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HAZARD ELIMINATION PROGRAM - MANUAL ON IMPROVING SAFETY OF INDIANA ROAD INTERSECTIONS AND SECTIONS

Volume 1
Research Report

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16. Abstract

The Hazard Elimination Program (HEP) is the section of the Safety Management System that focuses on road improvements and includes analytical tools for identification of safety problems and their remedies. This research project reviews the results of the past research for Indiana and other states and to develop guidelines that present a set of tools for hazard elimination through road improvements. It also includes developing regression models for predicting crash frequencies at all-way and two-way stop-controlled intersections.

Negative Binomial regression was used to develop separate models for two-way and all-way stop controlled intersections. These models predict typical frequency of all crashes, PDO crashes, and injury/fatal crashes at unsignalized intersections. In addition, improved criteria have been proposed for screening the Indiana road network for high-crash locations. The proposed criteria incorporate the level of uncertainty present in the process and consider severity of crashes.

The primary outcome of the project is the “Guidelines for Highway Safety Improvements in Indiana,” which comprises the second volume. Within this volume, the research results are compiled with other components selected after critical analysis of the present state-of-the-art and state-of-the-practice safety management methods. The Guidelines are ready to use by safety engineers and may also serve as a textbook for inexperienced users. The Guidelines include all required equations, tables with required default values, and calculation forms that organize the HEP process. The calculation forms can be used as an interface design for a computerized version. All major computational steps are illustrated with examples and a comprehensive example is included to demonstrate the entire HEP process.

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CHAPTER 1. INTRODUCTION

The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 triggered development of the Safety Management System (SMS) in the United States. The Transportation Equity Act for 21st Century (TEA 21) of 1997 encouraged further development of SMS. The primary aim of a safety management system is to reduce the number and severity of traffic crashes by ensuring that all opportunities to improve safety are identified, considered, implemented, and evaluated. The Hazard Elimination Program (HEP) is the part of the SMS that focuses on road improvements and includes analytical tools for identification of safety problems and their remedies. HEP is aimed at reducing crashes that occur on the road network and gives a systematic approach to find, analyze, and improve high crash locations.

1.1. Research Problem and Objectives

Indiana Highway Safety Program research projects within SMS have produced several components of the system. The results include area-wide detection of safety problems (Farooq et al., 1995), an enhanced method for detecting hazardous locations (Tarko et al. 1996), a set of crash-prediction models for road segments and signalized intersections, and new and updated crash reduction factors for road improvements (Eranky et al., 1998); (Tarko et al., 2000).

This research project proposes to review the results of the past research for Indiana and other states, conduct additional research tasks to fill the gaps, and develop a final document that presents a set of tools for hazard elimination through road improvements. The developed guidelines should be easy to integrate within the existing Indiana standards and will focus on improvements of geometry and traffic control on road segments and intersections. Further, the guidelines will include identification of high crash locations; identification of safety deficiencies and determination of adequate countermeasures by conducting safety reviews at high crash locations; economic evaluation of safety projects; an update of crash reduction factors using the crash reduction factor for the implemented safety improvement; and a check of the statistical significance of the crash reduction by implementation of the safety project.

The research objectives also include developing regression models for predicting crash frequencies at all-way and two-way stop-controlled intersections. Regression models have been developed for signalized intersections, rural two–lane, rural multilane, urban two-lane and urban multilane segments. These and other models would be a part of the methodology to identify high crash locations and other phases of local safety management through road improvements.

1.2. Report Organization

The report consists of two parts; the first volume is the research report and the second volume contains guidelines for highway safety improvements in Indiana. The research report is aimed to provide a factual basis for the guidelines. The guidelines concept will be discussed in the next chapter. The research report consists of a literature review, including research papers, guidelines, and manuals published during the last several years in the area of local safety improvements and safety management, particularly the state of the art and state of the practice for a safety management system. The shortcomings of the methods are addressed with suitable modifications and methods proposed for Indiana are discussed.

The research report reviews current methods for identifying high crash locations, finding safety deficiencies on highway locations, and evaluating proposed and implemented safety projects. Developing safety performance functions for unsignalized intersections is also discussed. Separate functions are developed for property damage only and injury/fatal crashes and for two-way stop-controlled and four-way stop-controlled intersections. Appendix A lists the intersections which have been used in this study, and Appendix B lists the results of regression for various forms of safety performance functions.

The next chapter presents the concept of the guidelines.

CHAPTER 2. CONCEPT OF THE GUIDELINES

The guidelines provide a description of the HEP process and analytical methods to facilitate it. The guidelines may serve as a textbook for inexperienced users and as a reference for experienced users. The guidelines should promote similarity and uniformity of safety methods and analyses performed across Indiana Department of Transportation (INDOT) and local transportation agencies in Indiana as a well-designed and uniformly implemented safety management system across agencies would make the effort by transportation agencies more effective. The guidelines have a complete set of equations, tables, forms, and reference material for all components of the HEP process. Examples are given for each step of the HEP and in the final chapter the entire process is illustrated through a comprehensive example. Worksheets are developed to provide a concise step-wise procedure for various calculations used in the HEP, which may be used as a starting point for developing software for various analytical tools used in HEP.

2.1. Organization of the Guidelines

The guidelines have seven chapters and several appendices. Chapter 1 provides an overview of the guidelines, a brief description of SMS and a brief description of HEP.

Chapter 2 provides an overview of the HEP and its components and provides a brief description of various processes involved in HEP.

Chapter 3 describes data acquisition and management in HEP and the information available in the databases used for safety management in Indiana.

Chapter 4 describes criteria that can be used in finding high crash locations. The data extracted from the databases referenced in Chapter 3 is used in checking the crash hazard of a road location. The chapter will look at existing methods for identifying high crash locations and recommend a method for Indiana. A step-wise procedure and illustrative examples for identifying high crash locations through recommended methods are provided and a brief discussion on the use of the recommended methods when the crash data is not available for full years.

Chapter 5 provides tools to analyze, find safety deficiencies, and determine appropriate countermeasures for sites that are identified as high crash locations in Chapter 4. It critically analyzes current methods for safety review and proposes a method for Indiana.

Chapter 6 discusses the procedure for an economic analysis of safety projects selected in Chapter 5. Existing methods will be analyzed and after making suitable modifications a method will be proposed for Indiana. An example illustrating the entire process is provided at the end of the chapter.

Chapter 7 provides a method of evaluating projects after they have been implemented, including a methodology for calculating the crash reduction factor for an implemented safety project, updating the crash reduction factor using the calculated crash reduction factor, and checking the statistical significance of the reduction in crashes.

Chapter 8 provides an example illustrating the HEP process. The various steps included in the chapter will be confirming the crash hazard, performing a safety review at the location, economically evaluating the proposed project, and conducting a post-implementation study for the safety project.

The guidelines contain various appendices that will be used in the HEP as well as forms for step-wise calculations for various procedures used in the HEP.

CHAPTER 3. IDENTIFICATION OF HIGH CRASH LOCATIONS

Identification of high crash locations is an important step in the HEP. Sites are selected from thousands of candidates that may have safety problems, from which a priority list of sites, which need improvement, is prepared using a specific criterion. It should be remembered that if the locations with serious safety problems are omitted from the identification phase, they are not considered again in the HEP cycle. In order to use the resources efficiently, only high crash locations should be selected for conducting a safety review. Existing methods for identification of high crash locations are discussed in this chapter, followed by the methods recommended for INDOT.

3.1. Methods in Use

A number of methods have been developed to identify high crash locations. These methods can be classified as representing either the system's perspective or the user's perspective of achieving safety. The systems perspective criterion aims at reducing as many crashes as practical and promoting the most cost-effective method for mitigation of hazard. The user perspective criterion aims at reducing excessive risk faced by individual users, which promotes fairness of the highway system by equalizing the risk faced by users (Hauer, 1996).

Crash frequency is a system perspective criterion. It is a basic measure of crash experience, easy to use as it requires only crash data. The crash frequency is estimated by dividing the number of crashes by the number of years. The crash frequencies are compared with a critical crash frequency to determine whether the location is a high crash location (Southeast Michigan Council of Governments, 1997; Missouri Highway and Transportation Department, 1990; UDOT, 1992). Selecting locations based solely on crash frequency does not consider exposure to risk, i.e., AADT or VMT, and although locations that tend to have high traffic volumes usually occupy higher positions on a prioritization list, their safety may be difficult to improve due to the large volumes.

Another method used to identify high crash locations is crash rate. Crash rate is a user perspective criterion. It is the number of crashes divided by the amount of vehicular exposure at the location. The locations are either prioritized by forming a list of high crash rate locations or comparing the crash rate with a threshold crash rate to determine the relative hazard at the location (Maryland State Highway Administration, 1998; Southeast Michigan Council of Governments, 1997). A drawback of this method is that it does not maximize the overall safety benefit in the system.

The number rate method combines the crash rate and crash frequency method, wherein the crash frequency and crash rate of a location must be greater than critical crash frequency and critical crash rate respectively in order for a location to be considered a high crash location (Missouri Highway and Transportation Department, 1990).

The crash severity method gives extra weight to the fatal (*F*) and injury (*I*) crashes so that they are given more importance than property damage only (*PDO*) crashes. The weighted F and I crashes are added to PDO crashes to arrive at an equivalent property damage only

(*EPDO*) number as shown in Equation 3.1 (Missouri Highway and Transportation Department, 1990).

$$EPDO = PD + EI \times I + EF \times F \qquad 3.1$$

where

PD = number of property damage only crashes,

I = number of injury crashes,

F = number of fatal crashes,

EI = weight for an injury crash, and

EF = weight for a fatal crash.

The severity rate method combines the crash rate and the crash severity methods to combine the advantages and eliminate the deficiencies of the two methods. In this method the *EPDO* number calculated from the crash severity method is divided by vehicular exposure at the location to obtain the *EPDO* rate (Missouri Highway and Transportation Department, 1990; Maryland State Highway Administration, 1998).

Some states use a combination of the above mentioned methods or use ad hoc functions to determine high crash locations. For example, the Oregon Department of Transportation uses the Safety Priority Index System (ODOT, 2003) which is comprised of three components: crash frequency, crash rate, and crash severity.

3.2. Quality Control Approach

Statistical control techniques, which are employed in industrial quality control, were suggested for identifying high crash locations by Norden, Orlandsky and Jacobs (1956). A significant change in crash structure at the location was attributed as the cause of crash rates being outside the control limits. This research assumed Poisson distribution of crashes and control limits were calculated by approximating Poisson distribution as Normal distribution, with the probability of exceeding the upper control limit as 0.5% and being lower than the lower control limit as 0.5%. A similar concept was proposed by Rudy (1962) and Morin (1967) with modifications in the equations to calculate the upper and lower control limits. The control limits were calculated by using the average crash rate (calculated by dividing the total number of crashes at the locations by the total number of car miles on these locations) as the expected crash rate at the location. Using the average crash rate as the expected crash rate does not take into account the differences in individual location characteristics.

The expected number of crashes at a location was proposed by Jorgenesen (1972) to be derived by using a multivariate model for various road categories. A non linear relationship between crash frequency and traffic flow was proposed by Hauer et al. (1988). A loglinear regression model to calculate the expected number of crashes was proposed by Maycock and Maher (1988). These functions will be referred to as safety performance functions, which are functions that return the expected number of crashes for a given set of location characteristics. The loglinear regression model is represented in Equation 3.2 (Tarko et al. 2000).

$$a = \beta_0 Y^{\delta} e^{\sum_i \beta_i X_i}, \qquad 3.2$$

where

a = expected annual number of crashes (crashes / year),

Y = annual average daily traffic or vehicle miles traveled,

Xi = other county characteristics measured on annual basis (explanatory variables), and

$\delta, \beta i$ = regression parameters.

Jorgensen (1972) proposed that ranking of locations should be done on the basis of the difference between observed crash frequency and the expected frequency predicted by regression models, normalized by dividing the difference by the square root of the expected frequency of crashes. This was a crude approximation for considering the uncertainty in the difference between the actual and the expected number of crashes at the location and was the first method to use approximate quality control.

If there is a Poisson variance of counts at each individual site and Gamma distribution for site-to-site variance in expected crash counts, then the overall distribution can be expected to be Negative Binomial. Previous work by Abbess et al. (1981) and Maher (1987) have found that Negative Binomial distribution is in good agreement with the crash data. Sung et al. (2001) propose a rate quality control method based on Negative Binomial distribution, but they calculate the expected number of crashes at the location as the average crash rate for the locations in the sample. This does not take into account the difference in individual location characteristics.

3.2.1. Index of Crash Frequency

Index of crash frequency (I_{CF}) (Equation 3.3) (Tarko, 2001) uses the approximate quality control method to identify high crash locations. It measures the difference between the expected and actual crash counts, which is divided by the standard deviation of the difference estimate. This method compares the expected crash frequency estimate for this type of location with the actual crash frequency for the location. A set of predictive equations are presented in Table 3.1 and Table 3.2 for calculating the expected number of crashes (Tarko et al, 2000; Lamptey et al., 2004). The equation for signalized intersection has a variable for number of legs without lanes exiting the intersection. In order to maintain simplicity and consistency it was decided to have the equation without this variable. As adequate data was not available to recalibrate the equation an average value of *N* was substituted in the equation and the constant was modified to 0.30. The over-dispersion parameter would be higher but due to lack of data the same over-dispersion parameter was used. These equations ensure fairness of the system by equalization of risk experienced by the users.

$$I_{CF} = \frac{A - a \times Y}{\sqrt{A + a^2 \times Y^2 \times D}} \qquad 3.3$$

where :

A = number of crashes during Y years,

a = typical annual number of crashes calculated with equations in Table 3.1,

Y = number of years in analyzed period, in years, and

D = over-dispersion parameter.

Equation 3.3 is derived using the following concepts. There is Poisson variance of counts at each individual site and Gamma distribution for site-to-site variance in expected crash counts, leading to an overall Negative Binomial distribution. The numerator measures the difference between the expected crash frequency estimate for this location and the actual crash frequency of the location. The denominator measures the uncertainty associated with this difference. The uncertainty is measured by the variance of the difference of expected crash frequency for this location and the actual crash frequency of the location, as shown by the following equations.

