. Refer to W.C. 405 for installation of traffic buttons.	25	Surface condition = 2 or light condition = 3 or 4
ROADWAY WORK GROUP			
Modernize facility to design standards	Provide modernization to all features within the right-of-way to achieve current desirable standards. This includes work such as widening the travel way, widening the shoulders, constructing shoulders, flattening the side slopes, and treating roadside obstacles.	15	All
Widen lane(s)	Provide additional width to the lane(s) refer to W.C 517 if adding a through lane	30	Roadway related = 2 or 3 or vehicle movements/manner of collision = 13, 21, 23, 30 or 33
Widen paved shoulder	Extend the existing paved shoulder to achieve desirable shoulder width. Refer to W.C. 504 for constructing a paved shoulder	12	Roadway related = 2 or 3 or first harmful event = 4
Construct paved shoulders	Provide paved shoulders to desirable width where no shoulders existed previously. Refer to W.C 503 for widening paved shoulders	15	Roadway related = 2 or 3 or vehicle movements/manner of collision = 20, 23-24 or 30 or first harmful event = 4
Improve vertical alignment	Reconstruct the roadway to improve sight distance	50	Roadway related = 2 or 3 or vehicle movements/manner of collision = 20-24, 30, 32 or 34
Improve horizontal alignment	Flatten existing curves. Refer to W.C 507 for providing superelevation, and W.C 508 for intersection realignment	50	Roadway related = 2 or 3 or vehicle movements/manner of collision = 20-24 or 30
Increase superelevation	Provide increased superelevation on an existing curve	65	Roadway related =2 or 3or vehicle movements/manner of collision =30
Realign intersection	Improve an existing intersection by partial or complete relocation of the roadway(s). Refer to W.C. 509 for channelization, and W.C 506 for improving horizontal alignments	To be defined	Will be determined from supplied diagram
Channelization	Install islands and/or pavement markings to control or prohibit vehicular movements. A sketch of the proposed channelization should be provided. Refer to W.C 508 for intersection realignment	To be defined	Will be determined from supplied diagram

Construct turnarounds	Provide turnarounds at an intersection where none existed previously	40	Intersection related = 1 or 2 and vehicle movement /manner of collision = 12,14,18,20,22,24,26,28,29 or 34
Add acceleration / deceleration lanes	Construct acceleration and/or deceleration lanes where none existed previously	10	Outside 2 lanes (main) and vehicle movements/manner of collision = 20 or 21
Entrance ramp modification	Reconstruct existing ramps to conform with current desirable standards.	30	Part of roadway involved =3 and vehicle movements /manner of collision = 20 or all crashes on outside 2 main lanes from 1/10 mile before connection to 2/10 mile after connection
Exit ramp modification	Reconstruct existing ramps to conform with current desirable standards.	20	Part of roadway involved =2 or 4 and roadway related = 2 or 3 or part of roadway involved = 2 or 4 and vehicle movements /manner of collision = 10-39
Grade separation	Construct vertical separation of intersecting roadways.	80	All
Construct interchange	Construct vertical separation of intersecting roadways to include interconnecting ramps	55	All
Close crossover	Permanently close an existing crossover	95	Part of roadway involved =1 and vehicle movements/manner of collision= 10, 14, 20-22, 24, 26, 28-30, 34 or 38
Add through lane	Provide an additional travel lane	28	Vehicle movements/manner of collision = 20-24, 26-27,29-30
Install continuous turn lane	Provide a continuous two-way left turn lane where none existed previously	40	Vehicle movements/manner of collision = 20-22, 24, 26,28-30, 34 or 38
Add left turn lane	Provide an exclusive left turn lane where none existed previously. The affected intersection approaches must be specified	25	Vehicle movements/manner of collision = 20-22, 24, 26, 28-30, 34 or 38
Lengthen left turn lane	Provide additional length to an existing exclusive left turn lane. Affected intersection approaches must be specified	40	Vehicle movements/manner of collision = 20-22
Add right turn lane	Provide an exclusive right turn lane where none existed previously. Affected intersection approaches must be specified	25	Vehicle movements/manner of collision = 20-23, 227, 33 or 36
Lengthen right turn lane	Provide additional length to an existing exclusive right turn lane. Affected intersection approaches must be specified	40	Vehicle movements/manner of collision = 20-22
Construct pedestrian over/under pass	Construct a pedestrian crossover where none existed previously	95	First harmful event = 1
Increase turning radius	Provide an increased turning radius at an existing intersection	10	Vehicle No.1 type = 2-3,8 and first harmful event = 7 or vehicle no. 2 type = 2-3, 8 and first harmful event = 7 or vehicle movements/manner of collision = 13, 20-21, 30 or 33
Convert to one way frontage roads	Convert two-way frontage roads to one-way operation	25	Part of Roadway Involved = 2

Increase vertical clearance (lower grade)	Increase vertical clearance of a roadway underneath an overhead obstacle by lowering the roadway grade	50	Object struck = 43
Increase vertical clearance (remove structure)	Remove an overhead structure in order to increase vertical clearance	95	Object Struck = 43
Construct median crossover	Provide crossovers in the median where none previously existed	20	Part of roadway involved = 1 and vehicle movement/manner of collision= 10, 14,20-22, 24,26,28,29,34 or 38
Remove raised median/concrete island	Permanently remove raised median/concrete island	35	Object struck = 21 or 36
Install jiggle bar tiles as a shoulder treatment	Install jiggle bar tiles on the shoulder as a shoulder texturing treatment	25	Roadway related = 2 or 3 or vehicle movement/manner of collision = 30
Texturize shoulders (rolled in or milled in)	Install milled-in or rolled-in rumble strips along the shoulder	25	Roadway related = 2 or 3 or vehicle movement/manner of collision = 30

State: Vermont
Source: Agency of Transportation

Improvement	Description	Reduction Factor (%)
Bridge replacement	Total replacement of a bridge with a new, safer structure	100
Experimental pavement marking	Raised reflector markers were installed at an interchange and permanent pavement markings	16
Guardrail improvements		6
Intersection realignment		30
Intersection signalization improvements	Traffic signal	62
Structure upgrading	Guardrail, bridge rail, signs and sign posts	70
Railroad grade crossing improvements	Reconstruction of a grade crossing and/or the installation of approach lights and gates	42
Reconstruction / Realignment	Improvements involving the alteration of the alignments off a sections of road	58
Restoration/rehabilitation	Improvements required to return an existing roadway to a condition of adequate structural support	58
Truck escape lanes		100*

* Truck crashes only