Table 3.1 Safety performance functions

Location	Safety Performance Functions	Over-dispersion parameter (D)
Signalized intersections	a=0.322×$Q^{0.953}$×exp(-0.345×N)	0.655
Rural multilane road segments	a =0.080×L×$Q^{1.052}$	2.89
Rural two-lane road segments	a =0.317×L×$Q^{0.589}$	1.10
Urban multilane road segments	a =0.073×L×$Q^{1.33}$	5.50
Urban two-lane road segments	a =0.103×L×$Q^{1.329}$	1.78
a = expected annual number of crashes at similar locations, considered typical, Q = AADT entering the intersection or the road section, in thousand vehicles per day, N = number of legs without lanes exiting the intersection, D = over-dispersion parameter, and L = road segments length, in miles		

$$Var(a) = D \times a^2,$$

$$Var(a_Y) = Var(Y \times a) = Y^2 \times D \times a^2,$$

$$Var(a_C) = A,$$

$$a_C - a_Y = A - Y \times a,$$

$$Var(a_C - a_Y) = Var(a_C) + Var(a_Y) = A + Y^2 \times D \times a^2.$$

where:

a = expected number of crashes,

a_Y = estimate of expected number of crash during Y years,

$Var(a_Y)$ = Variance of a_Y,

Y = years for which crash data is analyzed,

a_C = crash count estimate during Y years,

$Var(a_C)$ = Variance of a_C,

A = number of crashes during Y years, and

D = over-dispersion parameter.

As our knowledge about the expected value of the crashes at the location has uncertainty, there is an over-dispersion parameter associated with the safety performance functions. Over-dispersion is also associated with crash data having more variance than can be explained by Negative Binomial distribution.

Table 3.2 Safety performance functions (Lamptey et al., 2004)

Facility	Safety Performance Functions	Over-dispersion parameter (D)
Rural multilane road segment	$a = 0.737 \times L \times Q^{0.654}$	0.473
Rural two-lane road segment	$a = 0.922 \times L \times Q^{0.598}$	0.427
Urban multilane road segment	$a = 2.641 \times L \times Q^{0.458}$	2.095
Urban two-lane road segment	$a = 0.733 \times L \times Q^{0.917}$	1.459
Rural interstate	$a = 0.212 \times L \times Q^{0.939}$	1.642
Urban interstate	$a = 0.0056 \times L \times Q^{2.016}$	2.819
a = typical crash frequency in Indiana , in crashes per year, Q = AADT entering the intersection or along the road segment, in thousand vehicles per day, D = over-dispersion parameter, and L = road segment length, in miles.		

The index of crash frequency can be used in two different ways. In the first method, all the locations in the area are ranked using the index of crash frequency. The list of sorted locations forms a priority list for safety reviews, starting with the location for which the evidence of being a high crash location is strongest. In the second method, a location is singled out by public complaints or prior knowledge. In such cases the I_{CF} is used to determine whether this location is actually a high crash location as it compares the crash rate at the location with the expected crash rate for a typical location in the state. The I_{CF} value has significance, as, if the location has a value of I_{CF} greater than 2, then the location may be considered a high crash location. The higher the value of I_{CF} is, the stronger the evidence for the location to be a high crash location.

3.2.2. Index of Crash Cost

Index of crash cost (I_{CC}) compares the total cost of crashes at the location with the estimated total cost of crashes at a typical location (Equation 3.4). The method is similar to I_{CF} but it uses crash costs to incorporate severity. This equation is also based on the approximate quality control method and derived on the same principles as of index of crash frequency. A set of predictive equations are presented in Table 3.3 and Table 3.4 for calculating the expected number of PDO and I/F crashes (Tarko et al, 2000; Lamptey et al., 2004).

$$I_{CC} = \frac{C_{PD}(PD - Y \times a_{PD}) + C_{IF}(IF - Y \times a_{IF})}{\sqrt{(C_{PD}^2 \times PD + C_{IF}^2 \times IF + C_{PD}^2 \times Y^2 \times {a_{PD}}^2 \times D_{PD} + C_{IF}^2 \times Y^2 \times {a_{IF}}^2 \times D_{IF})}} \qquad 3.4$$

where:

C_{PD} = average cost of PDO crash,

C_{IF} = average cost of I/F crash,

PD = actual number of PDO crashes during Y years,

IF = actual number of I/F crashes during Y years,

a_{PD} = expected annual PDO crashes at similar locations,

a_{IF} = expected annual I/F crashes at similar locations,

Y = number of years in analyzed period, in years,

D_{PD} = Over-dispersion parameter for PDO crashes, and

D_{IF} = Over-dispersion parameter for I/F crashes.

3.3. Other Methods

Spring and Hummer (1995) propose the use of knowledge-based GIS applications in identifying high crash locations. GIS facilitates easier extraction, presentation, and access to the crash and road inventory records with a more user-friendly interface. Previous studies on the causes of crashes were used with GIS tools to identify high crash locations, rather than using statistical techniques. With the increasing use of GIS in engineering, this method provides non-traditional methods ways to identify high crash locations.

Tarko et al. (1996) proposed a criterion to rank locations based on the potential for crash reduction. Potential crash rate was defined as the difference between the crash rate at the location and the minimum crash rate possible for the location. Minimum crash rate is a part of the overall crash rate that cannot be reduced further by using safety improvements at the location. The objective of the criterion is to maximize crash reduction through low cost safety improvements at locations within the given budget constraints.

DeSalle (2002) proposed using the Internet to gather complaints from citizens about possible high crash locations. Locations reported by individuals as hazardous tended to be significantly more hazardous and individual complaints identified hazardous locations at a significantly higher rate than locations chosen randomly. Therefore, locations referred by individuals should be investigated for safety deficiencies that may have come up recently.

Table 3.3 Safety performance functions including severity

Facility	Safety Performance Functions	Over-dispersion parameter
Urban two-lane segment	$a_{IF} = 0.408 \times L \times Q^{1.224}$	1.935
	$a_{PD} = 0.604 \times L \times Q^{1.415}$	1.595
Urban multi-lane segment	$a_{IF} = 0.0008 \times L \times Q^{1.669}$	5.230
	$a_{PD} = 0.0063 \times L \times Q^{1.10}$	5.550
Rural two-lane segment	$a_{IF} = 0.0103 \times L \times Q^{0.925}$	1.025
	$a_{PD} = 0.0306 \times L \times Q^{0.853}$	1.055
Rural multi-lane segment	$a_{IF} = 0.0025 \times L \times Q^{0.865}$	2.580
	$a_{PD} = 0.0042 \times L \times Q^{1.138}$	2.900
Signalized intersection	$a_{IF} = 0.1954 \times Q^{0.723}$	0.639
	$a_{PD} = 0.1758 \times Q^{1.0334}$	0.646

a_{PD} = expected annual number of PDO crashes,

a_{IF} = expected annual number of Injury/Fatal crashes,

Q = AADT entering an intersection or road section, in thousand veh/day,

L = road segment length, in miles, and

D = over-dispersion parameter.

Table 3.4 Safety performance functions including severity (Lamptey et al., 2004)

Facility	Safety Performance Functions	Over-dispersion parameter
Rural two-lane segment	$a_{IF} = 0.208 \times L \times Q^{0.604}$	0.420
	$a_{PD} = 0.712 \times L \times Q^{0.592}$	0.430
Rural multilane segment	$a_{IF} = 0.107 \times L \times Q^{0.814}$	0.451
	$a_{PD} = 0.634 \times L \times Q^{0.615}$	0.484
Urban two-lane segment	$a_{IF} = 0.105 \times L \times Q^{1.080}$	1.253
	$a_{PD} = 0.603 \times L \times Q^{0.896}$	1.349
Urban multilane segment	$a_{IF} = 0.674 \times L \times Q^{0.435}$	1.588
	$a_{PD} = 2.028 \times L \times Q^{0.460}$	1.946
Rural interstate	$a_{IF} = 0.044 \times L \times Q^{0.917}$	1.053
	$a_{PD} = 0.169 \times L \times Q^{0.943}$	1.604
Urban interstate	$a_{IF} = 0.00048 \times L \times Q^{2.238}$	2.383
	$a_{PD} = 0.0057 \times L \times Q^{1.954}$	2.704

a_{PD} = typical PDO crash frequency, in PDO crashes per year,

a_{IF} = typical I/F crash frequency, in I/F crashes per year,

Q = AADT entering an intersection or along the road segment, in thousand veh/day,

L = road segment length, in miles, and

D = over-dispersion parameter.

Table 3.5 Crash costs (in 2001 dollars)

Crash Type	Injury/Fatal	Property Damage Only
Interstate rural routes	75,000	6,500
Interstate urban routes	52,000	6,500
US/SR rural routes	78,000	6,500
US/SR urban routes	48,000	6,500
Local rural routes	56,500	6,500
Local urban routes	42,500	6,500

3.4. Recommended Methods and Identified Needs of Research

Based on the literature review and studying the existing methods, the index of crash frequency and the index of crash cost are recommended for identifying high crash locations. These methods compare the crash experience of the location with the state-wide average of similar locations and confirm that the number of crashes at the location is significantly greater when compared to similar locations.

Concepts of quality control are used in these methods and these methods are simple to use. They require data which is easily available for all locations (AADT, crash counts and length of segments). I_{CC} method incorporates severity by using crash cost as the weights for injury and fatal crashes. These criteria can be used for both intersections and road segments. Also they can be used to formulate priority lists and confirm crash hazard at a location that has been singled out by user's complaints or previous experience. The methods also take into account time periods that are not multiple of full years.

All of the reviewed methods to identify high crash locations require data to be in multiples of years. To overcome this deficiency, a method is proposed in Section 3.6 to facilitate the use of these equations when the data is not in multiples of years. Another missing link is the safety performance functions for unsignalized intersections, which had not been developed for Indiana. This facet of the research will be discussed in the next section.

3.5. Safety Performance Function for Unsignalized Intersections

Safety performance functions have been developed for signalized intersections, urban two-lane, urban multilane, rural two-lane, and rural multilane segments in Indiana by

Tarko et al. (2000). One missing component is the safety performance functions for unsignalized intersections, which need to be developed in order to consider unsignalized intersections in the HEP. These functions are needed to include unsignalized intersections into identification of hazardous locations and to better estimate past crash frequencies and percent reduction of crash frequencies after road improvements are applied.

3.5.1. Data Collection

In order to develop safety performance functions for unsignalized intersections, each Indiana Department of Transportation (INDOT) district was asked to provide 10 locations on state or U.S. Roads which were two-way stop controlled intersections with flashers, two-way stop controlled intersections without flashers, four-way stop controlled intersections with flashers, and four-way stop controlled intersections without flashers. This data would help formulate safety performance functions for two-way stop controlled intersections and four-way stop controlled intersections and determine if flashers had an impact on the crash characteristics of the intersections. Only intersections on state and U.S. roads were requested so as to easily obtain the AADT of the intersections using the AADT flow maps provided by INDOT. Table 3.4 provides a summary of the data given by the districts.

The intersections were inspected, and the intersections where the main road and the reference road crossed twice were removed in order to get the crashes for the intersection accurately. Table 3.5 provides a summary of data obtained after removing the intersections with the above mentioned problem from original data. Appendix A lists all the intersections that were used to develop safety performance functions.

Table 3.6 Summary of data provided by districts

Districts	Two-way stop controlled with flashers	Two-way stop controlled without flashers	All-way stop controlled with flashers	All-way stop controlled without flashers	Total
Crawfordsville	10	10	8	2	30
Fort Wayne	10	10	10	10	40
Greenfield	9	12	12	6	39
Laporte	10	10	10	4	34
Seymour	8	10	15	4	37
Vincennes	10	1	10	0	21
Total	57	53	65	26	201

Table 3.7 Summary of data for unsignalized intersections

	Two-way stop controlled	Four-way stop controlled	Total
With Flasher	45	55	100
Without Flashers	40	14	54
Total	85	69	154

3.5.2. Statistical Analysis

Annual average daily traffic (AADT) was obtained from the Annual Average Daily Traffic County Flow Map (INDOT, 2000) as shown in Figure 3.1. AADT was obtained for all four legs of the intersection and was interpolated to get the AADT for the year 1998 as the crashes for all intersections were extracted for the years 1997 – 1999. If the AADT flow map for a location was available for the year 1998, it was assumed as the AADT for 1998, otherwise the AADT for the location was obtained for two different years and a linear interpolation was used to get the AADT for 1998.

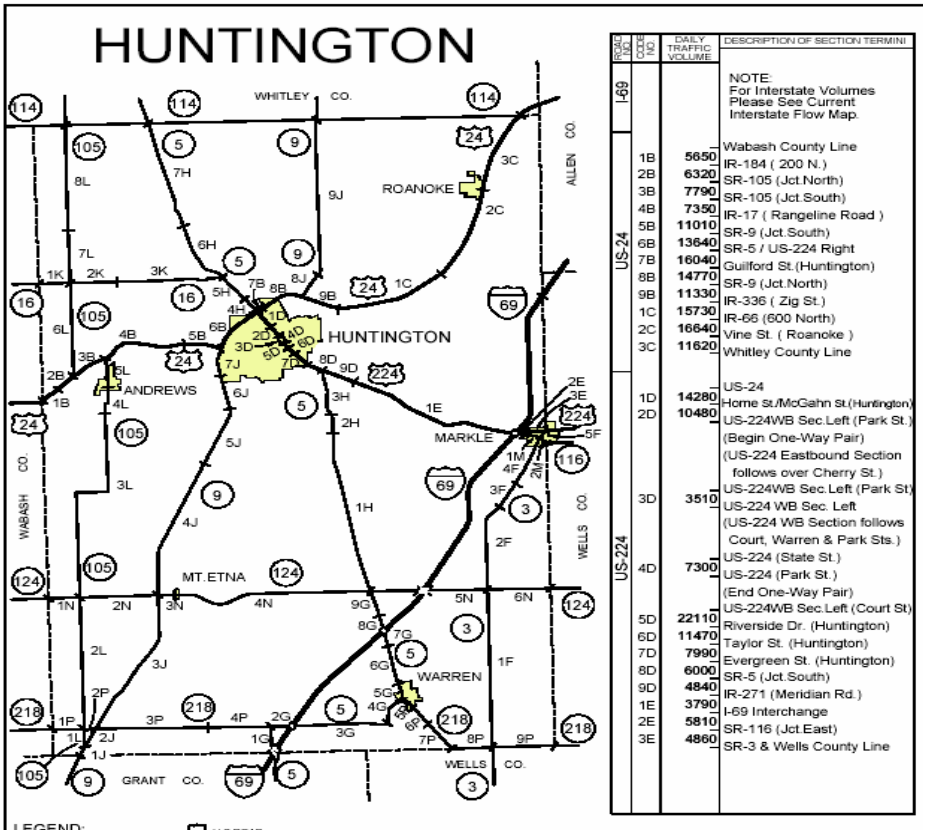

Figure 3.1 AADT flow map

The local names of the roads were obtained through Yahoo maps on the internet as shown in Figure 3.2. The local names are necessary to extract all crashes for the location as crashes are often reported using the local street names rather than road numbers.

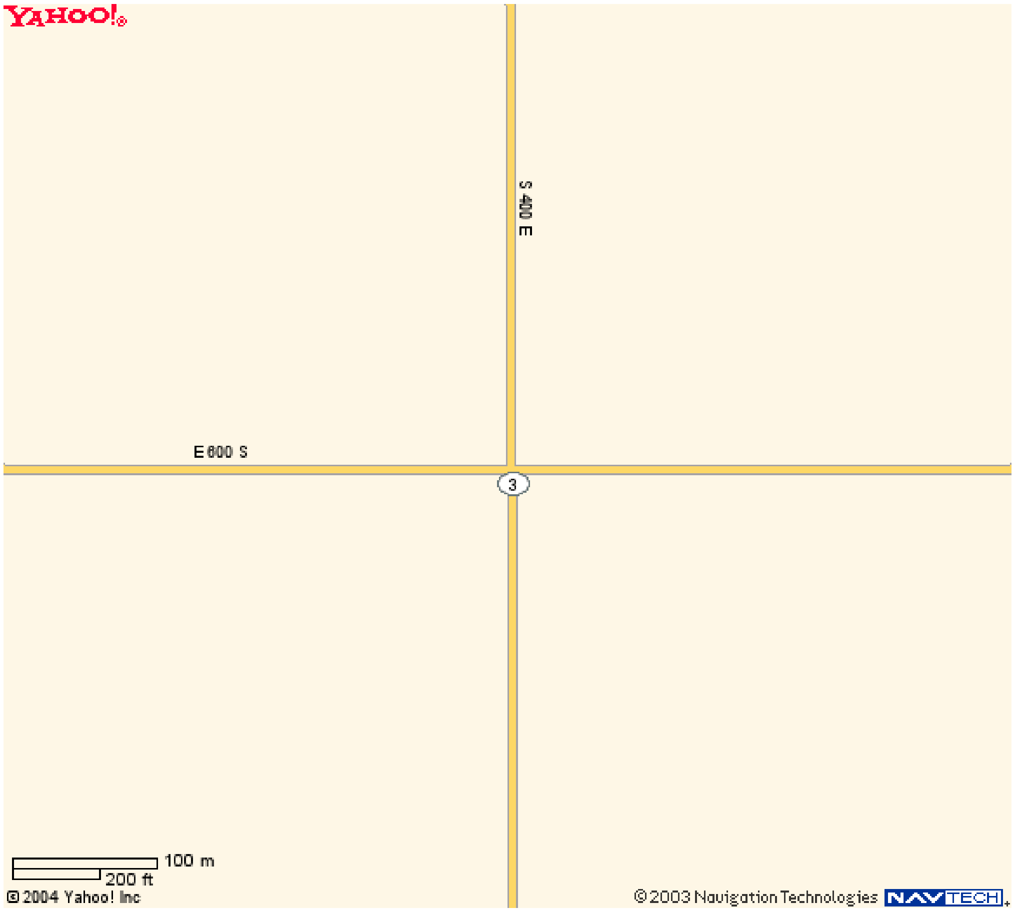

Figure 3.2 Using Yahoo maps to obtain local names of the State and US roads

After obtaining all the local street names they are converted to pseudo numbers which are used to extract crashes for a location. In the Indiana crash database, a crash location is described by the pseudo number of the road on which the crash occurred and the pseudo number of the reference road (crossing road). After obtaining the pseudo numbers for the main and reference roads, SQL queries were written to extract crashes that occurred at the location during the years 1997-1999. All crashes listed as occurring on an intersection and those whose location was not known but occurred within 100 feet of the intersection were considered to be occurring at the intersection. A list of all intersections with the number of PDO, and I/F crashes is shown in Appendix A.

As stated earlier, Negative Binomial distribution is the best fit to model crashes. Also a log-linear regression model is used for developing safety performance functions. AADT at the location and the presence of flashers at the location were used as variables in developing the models as this data is easy to obtain for all locations. Three different models were used, which are shown in Equations 3.5, 3.6, and 3.7. LIMDEP was used to develop these models.

$$a = e^{K} Q_1^{\beta 1} Q_2^{\beta 2} e^{\gamma F} \qquad 3.5$$

$$a = e^{K} \left(Q_1 Q_2\right)^{\beta} e^{\gamma F} \qquad 3.6$$

$$a = e^{K} \left(\frac{Q_1 + Q_2}{2}\right)^{\beta} e^{\gamma F} \qquad 3.7$$

where:

a = expected number of crashes,

K, γ, β_i = coefficients to be determined,

Q_1 = average AADT on two legs of major road, in thousand vehicles per day,

Q_2 = average AADT on two legs of minor road, in thousand vehicles per day,

F = whether the intersection has a flasher.

*Q_1 was taken to be the higher AADT

3.5.3. Discussion of Results

Regression models were developed for two-way stop-controlled intersections, four-way stop-controlled intersections, and all unsignalized intersections. Also different models to predict expected number of PDO and I/F crashes were developed. The models also included the presence of flashers as a binary variable. The results of the models are shown in Appendix B.

An over-dispersion parameter was found to be significant in all models, thus verifying that it was appropriate to model data with negative binomial regression. The results show that Equation 3.5 gives the lowest over-dispersion parameter. The models also show that the presence of flashers is not a significant variable in four-way stop controlled intersections and for I/F crashes at two-way stop controlled intersections. An interesting observation was that the presence of flashers was associated with higher expected number of crashes. This result might be interpreted as a result of self-selectivity bias (Washington et al., 2003). The warrants for flashers include "occurrence of five or more crashes during a 12-month period" or "minimum vehicular entering the intersection from all directions averages 400 vehicles per hour for any 2 hours of which vehicular traffic entering the intersection from the minor-street approaches averages at least 50 vehicles per hour for the same hours" (INDOT, 1988). This shows that flashers are installed at intersections where the volume is high or where a number of crashes already occur at the location, thus associating them with higher number of crashes.

The final models included in the guidelines are shown below. The models represented by Equation 3.7 were included even though they were not the best models, which was done to maintain consistency with the models developed for signalized intersections, urban two-lane and multilane segments, and rural two-lane and multilane segments. The difference in these models is not significant. Separate models for two-way stop controlled intersections and four-way stop controlled intersections were recommended due to the difference in the models. Also the effect of flashers was not included as it was found to be insignificant in all-way stop controlled intersections.

Table 3.8 Safety performance functions for two-way stop controlled intersections

$a = 0.522 \times Q^{1.093}$	D=0.359
$a_{PD} = 0.307 \times Q^{1.034}$	D=0.292
$a_{IF} = 0.234 \times Q^{1.099}$	D=0.649

Table 3.9 Safety performance functions for four-way stop controlled intersections

$a = 0.274 \times Q^{1.324}$	D=0.447
$a_{PD} = 0.182 \times Q^{1.434}$	D=0.265
$a_{IF} = 0.115 \times Q^{0.835}$	D=2.06

Table 3.10 Safety performance functions for stop controlled intersections

$a = 0.428 \times Q^{1.137}$	D=0.422
$a_{PD} = 0.255 \times Q^{1.189}$	D=0.288
$a_{IF} = 0.188 \times Q^{0.985}$	D=1.285

where:

a = expected number of annual crashes at similar locations,

a_{PD} = expected annual number of property damage only crashes at similar locations,

a_{IF} = expected annual number of injury/fatal crashes at similar locations,

Q = AADT entering an intersection or road section, in thousand vehicles per day, and

D = over-dispersion parameter.

3.6. Identifying High Crash Locations for Periods Less Than One Year

It is recommended that period of analysis should be multiple of one year to avoid seasonal variations but sometimes agencies want to identify high crash locations when the crash data is available for periods less than one year. The fluctuation in the monthly share of crashes is evident through Figure 3.3. The average monthly number of crashes have been derived from crash statistics from 1997 – 1999 obtained from the Indiana State Police crash information system. It is required to calculate unbiased share of crashes for periods which are less than one year.

In order to identify high crash locations for periods less than one year the value of *Y* in Equation 3.3 and 3.4 is suitably modified. The value of *Y* in Equation 3.3 and 3.4 should be the equivalence factors from Table 3.9 for periods for which crash data is analyzed. Equivalence factors are derived by estimating monthly share of crashes. A similar approach can be used when crash data is analyzed for periods greater than one year.

Figure 3.3 Average monthly number of crashes during 1997 - 1999

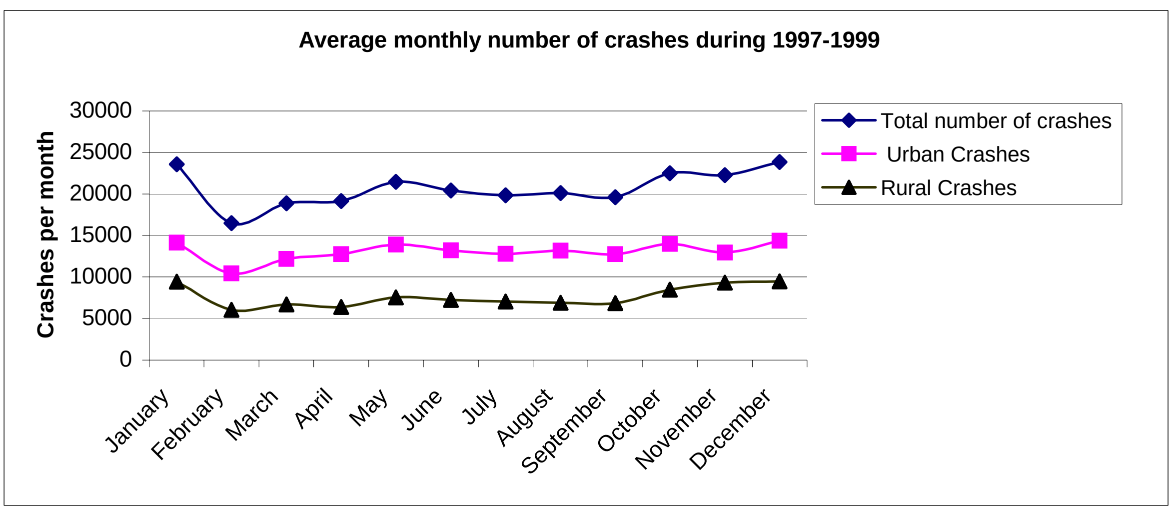

Table 3.11 Monthly equivalence factors

Month	Total	Urban	Rural
January	0.096	0.091	0.103
February	0.066	0.066	0.066
March	0.076	0.077	0.073
April	0.078	0.083	0.070
May	0.086	0.087	0.082
June	0.082	0.084	0.079
July	0.080	0.082	0.077
August	0.081	0.085	0.076
September	0.080	0.082	0.075
October	0.090	0.089	0.093
November	0.087	0.081	0.102
December	0.098	0.094	0.103

CHAPTER 4. SAFETY REVIEW OF HIGH CRASH LOCATIONS

This chapter presents a methodology for analyzing sites that are identified as high crash locations, identifying deficiencies, and proposing countermeasures at these locations. The chapter examines existing literature for finding safety deficiencies and countermeasures at a high crash location; the history, purpose, benefits, and stages of road safety audits and new initiatives in the recommended method to conduct safety reviews in Indiana.

4.1. Traditional Methods in Use

The "Highway Safety Engineering Studies: Procedural Guide" (FHWA, 1981) provides exhaustive guidelines for identifying safety deficiencies and countermeasures for identified high crash locations, naming the whole process "Conduct Engineering Studies." It gives a basic outline for conducting safety review, which include the following steps.

- Performing crash study procedures – The purpose of this activity is to collect and analyze crash data to identify possible safety deficiencies. Five crash analysis procedures are listed to identify safety deficiencies, which include crash summary by type, severity, contributing circumstances, environmental conditions, and time of day.

- Field review location – A preliminary review of the physical environment and traffic operations should be conducted. The review is used to verify site data in performing crash analysis procedures, the presence of deficiencies suspected on the basis of crash data, and the physical features and traffic operations at the site.
- Select appropriate traffic, environment and studies – This step is needed to verify the safety deficiencies suspected from the first two steps by conducting detailed traffic, environment, and special study procedures. Traffic-based studies include a volume study, a spot speed study, a travel time and delay study, a roadway and intersection capacity study, a traffic conflict study, a gap study, a traffic lane occupancy study, and a queue study. Environment-based studies include a roadway inventory study, a sight distance study, a skid resistance study, a highway lighting study and a weather-related study. Special studies include a school crossing study, a rail road crossing study, a traffic control device study and a bicycle or pedestrian study. Detailed literature is provided on various methods to conduct these studies in this section. FHWA (1981) has been referred to in the guidelines as a source for professionals undertaking an engineering study to find literature on how to conduct the studies. "Manual of Transportation Engineering Studies" (Hummer et al., 1994) is also a good source to find literature on these studies.
- Performing procedure – This step develops a data collection plan for conducting engineering studies at the location.
- Identifying safety deficiencies - This step compiles data collected in the previous steps, reviews the findings, and identifies safety deficiencies.

- Develop feasible countermeasures – In this step appropriate countermeasures are developed for the safety deficiencies identified in the previous step.

The Procedural Guide (FHWA, 1981) provides exhaustive literature on the methodology for finding safety deficiencies at the location but it stresses how to conduct various studies at the location, rather than provide a concise step wise procedure to find safety deficiencies. The large amount of information presented may be confusing for agencies looking for a step-wise procedure for conducting safety reviews at high crash locations.

A concise step-wise procedure is provided in the "Manual on Identification, Analysis and Correction of High Accident Locations" (Missouri, 1990). The guidelines provide a detailed method to construct collision diagram and condition diagram and stresses on use of a checklist in conducting on-site investigation. It provides a good starting point for writing the chapter on safety review in the guidelines.

4.2. Road Safety Audits

Austroads (2000) defines a road safety audit as "a formal examination of a future road or traffic project, an existing road, or any project which interacts with road users, in which an independent, qualified team reports on the project's accident potential and safety performance."

The concept of road safety audits started in Great Britain during the 1980s. The first guideline for road safety audits was published by the Institution of Highways and Transportation (IT) in United Kingdom in 1990 and was titled "Guidelines for the Safety Audit of Highways." In 1994, association of Australian and New Zealand road transport and traffic authorities known as Austroads, released guidelines on safety audits titled as "Road Safety Audit". Road safety audits first appeared in the U.S. when Federal Highway Administration (FHWA) appointed a scanning team to study the safety audit process in Australia and New Zealand. The first pilot study was started by FHWA in 1998 to determine the feasibility of incorporating road safety audits in roadway project development and construction (Hildebrand and Wilson, 1999).

Austroads (1994) and IT (1990) indicate the benefits of conducting road safety audits are reduction of the occurrence and severity of crashes on new and existing roads, incorporation of safety in planning, design, and construction of roads, and reduction of the cost of the projects by reducing post-implementation modifications (Hildebrand and Wilson, 1999).

Safety audits can be conducted at all the stages of design and construction process. The earlier a safety audit is conducted, the more beneficial it would be. The various stages when a safety audit can be conducted are specified as: feasibility, preliminary design, detailed design, preopening, and existing roads (Hildebrand and Wilson, 1999).

Safety audits at existing roads, known as safety review, fills in the missing gaps in literature on safety review in Missouri (1990) and FHWA (1981). These studies and input from professional judgment and reasoning were used in the chapter on safety review of high crash locations.

4.3. Proposed Method

The safety review proposed for Indiana HEP will concentrate on safety audits for existing roads. Some of the new initiatives in the proposed method are discussed in this section. A detailed flow chart of the entire process is included in guidelines and is shown in Figure 4.1. The safety review was divided into the following phases:

- Preliminary analysis
- Site investigation
- Post visit analysis
- Safety review documentation

4.3.1. Checklists

Checklists are an extensive collection of possible roadway deficiencies leading to safety problems. Various available checklists were studied (Hildebrand and Wilson, 1999; Austroads, 1994; Calvert and Ellinger, 1999; Main Roads, Western Australia, 1997). They are primarily used for conducting safety audits during the design and pre-opening stages of locations. They were found to be repetitive and including items not suitable for existing roads. The checklist in the guideline was developed for existing roads by compiling the existing checklists and adding new items. Checks on motorists' behavior which may indicate safety problems have been added. The checklist was formulated in such a way that if the answer to a safety check is yes, it is indicative of a safety deficiency. The resulting checklist is divided into five groups. The largest group, Group A, lists causes that may be applied to all locations. Group B lists additional causes that are unique to lane merging and diverging behavior and are more typical to interchanges. Group C lists additional possible causes that are typical to intersections. Group D adds to the three previous groups and lists additional possible causes that are unique to signalized intersections. Group E lists possible causes applicable for railroad crossings. The checklist has been built around the concept of checklist expansion. Table 4.1 explains the concept by showing the applicability of each check group. It is expected that a customized checklist will be prepared for the location after selecting proper groups, identifying predominant crash patterns, and marking the relevant checks to be performed at the location. Figure 4.2 shows the first page of the checklist.

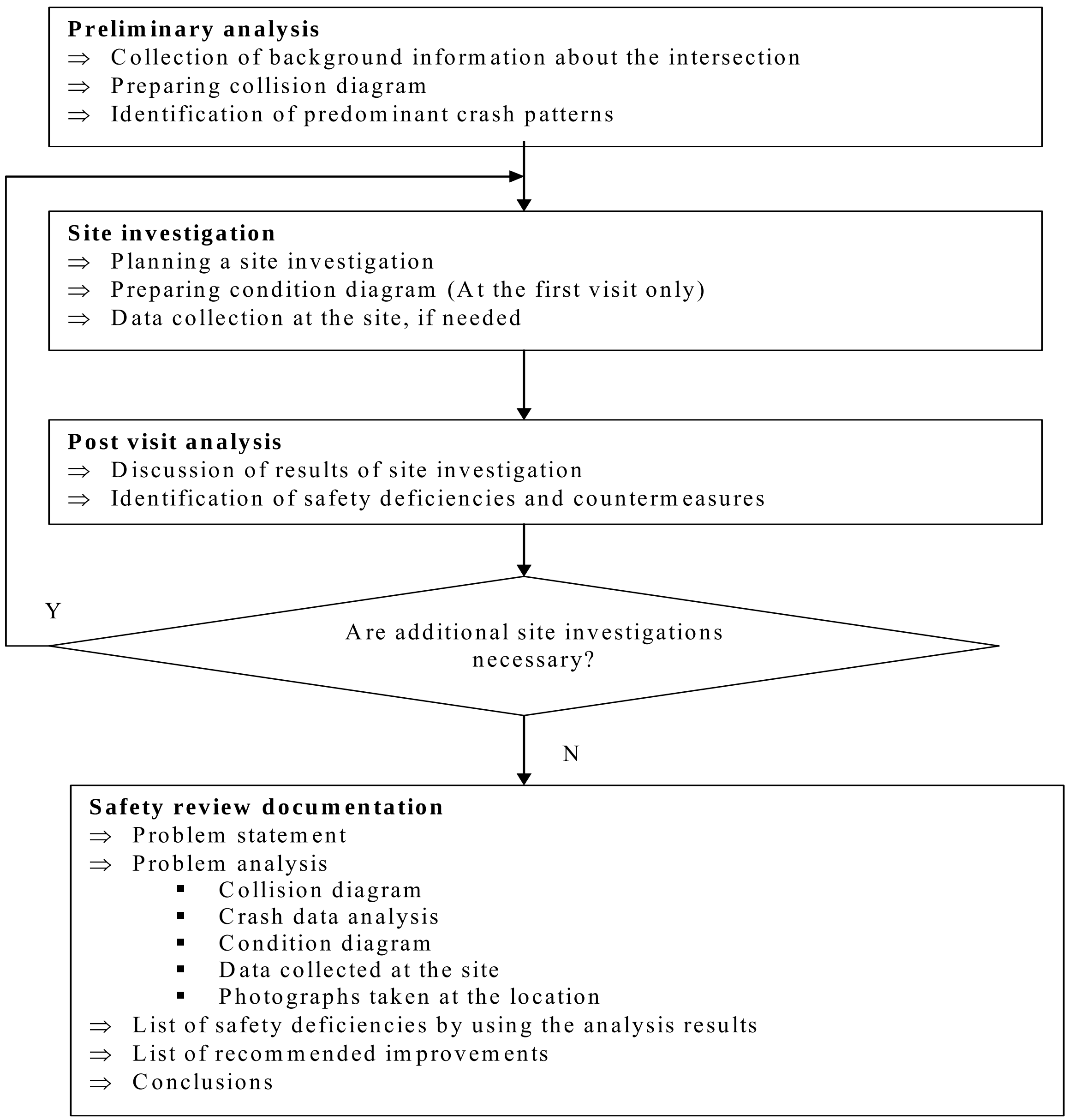

Figure 4.1 Flow chart of safety review process

Table 4.1 Applicability of check groups (X means applicable)

Facility	Check groups				
	A	B	C	D	E
Segments	X				
Interchanges	X	X			
Intersections	X	X	X		
Signalized intersections	X	X	X	X	
Railroad crossings	X	X	X	X	X

4.3.2. Site Investigation

The aim of the site investigation is to determine the existing local conditions at the location which includes control, geometry and traffic characteristics. A schematic diagram to represent various activities involved in a site investigation is shown in Figure 4.3. A detailed discussion is provided on how to conduct a site investigation, which includes discussion among the safety reviewers, a step not present in any previous guidelines.

4.3.3. Data Collection

Depending upon the results of the crash analysis and inspection of the site, engineering studies may be required. A brief description of some of these studies is provided in the guidelines and could include a spot speed study, a travel time study, a volume study, a roadway and intersection capacity study, a gap study, a traffic lane occupancy study, a queue length study, and a traffic conflict study.

4.4. Safety Review Documentation

The items to be included in the safety review documentation are provided in the guidelines. These includes a brief description of the location where the safety project is to be implemented, a summary of the crash data, any predominant patterns found in the crash data of the location, procedure used in finding the safety deficiency at the location, and an economic evaluation of the safety project, and a conclusion that summarizes the entire process and lists the merits of the safety project.

Safety Review Checklist **Form F4.1**

Facility Type________________________Location_________________________________

____

Date:__________________Time_________________Weather_________________________

	Possible causes	Probable causes
Group A		
Moving lanes		
Lane widths are inadequate for vehicle classes that are common to the location	_____	_____
Number of lanes inadequate for traffic	_____	_____
Readability		
Lanes end abruptly without prior warning (lanes are not aligned)	_____	_____
Auxiliary/Turning Lanes		
Inadequate advance warning of lane drops	_____	_____
Driveways		
Improper location of driveways(e.g. driveways are too close to the intersection)	_____	_____
Driveways are closely spaced	_____	_____
Inadequate visibility of driveways	_____	_____
Shoulders		
Shoulder width inadequate for vehicle classes that are common to the intersection	_____	_____
Inappropriate shoulder surfacing	_____	_____
Rumble strips not installed where warranted	_____	_____
Shoulders are poorly maintained	_____	_____
Insufficient contrast of shoulders	_____	_____
Horizontal and vertical alignment		
Horizontal or vertical alignment affect the visibility of the intersection	_____	_____
Abrupt changes in elevation	_____	_____
Inadequate visibility at sag and crest curves	_____	_____
Location at high side/low side of superelevation	_____	_____
Excessive curves that cause sliding in adverse weather condition	_____	_____
Excessive grades present, which could be unsafe in adverse weather conditions	_____	_____
Pavement markings / Delineation		
Pavement markings (center lines, edge lines etc) are not clearly visible in day or night time conditions	_____	_____

Figure 4.2 Checklist for safety review (first page)

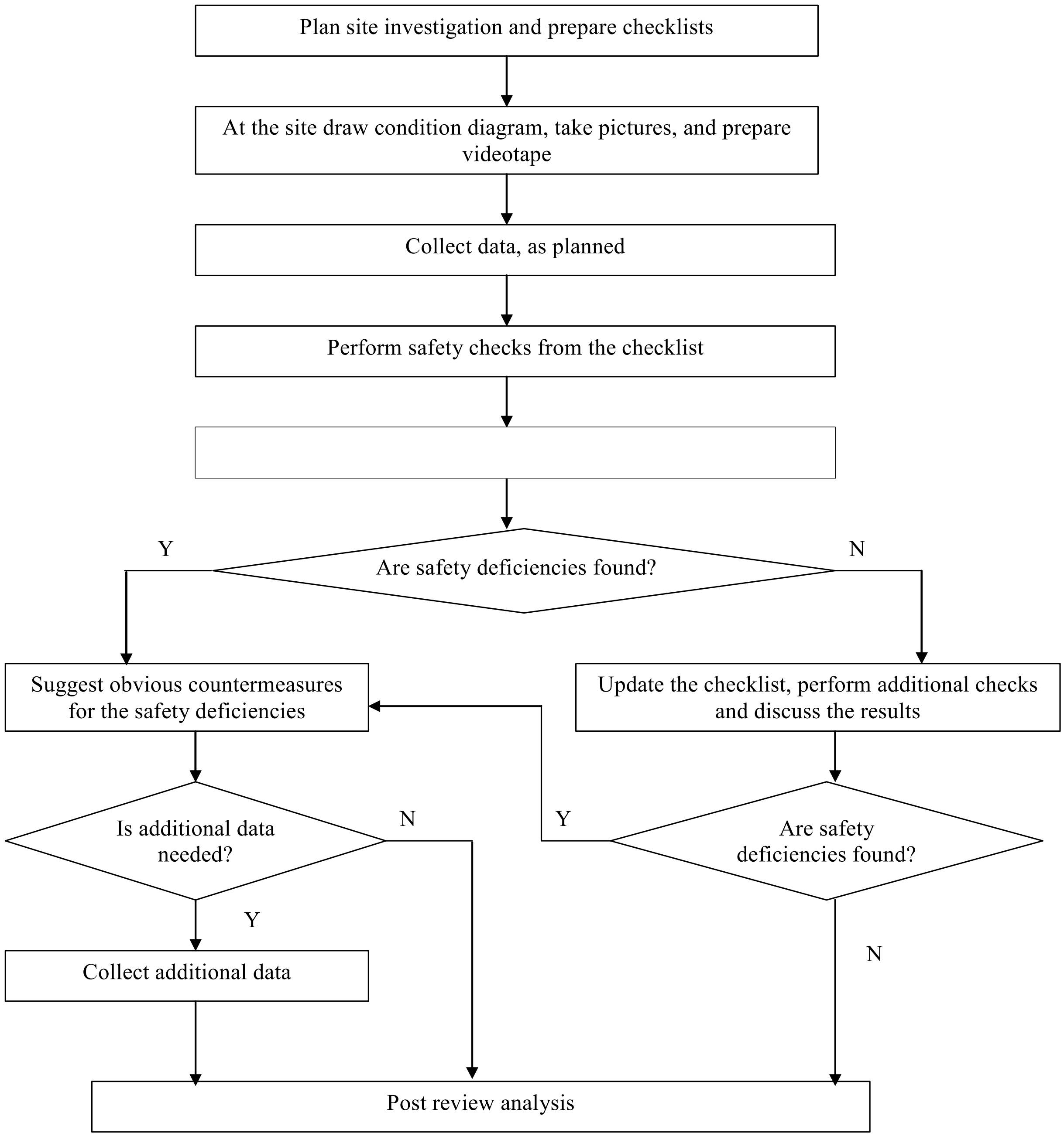

Figure 4.3 Schematic representation of on site visit

CHAPTER 5. ECONOMIC EVALUATION OF PROJECTS

Safety projects are evaluated to select those which provide maximum economic benefit. The objective of the economic evaluation is to compare the overall benefits with the overall costs of various projects to determine their economic feasibility and to decide which project provides the maximum economic benefit. This chapter discusses existing methods for economic evaluation, and the shortcomings of the method proposed in INDOT Design Manual (INDOT, 1994), and proposes a modified method for evaluating safety projects in Indiana.

5.1. Existing Methods for Economic Evaluation

"A Manual on User Benefit Analysis of Highway and Bus Transit Improvements" (AASHTO, 1977) presents a methodology for calculating user benefits and agency costs for highway and bus transit improvements and is a standard reference for economic analysis of projects (INDOT, 1994). It does not include the non-user social, economic, and environmental effects, such as air pollution or change in land use in its evaluation. The various steps included in this methodology are updating user cost factors, selecting economic study features, describing project characteristics and estimating project costs, calculating unit user costs, calculating user benefits, converting to annual benefits and estimating present values, and determining economic desirability (AASHTO, 1977).

"Highway Safety Engineering Studies: Procedural Guide" (FHWA, 1981) describes various inputs and procedures to determine the economic feasibility of the recommended countermeasures. The key inputs to the methods for economic evaluation are as follows:

- Crash reduction benefit is the cost of crashes saved by implementing a safety project.
- Project implementation cost includes all costs including right of way, construction, labor, equipment, design and other costs associated with the implementation of a project.
- Change in annual maintenance and operation costs is associated with operating and maintaining the location at a desired level of safety.
- Service life of a safety project is defined as the time period during which the improvement reasonably affects the crash rates at the location.
- The Salvage value of a safety project represents the cost of the safety project after the end of service life minus the costs involved in removing, repairing, transferring, or selling the devices in the project.
- Traffic growth factor represents the rate at which traffic is expected to grow. It is used to determine the rate at which the crashes are expected to grow based on the assumption that the increase in the number of crashes will be proportional to the increase in traffic volume at the location.

Using the above mentioned inputs, various procedures can be used to perform an economic analysis of safety projects which include:

- Cost-effectiveness method as defined in (FHWA, 1981) determines the cost to an agency to prevent a single crash. This method can be applied to one type of crash at a time. Its advantages include that it does not assign a dollar value to human life and its disadvantages are that it is difficult to evaluate the effects of multiple improvements.

- Time of return estimates the time when expected benefits begin to exceed expected costs. The advantages are that it directly estimates the time required by a safety project to pay off. Its disadvantages are that it does not account for the estimated interest rates, service lives, and salvage values.
- Rate of return determines the interest rate for which the net present value of benefits of the safety project are equal to the net present value of costs associated with the safety project. The advantage of this method is that it does not rely on the interest rate. Its disadvantages are that it is an iterative, trial and error procedure, whose results may be difficult to interpret.
- Net present value gives the difference between the present value of expected benefits and expected costs associated with the implementation of the safety project. Its advantages include its relative ease of calculation and that it considers optimization benefits for each individual location. Its disadvantage is that it does not recommend low cost safety improvements.
- Benefit and cost ratio is the ratio of expected benefits and expected costs associated with the safety project. Its advantages are that it is a straightforward method and optimizes the expected benefits on a system-wide basis. Its disadvantage is that it does not provide an exact dollar amount of the benefits of the safety project and providing only a ratio which could be misleading (FHWA, 1981).

These methods do not consider an increase in the expected number of crashes during the service life of safety improvements at the location. This is corrected in the following methodology proposed in the INDOT Design Manual (INDOT, 1994).

The INDOT methodology is based on AASHTO (1977) for economic evaluation of safety projects in Chapter 50-2.0 of the INDOT Design Manual, while accounting for an increase in the number of crashes per year during the service life of safety project. The method can be summarized to consist of the following steps: collecting crash data; identifying the proposed safety improvement; determining the cost of implementation, service life, and salvage value of the project, predicting crash reduction benefits by multiplying the number of crashes saved by the cost of crashes; estimating project costs and calculating the benefit-cost ratio and net annual benefit. This method does not account for the "regression to mean effect", discussed in the next chapter, does not allow for a time period in between years with crash data and analysis year and does not take into account that crash data is distributed over several years. These corrections are provided in the proposed method, which are discussed in the next section.

5.2. Proposed Method

The proposed method closely follows the method recommended for economic analysis in the INDOT Design Manual, (INDOT, 1994) with certain modifications, which are described as follows.

The recommended method introduces the terms, "analysis year" and "before period." The before period indicates years for which crash data is analyzed. The current method does not account for the crash data to be distributed over several years. In the proposed method the mid-point of the before period is assumed to have the average crash frequency for the before period. The crash frequency for the before period is updated to the crash frequency for the analysis year by use of an exposure adjustment factor, which is discussed later in this section. Also; the method does not account for the years in between the time when crash data is collected and when the economic analysis is done. In the proposed method all of the user benefits and agency costs would be brought to the dollar value of the analysis year, which allows for time in between the years of crash data and the analysis year. The service years would start one year after the analysis year and would extend throughout the service life of the project. Figure 5.1 shows the time components of the economic evaluation. For example, the crash data is collected at a location during the years 2004 – 2006. The analysis was done in 2009, which is the analysis year, and the service life starts from 2010.

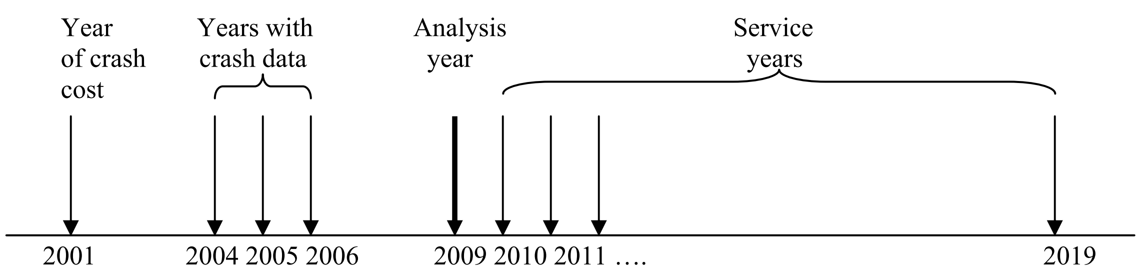

Figure 5.1 Time components of economic evaluation

The number of reported crashes at the location should be combined with the expected number of crashes at the location, calculated using the safety performance functions. Combining reported crashes and typical crash frequencies obtained from a safety performance function is used to mitigate the “regression to mean effect.” Equation 5.1 is used to combine reported number of crashes and typical crash frequency from safety performance functions and to adjust the expected crash estimate to the analysis year. This correction assures the crash benefits are not inflated and present a more accurate value of crashes saved.

The new method consists of the steps which are described as follows:

Step 1. Collect the required input. All relevant data used in calculating the *B/C* ratio and *NAB* are collected in this step, which includes crash data, traffic volumes, traffic growth factor, proposed safety improvement, construction cost, salvage value, change in annual maintenance costs, and service life of the proposed safety improvement The collected data is used in Steps 5 and 6 to estimate the user benefits and the agency costs.

Step 2. Estimate the crash frequency for the analysis year. In this step the number of reported crashes are combined with the typical crash frequency at the location to mitigate the "regression to mean effect", discussed in the next chapter, and adjusting the estimate to the analysis year using Equation 5.1.

$$a_P = \frac{\frac{1}{D} + A}{\frac{1}{D \times a} + Y} \times \left(1 + \frac{R}{100}\right)^{Z \times Y_2} \qquad 5.1$$

where:

a = expected crash frequency estimate (crashes / year) calculated using safety performance functions,

D = over-dispersion parameter for the safety performance function,

A = number of crashes during Y years,

Y = number of years for which crash data is available,

R = exposure change rate in percent,

Z = constant taken from Table 5.1

a_P = crash frequency in the analysis year, and

Y_2 = number of years between the midpoints of the before period and the analysis year.

Table 5.1 Z values for road facilities

Facility	PDO	I/F
Signalized intersection	1.033	0.723
Two-way stop controlled intersection	1.034	1.099
All-way stop controlled intersection	1.434	0.835
Rural multi-lane segment	0.615	0.814
Rural two-lane segment	0.592	0.604
Urban multi-lane segment	0.460	0.435
Urban two-lane segment	0.896	1.080
Rural interstate	0.943	0.917
Urban interstate	1.954	2.238

Step 3. Determine the crash reduction factors (*CRF*) and the service life of the safety improvement. *CRF* is the expected percent reduction in crashes due to implementation of the safety project. The crash reduction factors are taken from a previous study for Indiana by Tarko et al. (2000). For improvements involving multiple alternatives, Equation 5.2 should be used to calculate the total percent crash reduction for multiple improvements, (Taro, 1979). The service value of safety projects recommended by INDOT can be taken from the INDOT Design Manual, (INDOT, 1994).

$$CRF = 100 - \prod_{k=1}^{m}(100 - CRF_k) \qquad 5.2$$

where:

CRF = total percent crash reduction factor for multiple improvements, and

CRF_k = crash reduction factor for the k^{th} improvement.

Step 4. Estimate the exposure adjustment factor (*EAF*). This step estimates the *EAF*, which is used to predict the future number of crashes expected if the safety project is not implemented. It is based on the assumption that the change in the crash frequency will be proportional to the *EAF*, which depends on a change in exposure to risk (AADT for intersections and VMT for segments). *EAF* for some year after the implementation of safety project can be calculated using Equation 5.3.

$$EAF = (1 + \frac{R}{100})^{Z \times Y_1} \qquad 5.3$$

where:

R = exposure change rate in percent, assumed to be 2% unless otherwise specified,

Z = constant taken from Table 5.1, and

Y_1 = number of years between the analysis year and the future year of service.

Step 5. Calculate the present worth of total crash benefits. A dollar value is assigned to the number of crashes saved due to implementation of the safety project. This estimate applies to the entire service life of the project. Annual crash reduction (*CR*) and annual benefits (*AB*) in analysis year dollars for each severity are calculated as follows:

$$CR = a_P \times EAF \times CRF\ , \qquad 5.4$$

$$AB = CR \times C_P \times PWF_{SP}. \qquad 5.5$$

where:

CR = annual crash reduction,

AB = annual benefits,

a_P = average annual number of crashes in the analysis year, calculated in Step 2,

CRF = crash reduction factor,

EAF = exposure adjustment factor,

C_P = estimated cost of the crash in the analysis year, explained in the next section, and

PWF_{SP} = present worth factor (single payment) calculated as

$$PWF_{SP} = \frac{1}{(1+I)^T}$$

where:

I = interest rate, and

T = service life of the safety improvement.

This step returns the value of the total annual benefits for each year of the service life of the safety project calculated in dollar value of the analysis year. *AB* are summed for the entire service life of the project to obtain the total crash benefit, termed as present worth benefit (*PWB)*. *PWB* is multiplied by capital recovery factor to obtain equivalent uniform annual benefit as shown in Equation 5.7.

$$PWB = \sum_{k=1}^{T} AB_k \ , \qquad 5.6$$

$$EUAB = PWB \times CF \qquad 5.7$$

where:

CF = capital recovery factor,

PWB = present worth benefit, and

$EUAB$ = equivalent uniform annual benefit.

Crash cost values are of major importance in computing the expected crash benefits. The most commonly used sources of information about crash costs are the National Safety

Council (NSC) and the National Highway Traffic Safety Administration (NHTSA). The NSC cost estimates include wage losses, medical expenses, insurance administrative costs, and property damage. The NHTSA cost estimates includes the calculable costs associated with each fatality and injury plus the costs to society. INDOT recommends NSC crash cost values. In 2001, NSC proposed a value of \$6,500 for a PDO crash, \$36,500 for an injury crash, and \$104,000 for a fatal crash. In order to find the cost of an injury/fatal crash, number of injury and fatal crashes occurring on various types of facilities was determined from the Indiana crash database. These numbers are listed in Table 5.2. The number of injury crashes was taken as the weight for injury crashes and number of fatal crashes was taken as the weight for fatal crashes. The resulting weighted average is taken as crash cost values for different facilities. These values are listed in Table 3.5.

Step 6. Calculate the present worth of total agency costs.

Equivalent uniform annual costs (*EUAC*) can be calculated using Equation 5.8.

$$EUAC = (PC + M \times PWF_{EPS} - S \times PWF_{SP}) \times CF \qquad 5.8$$

where:

PC = initial project implementation cost,

M = change in annual maintenance cost,

CF = capital recovery factor,

PWF_{SP} = present worth factor (single payment),

S = salvage value,

PWF_{EPS} = present worth factor (equal payment series) calculated as

$$PWF_{EPS} = \frac{(1+I)^T - 1}{I(1+I)^T}$$

where:

I = interest rate, assumed to be 4% unless otherwise specified, and

T = service life of the safety improvement.

Table 5.2 Number of crashes on various road facilities

Crash Type	Year	Property Damage Only	Injury	Fatal
Interstate urban routes	97	3673	947	15
	98	3513	885	17
	99	3995	960	12
Interstate rural routes	97	6171	1545	53
	98	5428	1322	61
	99	6117	1516	60
US/SR urban routes	97	14831	5312	49
	98	14969	5322	63
	99	15224	5276	74
US/SR rural routes	97	22505	7836	316
	98	21245	7586	331
	99	21601	7175	327
Local urban routes	97	105198	25973	171
	98	104708	26371	144
	99	107128	24738	156
Local rural routes	97	40341	12509	239
	98	40222	12182	258
	99	41610	12051	257

Step 7. Calculate the *B/C* ratio and *NAB*. The *B/C* ratio is obtained by dividing the *EUAB* by the *EUAC* as shown in Equation 5.9 and *NAB* is obtained by subtracting the *EUAC* from *EUAB* shown in Equation 5.10.

$$B/C = \frac{EUAB}{EUAC}, \qquad 5.9$$

$$NAB = EUAB - EUAC \qquad 5.10$$

Step 8. Conclusions. The *B/C* ratio and the *NAB* of the project are considered to determine the economic feasibility of the project. When the *B/C* ratio is greater than one, the safety project is economically prudent.

CHAPTER 6. POST-IMPLEMENTATION STUDY

The effectiveness of a safety project at a location should be tested for the significance of crash reduction and crash reduction factor should be calculated for the implemented safety project. This chapter reviews the state of the art and state of the practice for a post-implementation study; proposes a method to calculate new crash reduction factor for an implemented safety project; combines the old crash reduction factor with the new crash reduction factor to give an updated crash reduction factor; and checks whether the reduction in crashes was statistically significant.

6.1. Current Methods

The purpose of a post-implementation study is to check the effect of an implemented project on safety. This section discusses the current state of art for estimating crash reduction and checking the significance of crash reduction due to the implementation of the safety project.

6.1.1. Estimating Crash Reduction

Crash reduction from a safety project can be estimated using one of the following two methods, a before and after study or a cross-sectional analysis.

Before and after study is more widely used for examining the effects of implementation of safety projects. A Cross-sectional analysis has limited use because it compares the safety of two entities that are of a very different nature but it is often used when a safety improvement substantially modifies the location (Hauer, 1997). For example, when an unsignalized intersection is converted to a signalized intersection, cross sectional analysis is used to compare the safety of signalized intersections with unsignalized intersections. Before and after studies, investigates the change from a safety improvement at a location where most of their other attributes remain unchanged. The safety effects before and after the improvement are also noted (Hauer, 1997). The basic components of a before and after study are, predicting the safety of the location in the period after the implementation of the safety project had the safety project not been implemented, A_{0A}; and estimating the safety of the location in the period after the implementation of the project, A_A; (Hauer, 1997). Different methods are available to calculate A_{0A} which will be discussed in subsequent sections. A_A is generally taken as the number of counts in the period after the implementation of the project. Mahalel (1986), and Hauer (1997) have examined the question of whether crash frequency or crash rate is a better indicator of safety and concluded that crash frequency is a better estimator of safety as crash rates assume a linear relationship of crashes and exposure, which might not be true at high exposure rates.

The various methods in predicting the safety of a location in the period after the implementation of the safety project, had the safety project not been implemented, can be calculated using the following methods:

- Naive before and after study
- Adjustment for changes in exposure
- Control group

- Empirical Bayes approach

The Naive before and after study assumes that with the passage of the time there is no change in the factors affecting the safety of the location other than the tested safety improvement. Therefore, the crash count before the implementation of the safety project is equal to the expected count after its implementation (before and after periods are equal) had the safety project not been implemented. The resulting change in the number of crashes is due to the effect of the safety project and factors which can be measured such as changes in exposure, and unmeasured factors such as changes in weather, standards of reporting, or driver behavior. These factors may also produce bias in estimates as the method does not incorporate the "regression to mean". When a shorter duration of period before and after the implementation of safety project is chosen, the changes are mainly due to the safety project as the above mentioned factors would not change appreciably in a shorter duration (Hauer 1997).

The change in exposure may affect the safety at the location. As data on change in exposure can be measured, the expected number of crashes after the implementation of the safety project, had the safety project not been implemented, A_{0A}, should be adjusted for this change. Traffic volumes are collected before and after implementation of the safety project. As the safety performance functions link the expected number of crashes and exposure, A_{0A} is adjusted for changes in exposure before and after implementation of the safety project (Hauer, 1997).

The Naive before and after study cannot distinguish between the changes caused by the safety project and by other unmeasured causes such as changes in weather, standards of reporting or driver behavior. Control groups are used to predict the estimate caused by unmeasured factors. A group of locations where no safety improvement has taken place and similar to the location where the safety project has been implemented are selected. The control group will be indicative of safety changes by unrecognized factors on the assumption that these factors have changed similarly on these locations and have the same safety effect on the control group and the locations where safety projects have been implemented (Hauer 1997).

Due to the highly random nature of crashes, crashes tend to reduce at high crash locations even without implementation of safety project, which is known as the "regression to mean effect" (Abbess, et al., 1981). In order to counter this effect, the Empirical Bayes method is used, where the expected number of crashes after the implementation of the safety project had the safety project not been implemented, A_{0A}, is calculated using the crash counts in the before period and expected crash frequency at similar locations (Hauer 1997). A loglinear regression model proposed by Maycock and Maher (1988) is used to calculate expected crash frequency for similar locations using exposure and other geometric characteristics of the location. The Emperical Bayes method can be used together with the control group to get the advantages of both methods.

Cross-sectional analysis includes comparing the safety of a group of locations having a common feature with a group of locations that do not have such a feature (Hauer 1997). For example, to study the effect of adding a signal to an unsignalized intersection, the safety of unsignalized intersections is compared with signalized intersections. In this method the locations do not undergo any major changes within the study period (Tarko et al., 1996).

6.1.2. Testing the Significance of Crash Reduction

Current state-of-practice for testing the significance in crash reduction is discussed as follows.

McShane and Roess (1990) use Poisson, Chi Square, or Normal Distribution for checking the significance of crash reduction. Figure 1 is taken from "Manual of Traffic Engineering Studies" (Box and Oppenlander, 1976) and uses a Chi Square and Poisson distributions to test the significance of crash reduction with an 8% significance level.

Normal distribution is also used to test the significance of crash reduction. In this method crash counts are assumed to be Poisson distributed with their mean equal to variance. A normal approximation is assumed for large Poisson counts and Z is calculated using Equation 6.1. The Z value is compared to a critical Z^*, calculated for a particular significance level, to check for crash reduction at a particular significance level.

Previous work by Abbess et al. (1981) and Maher (1987) have found that Negative Binomial distribution is in good agreement with the crash data; therefore these methods need to be updated. The current state-of-practice does not take into account the "regression to mean effect," using control locations and multiple locations in the post-implementation study and updating crash reduction factors.

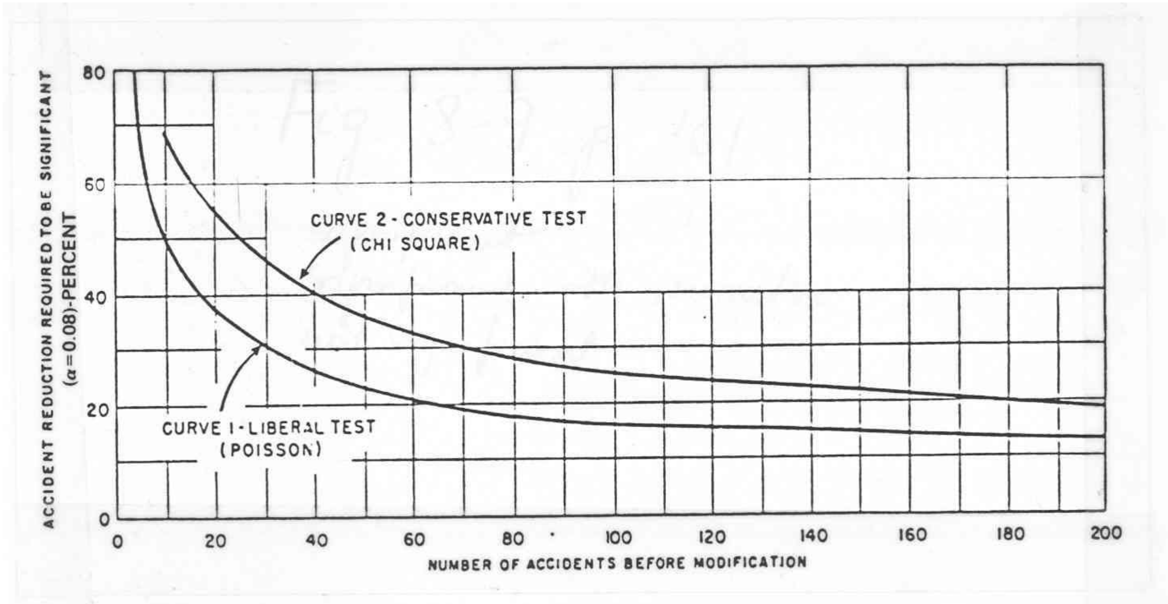

Figure 6.1 Chi square and Poisson test for crash reduction significance, (Box and Oppenlander, 1976)

$$Z = \frac{A_B - A_A}{\sqrt{A_B + A_A}} \qquad 6.1$$

where:

A_B = number of accidents during *n* years before the treatment, and

A_A = no. of accidents *n* years after the treatment.

6.2. Proposed Methods

The proposed method takes into consideration the "regression to mean effect," changes in exposure, control groups, and multiple locations to calculate crash reduction factors for implemented safety projects in order to calculate and update crash reduction factors and check the statistical significance of the reduction in crashes. The following sections discuss in detail the calculations of the above mentioned factors.

6.2.1. Crash Reduction Factors

The crash reduction factor is used to calculate the benefits provided by the safety project. The crash reduction factor for the project is calculated using crash data before and after implementing the safety project, for which the equations are presented below. Expected crash frequency in the period after implementation of the safety project, had the safety project not been implemented, is calculated using Equation 6.2, accounting for the "regression to mean effect" and changes in exposure at the location. CRF_2, the new crash reduction factor and its standard deviation, is calculated using Equation 6.8 and Equation 6.9, (Tarko, 2003).

$$a_{0A} = \frac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \times \left(\frac{E_A}{E_B}\right)^Z, \qquad 6.2$$

$$a_A = \frac{A_A}{Y_A}, \qquad 6.3$$

$$\theta = \frac{a_A}{a_{0A}}, \qquad 6.4$$

$$Var(\theta) = \left(\frac{1}{a_{0A}}\right)^2 \times Var(a_A) + \left(\frac{a_A}{a_{0A}{}^2}\right) \times Var(a_{0A}), \qquad 6.5$$

$$Var(a_{0A}) = \frac{\frac{1}{D} + A_B}{\left(\frac{1}{D \times a_B} + Y_B\right)^2} \times \left(\frac{E_A}{E_B}\right)^{2Z}, \qquad 6.6$$

$$Var(a_A) = \frac{A_A}{Y_A{}^2}, \qquad 6.7$$

$$CRF_2 = \left(1 - \frac{a_A}{a_{0A}} - \frac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100\ ,, \quad 6.8$$

$$SD_2 = \sqrt{\frac{Var(a_A)}{(a_{0A})^2} + \frac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100\ . \quad 6.9$$

where:

a_{0A} = expected number of crashes per year in the period after implementation of the safety project had the safety project not been implemented,

a_B = expected crash frequency estimate (crashes / year) calculated using safety performance functions,

D = over-dispersion parameter,

A_B = number of crashes during the period before implementation of the safety project,

Y_B = number of years for which crash data is analyzed before implementation of the safety project,

E_B = average daily exposure during the period before the safety project is implemented (exposure for intersections is average AADT at the intersection whereas for segments it is the product of AADT and the length of the segment),

E_A = average daily exposure during the period after the safety project is implemented,

a_A = number of crashes per year during the period after the implementation of safety project,

A_A = number of crashes during the period after the implementation of safety project for which crash data is collected,

Y_A = number of years for which crash data is analyzed after the implementation of safety project,

θ = crash reduction,

$Var(\theta)$ = variance of θ,

CRF_2 = crash reduction factor calculated using the crash data obtained after implementing the safety project, in percent,

$Var(a_{0A})$ = variance of a_{0A},

$Var(a_A)$ = variance of a_A, and

SD_2 = Standard deviation of the crash reduction factor for the implemented safety project, in percent.

6.2.2. Crash Reduction Factor using a Control Group

In order to account for unknown factors that may cause a change in the number of crashes after implementation of the safety project, crash reduction factors are calculated using a control group, which consists of locations that have characteristics similar to locations where the safety project is implemented, but at these locations the safety project is not implemented. The expected number of crashes per year in the period after implementation of the safety project, a_{0A}, the number of crashes per year during the period after the implementation of the safety project, a_A, the crash reduction, θ, and the variance of crash reduction, $Var(\theta)$, are calculated using Equations 6.2, 6.3, 6.4, and 6.5 respectively for locations in the control group. Using these values, the crash reduction factor and its standard deviation is calculated using Equations 6.10 and 6.11 respectively (Tarko, 2003).

$$CRF_2 = \left(1 - \frac{\theta}{\theta'}\right) \times 100, \qquad 6.10$$

$$SD_2 = 100 \times \sqrt{\left(\frac{1}{\theta'}\right)^2 \times Var(\theta) + \left(\frac{\theta}{\theta'^2}\right)^2 \times Var(\theta')} \qquad 6.11$$

where:

θ = crash reduction,

$Var(\theta)$ = variance of θ,

θ' = crash reduction at the location with control group,

$Var(\theta')$ = variance of θ',

CRF_2' = crash reduction factor after implementing the safety project with control group, in percent, and

SD_2' = standard deviation of the crash reduction factor for the implemented safety project with the control location, in percent.

6.2.3. Crash Reduction Factor for Multiple Sites

The crash reduction factor for multiple sites with a control group is calculated using the following equations (Tarko, 2003). The expected number of crashes per year in the period after the implementation of safety project and its variance, a_A; $Var(a_A)$, and the number of crashes per year during the period after implementation of the safety project and its variance , a_{0A}; $Var(a_{0A})$, are calculated for each treated location and untreated (control) location. The total values for the treated sites and control group locations are calculated using Equations 6.12, 6.13, 6.14, and 6.15. Crash reduction and its variance, θ, $Var(\theta)$, and crash reduction and its variance for control group, θ' and $Var(\theta')$ are calculated using Equations 6.4 and 6.5, as for a single location but using the total values for a_A, $Var(a_A)$, a_{0A}, and $Var(a_{0A})$. The crash reduction factor and its standard deviation using a control group are calculated using Equations 6.10 and 6.11 respectively, while crash reduction factors and its standard deviation without using a control group are calculated using Equations 6.8 and 6.9 (Tarko, 2003).

$$a_A = \sum_i a_{Ai} \qquad 6.12$$

$$Var(a_A) = \sum_i Var(a_{Ai}) \qquad 6.13$$

$$a_{0A} = \sum_i a_{0Ai} \qquad 6.14$$

$$Var(a_{0A}) = \sum_i Var(a_{0Ai}) \qquad 6.15$$

6.2.4. Updating Crash Reduction Factor

The updated crash reduction factor, *CRF*, is calculated using the CRF_1 and CRF_2 estimates and their standard deviations SD_1 and SD_2 respectively using Equation 6.16 (Tarko, 2003). In order to derive the equation it is assumed that the old and new crash reduction factors are independent. The calculated *CRF* becomes CRF_1 for further analysis of safety projects and for updating the crash reduction factor.

$$CRF = \frac{SD_1^2 \times CRF_2 + SD_2^2 \times CRF_1}{SD_1^2 + SD_2^2} \qquad 6.16$$

where:

CRF = updated crash reduction factor, percent,

CRF_1 = crash reduction for the project proposed by Tarko et al. (2000),

CRF_2 = crash reduction factor calculated using the crash data obtained after implementing the safety project, in percent,

SD_1 = standard deviation of the old crash reduction factor, in percent, and

SD_2 = standard deviation of the new crash reduction factor for the implemented safety project, in percent.

The standard deviation of the updated crash reduction factor is calculated using Equation 6.17, which uses standard deviations SD_1 and SD_2. The calculated SD becomes SD_1 for further analysis of safety projects and for updating the crash reduction factor.

$$SD = \sqrt{\frac{SD_2^4 \times SD_1^2 + SD_1^4 \times SD_2^2}{(SD_1^2 + SD_2^2)^2}} \qquad 6.17$$

where:

SD = standard deviation of updated crash reduction factor,

SD_1 = standard deviation of the old crash reduction factor, in percent, and

SD_2 = standard deviation of the new crash reduction factor for the implemented safety project, in percent.

6.2.5. Significance of Crash Reduction

The effectiveness of the safety project should be tested to determine whether the reduction in crashes is large enough to exclude fluctuations caused solely by crashes. The recommended period before and after the implementation is three years for each period but longer periods increase the confidence of the results and should be considered. In all cases, the periods should be multiples of full years to eliminate the undesirable effect of seasonal variations of crashes. As stated earlier, Negative Binomial distribution is used to model crash data.

It is not suitable to compare only the data before the implementation of the safety project with the data after implementation due to presence of the "regression to mean effect." The number of crashes at the location had the project not been implemented is calculated using the crash counts and the expected number of crashes at the location using Equation 6.18. The expected number of crashes for the after period if there were no project implementation takes into account the changes in exposure, the "regression to mean effect," and the time period of the data collected before and after the improvement. This value is compared to the actual number of crashes that occurred during the same period calculated using Equation 6.23.

$$\overline{A_{0Ai}} = Y_{Ai} \times a_{0Ai} \times \theta' \qquad 6.18$$

$$Var\left(\overline{A_{0Ai}}\right) = Y_{Ai}{}^{2} \times \left(a_{0Ai}{}^{2} \times SD_{2}{}' + \theta'^{2} \times Var\left(a_{0Ai}\right)\right) \qquad 6.19$$

$$\overline{A_{0A}} = \sum_{i} \overline{A_{0Ai}} \qquad 6.20$$

$$Var\left(\overline{A_{0A}}\right) = \sum_{i} Var\left(\overline{A_{0Ai}}\right) \qquad 6.21$$

$$D_{0A} = \frac{Var\left(\overline{A_{0A}}\right) - \overline{A_{0A}}}{\left(\overline{A_{0A}}\right)^{2}} \qquad 6.22$$

$$A_{A} = \sum_{i} A_{Ai} \qquad 6.23$$

where :

$\overline{A_{0Ai}}$ = expected number of crashes at the location had the project not been implemented during the after period at a treated location i,

Y_{Ai} = number of years for which crash data is analyzed after the implementation of safety project i,

$\theta^{'}$ = crash reduction at the location with control group,

a_{0Ai} = expected number of crashes per year in the period after implementation of the safety project i had the safety project not been implemented,

$SD_2^{'}$ = standard deviation of the crash reduction factor for the implemented safety project with the control location, in percent,

$Var(\overline{A_{0Ai}})$ = variance of $\overline{A_{0Ai}}$,

$Var(a_{0Ai})$ = variance of a_{0Ai},

$\overline{A_{0A}}$ = sum of expected number of crashes at the location had the project not been implemented during the after period for all treated locations,

D_{0A} = over-dispersion for $\overline{A_{0Ai}}$,

A_A = sum of crashes at the treated locations during the after period.

Negative Binomial distribution is used to calculate the critical number of crashes for a given, $\overline{A_{0A}}$ and D_{0A}. If the crashes after the implementation of the safety project, A_A, are less than the critical number of crashes for a particular significance level, the crash reduction is said to be significant at that significance level as shown by Equation 6.25.

$$\Pr(A \le A_A) = \text{Cumulative Negative Binomial}\left(A_A, \overline{A_{0A}}, D_{0A}\right), \qquad 6.24$$

$$\text{If } \Pr(A \le A_A) \le \text{ Significance level.} \qquad 6.25$$

Figure 6.2 and 6.3 will help in determining whether the reduction in crashes is significant at 10% significance level based on Negative Binomial distribution. Figure 6.2 is used when D_A is greater than 0.01, and Figure 6.3 is used when D_A is less than 0.01. For low values of D_A, Negative Binomial distribution can be approximated as Poisson distribution, and Figure 6.3 is thus made using Poisson distribution. Using D_A and corresponding $\overline{A_A}$, the critical number of crashes is determined from the Y axis of Figure 6.2 or Figure 6.3 depending on the value of D_A. If the number of crashes in the period after the project implementation is less than the critical number of crashes, then the safety improvement is statistically significant at 10% level of significance.

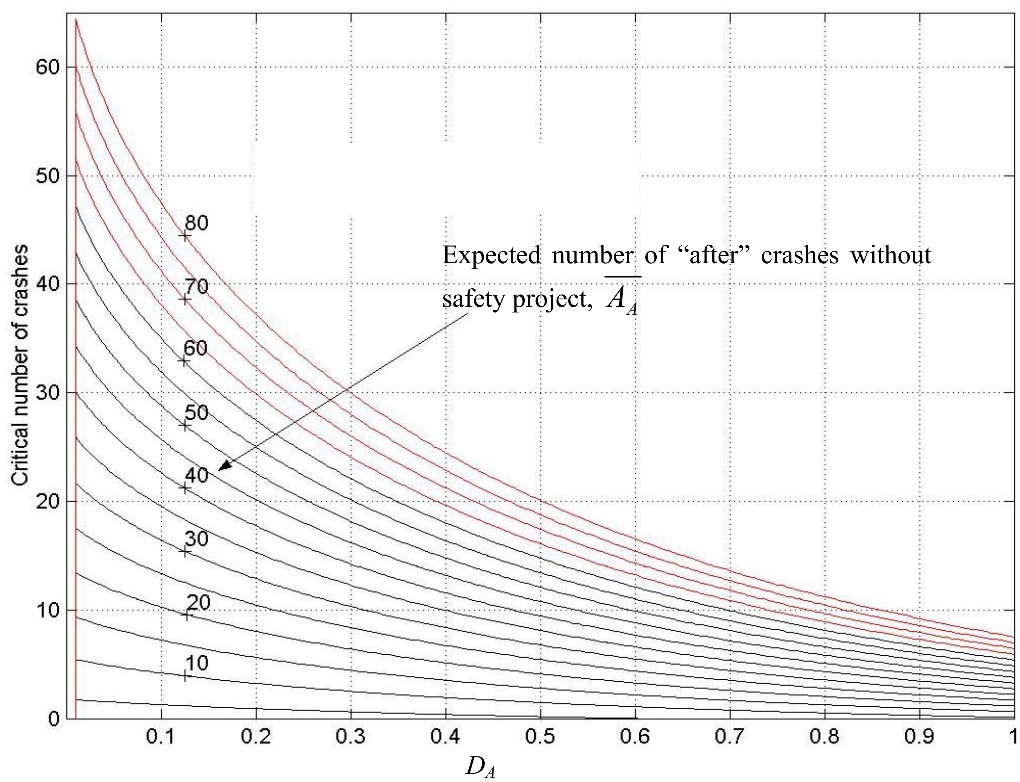

Figure 6.2 Critical number of crashes for D_A greater than 0.01, at a significance level of 10%

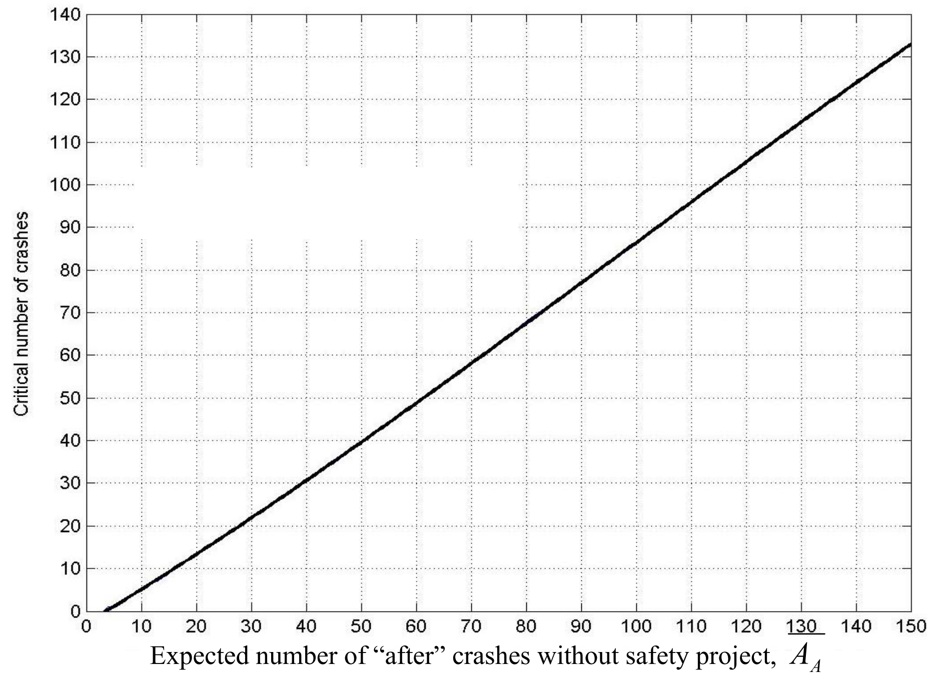

Figure 6.3 Critical number of crashes for D_A less than 0.01, at a significance level of 10%

CHAPTER 7. CONCLUSION

The objective of the research was to develop guidelines that present a set of tools for hazard elimination through road improvements. The guidelines would promote similarity and uniformity of safety methods and analyses performed across INDOT and local transportation agencies in Indiana. A well-designed and uniformly implemented safety management system across agencies would make the effort by transportation agencies more effective.

The guidelines include identification of high crash locations; identification of safety deficiencies and determination of adequate countermeasures by conducting safety reviews at high crash locations; economic evaluation of safety projects; an update of crash reduction factors using the crash reduction factor for the implemented safety improvement; and a check of the statistical significance of the crash reduction by implementation of the safety project. Worksheets were developed to provide a concise step-wise procedure for various calculations used in the HEP.

The research objectives also included developing regression models for predicting crash frequencies at all-way and two-way stop-controlled intersections. These models would be a part of the methodology to identify high crash locations and other phases of local safety management through road improvements. Negative Binomial distribution was used to develop these models. Separate models were developed for two-way and all-way stop controlled intersections. These models would predict typical crash frequency, typical PDO crash frequency, and typical I/F crash frequency at unsignalized intersections.

The worksheets can be used as a starting point for developing software for various analytical tools used in HEP. The safety performance functions were developed considering crashes which occurred within 100 feet of the intersection. These functions should be updated if INDOT decides to use a different length to classify crashes as intersection related crashes. The guidelines should be a continuing document, which should be updated every 10 years or so to incorporate new ideas in safety and present the state of art in safety management.

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LIST OF REFERENCES

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APPENDIX A

List of locations used in developing safety performance functions for unsignalized intersections

Table A.1 Two-way stop-controlled intersections with flashers

County	Route 1	Route 2	Property Damage Only	Injury/Fatal
Allen	US 30	SR 101	2	6
Allen	SR 37	SR 101	4	7
Boone	SR 32	SR 75	0	4
Daviess	US 50 / 150	SR 257	12	21
Elkhart	SR 13	SR 4	5	1
Fulton	US 31	SR 110	3	1
Gibson	SR 57	SR 168	1	2
Henry	US 40	SR 3	3	0
Jasper	US 231	SR 110	3	8
Lagrange	SR 120	SR 5	6	1
Lawrence	SR 37	SR 54	12	11
Miami	US 24	SR 19	6	4
Pike	SR 57	SR 356	4	0
Ripley	US 421	SR 350	6	1
Scott	SR 256	SR 203	3	4
Steuben	US 20	SR 327	9	4
Sullivan	US 41 / 150	SR 58	0	2
Washington	SR 56	SR 337	0	0
White	US 421	SR 16	4	1

Table A.2 Two-way stop-controlled intersections without flashers

County	Route 1	Route 2	Property Damage Only	Injury/Fatal
Allen	US 24	SR 101	1	6
Blackford /Jay	SR 26	SR 167	0	0
Fountain	US 41	SR 32	3	2
Franklin	US 52	SR 229	2	0
Grant	SR 22	SR 5	1	1
Hamilton	SR 37	SR 213	2	1
Hendricks	SR 75	SR 236	1	0
Hendricks/Putnam	SR 75	SR 240	2	0
Howard	US 35/ SR 22	SR 213	4	0
Huntington	SR 9	SR 105	1	0
Huntington	SR 105	SR 124	1	0
Huntington	US 224	SR 116	1	1
Lagrange	US 20	SR 3	3	2
Marshall	SR 10	SR 117	0	0
Marshall	SR 110	SR 117	0	0
Perry	SR 62	SR 145	1	2
Pike	SR 64	SR 257	0	0
Randolph	US 36	SR 227	3	0
Scott	SR 203	SR 362	0	1
Starke	SR 10	SR 23	0	0
Steuben	SR 127	SR 827	5	3
Washington	SR 39	SR 256	0	0

Table A.2 All-way stop-controlled intersections with flashers

County	Route 1	Route 2	Property Damage Only	Injury/Fatal
Bartholomew	SR 9	SR 46	4	2
Blackford	SR 3	SR 18	3	0
Boone	US 421	SR 32	9	2
Clark	US 31	SR 160	8	0
Clinton	SR 26	SR 29	5	2
Dearborn	SR 46	SR 1	3	1
Dekalb	SR 205	SR 327	3	5
Fulton	SR 19	SR 14 / 114	4	0
Grant	SR 5	SR 18	4	0
Grant	US 35/ SR 22	SR 13	11	3
Greene	SR 231	SR 57	6	1
Greene	SR 48	SR 59	0	0
Greene	SR 45	SR 58	2	0
Harrison	SR 135	US 150	8	1
Hendricks	US 136	SR 39	4	0
Huntington	SR 3	SR 124	1	0
Huntington	SR 9	SR 218	5	5
Huntington	US 224	SR 3	2	0
Huntington	SR 3	SR 218	2	0
Jefferson	SR 3	SR 256	0	0
Johnson	SR 44	SR 144	7	0
Knox	SR 58	SR 159	0	0
Knox	SR 59	SR 67	1	0
Laporte	US 421	SR 8	4	1
Madison	SR 32	SR 13	8	2
Madison	SR 13	SR 38	2	1
Pike	SR 56	SR 257	0	0
Porter	SR 8	SR 49	8	1
Pulaski	US 35	SR 119	14	0
Ripley	SR 101	SR 350	5	1
Ripley	SR 46	SR 129	0	0
Shelby	US 52	SR 9	6	2
Spencer	SR 62	SR 162	2	1
Switzerland	SR 56	SR 250	1	0
Warrick	SR 9	SR 68	5	0

Table A.2 All-way stop-controlled intersections without flashers

County	Route 1	Route 2	Property Damage Only	Injury/Fatal
Dekalb	SR 8	SR 327	13	3
Fountain	SR 55	SR 341	1	0
Hamilton	SR 38	SR 47	1	0
Huntington	SR 3	SR 116	2	0
Huntington	SR 16	SR 105	1	0
Newton	SR 114	SR 55	0	0
Steuben	SR 120	SR 327	1	0
Switzerland	SR 129	SR 250	0	0
Washington	SR 39	SR 256	0	0

APPENDIX B

Limdep output for safety performance functions for unsignalized intersections

Limdep output for Equation 3.7

$$\overline{A} = e^{K}\left(\frac{Q_1 + Q_2}{2}\right)^{\beta} e^{\gamma F}$$

Two-way stop-controlled intersections

```
+--------------------------------------------+
| Negative Binomial Regression               |
| Maximum Likelihood Estimates               |
| Dependent variable                 TOT     |
| Weighting variable                 ONE     |
| Number of observations              85     |
| Iterations completed                 8     |
| Log likelihood function      -208.7720     |
| Restricted log likelihood    -237.0612     |
| Chi-squared                   56.57821     |
| Degrees of freedom                   1     |
| Significance level            .0000000     |
+--------------------------------------------+
+---------+--------------+----------------+--------+---------+----------+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of X|
+---------+--------------+----------------+--------+---------+----------+
 Constant -5.268270492      1.2844893       -4.101   .0000
 LAADT3    .8060734501      .16746327        4.813   .0000  7.9108194
 FLASH     .7320368952      .20561921        3.560   .0004  .52941176
         Overdispersion parameter for negative binomial model
 Alpha     .2518547577      .72606801E-01    3.469   .0005
```

```
+--------------------------------------------+
| Negative Binomial Regression               |
| Maximum Likelihood Estimates               |
| Dependent variable                 PDO     |
| Weighting variable                 ONE     |
| Number of observations              85     |
| Iterations completed                 8     |
| Log likelihood function      -167.4480     |
| Restricted log likelihood    -174.7057     |
| Chi-squared                   14.51556     |
| Degrees of freedom                   1     |
| Significance level            .1390063E-03 |
+--------------------------------------------+
+---------+--------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+--------------+----------------+--------+---------+----------
+
 Constant -5.661370912      1.5565506       -3.637   .0003
```

```
 LAADT3    .7822450640      .20026707        3.906   .0001  7.9108194
 FLASH     .7148488844      .22613899        3.161   .0016  .52941176
          Overdispersion parameter for negative binomial model
 Alpha     .1903091266      .64617640E-01    2.945   .0032
              +---------------------------------------------+
              | Negative Binomial Regression                |
              | Maximum Likelihood Estimates                |
              | Dependent variable                 INJ      |
              | Weighting variable                 ONE      |
              | Number of observations              85      |
              | Iterations completed                 8      |
              | Log likelihood function      -163.5039      |
              | Restricted log likelihood    -186.1801      |
              | Chi-squared                   45.35223      |
              | Degrees of freedom                   1      |
              | Significance level            .0000000      |
              +---------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -6.096573935      2.0753373       -2.938   .0033
 LAADT3    .8061848133      .26426888        3.051   .0023  7.9108194
 FLASH     .7753401121      .26656017        2.909   .0036  .52941176
          Overdispersion parameter for negative binomial model
 Alpha     .5185977233      .15626628        3.319   .0009
```

All-way stop-controlled intersections

```
               +---------------------------------------------+
               | Negative Binomial Regression                |
               | Maximum Likelihood Estimates                |
               | Dependent variable                   TOT    |
               | Weighting variable                   ONE    |
               | Number of observations                69    |
               | Iterations completed                   8    |
               | Log likelihood function       -165.1220    |
               | Restricted log likelihood     -197.9883    |
               | Chi-squared                    65.73260    |
               | Degrees of freedom                     1    |
               | Significance level             .0000000    |
               +---------------------------------------------+
+---------+--------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+--------------+----------------+--------+---------+----------
+
 Constant -8.995605818      1.9321990       -4.656   .0000
 LAADT3    1.234498946      .23825868        5.181   .0000  8.0448979
 FLASH     .4409615268      .31737203        1.389   .1647  .79710145
          Overdispersion parameter for negative binomial model
 Alpha     .4278042218      .85981360E-01    4.976   .0000

               +---------------------------------------------+
               | Negative Binomial Regression                |
               | Maximum Likelihood Estimates                |
               | Dependent variable                   PDO    |
               | Weighting variable                   ONE    |
               | Number of observations                69    |
               | Iterations completed                   8    |
               | Log likelihood function       -145.0129    |
               | Restricted log likelihood     -156.6303    |
               | Chi-squared                    23.23497    |
               | Degrees of freedom                     1    |
               | Significance level             .1432939E-05 |
               +---------------------------------------------+
+---------+--------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+--------------+----------------+--------+---------+----------
+
 Constant -10.40201545      2.0896460       -4.978   .0000
 LAADT3    1.376995647      .24554906        5.608   .0000  8.0448979
 FLASH     .4096627893      .31921393        1.283   .1994  .79710145
          Overdispersion parameter for negative binomial model
 Alpha     .2545785434      .73645285E-01    3.457   .0005

               +---------------------------------------------+
               | Negative Binomial Regression                |
               | Maximum Likelihood Estimates                |
               | Dependent variable                   INJ    |
               | Weighting variable                   ONE    |
               | Number of observations                69    |
               | Iterations completed                   8    |
               | Log likelihood function       -89.94091    |
               | Restricted log likelihood     -114.6535    |
               | Chi-squared                    49.42520    |
```

```
              | Degrees of freedom                    1      |
              | Significance level            .0000000       |
              +----------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -5.987108667      4.5627940       -1.312   .1895
 LAADT3    .6679972507      .59620811        1.120   .2625  8.0448979
 FLASH     .6000100869      .79452804         .755   .4501  .79710145
         Overdispersion parameter for negative binomial model
 Alpha     2.001427423      .62799780        3.187   .0014
```

Stop-controlled intersections

```
               +---------------------------------------------+
               | Negative Binomial Regression                |
               | Maximum Likelihood Estimates                |
               | Dependent variable                 TOT      |
               | Weighting variable                 ONE      |
               | Number of observations             154      |
               | Iterations completed                 8      |
               | Log likelihood function      -382.0647      |
               | Restricted log likelihood    -454.8209      |
               | Chi-squared                   145.5123      |
               | Degrees of freedom                   1      |
               | Significance level            .0000000      |
               +---------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -6.552511310      1.0633435       -6.162   .0000
 LAADT3    .9615681250      .13701977        7.018   .0000  7.9708935
 FLASH     .4986081654      .17639207        2.827   .0047  .64935065
         Overdispersion parameter for negative binomial model
 Alpha     .3765126760      .60732355E-01    6.200   .0000

               +---------------------------------------------+
               | Negative Binomial Regression                |
               | Maximum Likelihood Estimates                |
               | Dependent variable                 PDO      |
               | Weighting variable                 ONE      |
               | Number of observations             154      |
               | Iterations completed                 7      |
               | Log likelihood function      -315.3405      |
               | Restricted log likelihood    -335.6621      |
               | Chi-squared                   40.64313      |
               | Degrees of freedom                   1      |
               | Significance level            .0000000      |
               +---------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -7.554451066      1.0816681       -6.984   .0000
 LAADT3    1.023364932      .13292532        7.699   .0000  7.9708935
 FLASH     .5525170075      .15809906        3.495   .0005  .64935065
         Overdispersion parameter for negative binomial model
 Alpha     .2383402138      .50621783E-01    4.708   .0000

               +---------------------------------------------+
               | Negative Binomial Regression                |
               | Maximum Likelihood Estimates                |
               | Dependent variable                 INJ      |
               | Weighting variable                 ONE      |
               | Number of observations             154      |
               | Iterations completed                 8      |
               | Log likelihood function      -270.7985      |
               | Restricted log likelihood    -344.5591      |
```

```
              | Chi-squared                      147.5210      |
              | Degrees of freedom                      1      |
              | Significance level               .0000000      |
              +----------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -6.391645648      2.2108669       -2.891   .0038
 LAADT3    .8229271287      .28510362        2.886   .0039  7.9708935
 FLASH     .4465493538      .32052475        1.393   .1636  .64935065
         Overdispersion parameter for negative binomial model
 Alpha     1.237868305      .24946292        4.962   .0000
```

Limdep output for Equation 3.5

$$\overline{A} = e^{K} Q_1^{\beta 1} Q_2^{\beta 2} e^{\gamma F}$$

Two–way stop-controlled intersections

```
+-----------------------------------------------+
| Negative Binomial Regression                  |
| Maximum Likelihood Estimates                  |
| Dependent variable                  TOT       |
| Weighting variable                  ONE       |
| Number of observations               85       |
| Iterations completed                 10       |
| Log likelihood function       -201.9893       |
| Restricted log likelihood     -219.9482       |
| Chi-squared                    35.91776       |
| Degrees of freedom                    1       |
| Significance level             .0000000       |
+-----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Constant	-7.449286406	1.2606000	-5.909	.0000	
LAADT1	.4038460910	.15316029	2.637	.0084	8.3069037
LAADT2	.7445721383	.17643994	4.220	.0000	7.1069126
FLASH	.4765697071	.20724489	2.300	.0215	.52941176
	Overdispersion parameter for negative binomial model				
Alpha	.1809679801	.52814568E-01	3.426	.0006	

```
+-----------------------------------------------+
| Negative Binomial Regression                  |
| Maximum Likelihood Estimates                  |
| Dependent variable                  PDO       |
| Weighting variable                  ONE       |
| Number of observations               85       |
| Iterations completed                 10       |
| Log likelihood function       -160.8552       |
| Restricted log likelihood     -163.9176       |
| Chi-squared                    6.124605       |
| Degrees of freedom                    1       |
| Significance level             .1333131E-01   |
+-----------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Constant	-8.205298833	1.5105996	-5.432	.0000	
LAADT1	.3831765613	.16824838	2.277	.0228	8.3069037
LAADT2	.7938245374	.18704023	4.244	.0000	7.1069126
FLASH	.4318407695	.21823610	1.979	.0478	.52941176
	Overdispersion parameter for negative binomial model				
Alpha	.1095870700	.63405064E-01	1.728	.0839	

```
+--------------------------------------------+
| Negative Binomial Regression               |
| Maximum Likelihood Estimates               |
| Dependent variable                 INJ     |
| Weighting variable                 ONE     |
| Number of observations              85     |
| Iterations completed                 9     |
| Log likelihood function      -160.8578     |
| Restricted log likelihood    -179.5851     |
| Chi-squared                   37.45463     |
| Degrees of freedom                   1     |
| Significance level            .0000000     |
+--------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Constant	-8.132490817	2.2184506	-3.666	.0002	
LAADT1	.4393752709	.25830225	1.701	.0889	8.3069037
LAADT2	.6812050542	.30853584	2.208	.0273	7.1069126
FLASH	.5489261762	.29191141	1.880	.0600	.52941176
	Overdispersion parameter for negative binomial model				
Alpha	.4485976624	.13680038	3.279	.0010	

All-way stop-controlled intersections

```
                +--------------------------------------------+
                | Negative Binomial Regression               |
                | Maximum Likelihood Estimates               |
                | Dependent variable                 TOT     |
                | Weighting variable                 ONE     |
                | Number of observations              69     |
                | Iterations completed                10     |
                | Log likelihood function      -165.3795     |
                | Restricted log likelihood    -200.2139     |
                | Chi-squared                   69.66878     |
                | Degrees of freedom                   1     |
                | Significance level            .0000000     |
                +--------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -8.868602941      2.0603382       -4.304   .0000
 LAADT1    .5405114581      .16259755        3.324   .0009  8.2396771
 LAADT2    .6881437264      .23350691        2.947   .0032  7.7344149
 FLASH     .4801669105      .35317950        1.360   .1740  .79710145
          Overdispersion parameter for negative binomial model
 Alpha     .4461516609      .92587088E-01    4.819   .0000

                +--------------------------------------------+
                | Negative Binomial Regression               |
                | Maximum Likelihood Estimates               |
                | Dependent variable                 PDO     |
                | Weighting variable                 ONE     |
                | Number of observations              69     |
                | Iterations completed                 9     |
                | Log likelihood function      -145.8069     |
                | Restricted log likelihood    -158.3256     |
                | Chi-squared                   25.03726     |
                | Degrees of freedom                   1     |
                | Significance level            .0000000     |
                +--------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -10.12752753      2.1418213       -4.728   .0000
 LAADT1    .8051202462      .16831452        4.783   .0000  8.2396771
 LAADT2    .5401343308      .21694754        2.490   .0128  7.7344149
 FLASH     .4121002071      .34232831        1.204   .2287  .79710145
          Overdispersion parameter for negative binomial model
 Alpha     .2718453406      .77946672E-01    3.488   .0005

                +--------------------------------------------+
                | Negative Binomial Regression               |
                | Maximum Likelihood Estimates               |
                | Dependent variable                 INJ     |
                | Weighting variable                 ONE     |
                | Number of observations              69     |
                | Iterations completed                10     |
                | Log likelihood function      -88.97097     |
```

```
               | Restricted log likelihood     -112.2879       |
               | Chi-squared                    46.63394       |
               | Degrees of freedom                    1       |
               | Significance level             .0000000       |
               +-----------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -6.359908993      5.2032799       -1.222   .2216
 LAADT1   -.1790509711      .63025260        -.284   .7763  8.2396771
 LAADT2    .9207636375      .75402777        1.221   .2220  7.7344149
 FLASH     .6642341986      .90515598         .734   .4630  .79710145
         Overdispersion parameter for negative binomial model
 Alpha     1.893602819      .58927203        3.213   .0013
```

Stop-controlled intersections

```
+-------------------------------------------+
| Negative Binomial Regression              |
| Maximum Likelihood Estimates              |
| Dependent variable                   TOT  |
| Weighting variable                   ONE  |
| Number of observations               154  |
| Iterations completed                   9  |
| Log likelihood function      -380.5861    |
| Restricted log likelihood    -451.4405    |
| Chi-squared                   141.7087    |
| Degrees of freedom                     1  |
| Significance level            .0000000    |
+-------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Constant	-7.089527639	1.0700819	-6.625	.0000	
LAADT1	.6355787887	.11964773	5.312	.0000	8.2767827
LAADT2	.4037686693	.12844415	3.144	.0017	7.3880662
FLASH	.4218958719	.19518044	2.162	.0307	.64935065
	Overdispersion parameter for negative binomial model				
Alpha	.3659575121	.58912873E-01	6.212	.0000	

```
+-------------------------------------------+
| Negative Binomial Regression              |
| Maximum Likelihood Estimates              |
| Dependent variable                   PDO  |
| Weighting variable                   ONE  |
| Number of observations               154  |
| Iterations completed                   8  |
| Log likelihood function      -311.5755    |
| Restricted log likelihood    -329.4638    |
| Chi-squared                   35.77662    |
| Degrees of freedom                     1  |
| Significance level            .0000000    |
+-------------------------------------------+
```

Variable	Coefficient	Standard Error	b/St.Er.	P[|Z|>z]	Mean of X
Constant	-8.435565353	1.1348572	-7.433	.0000	
LAADT1	.6036716411	.12956847	4.659	.0000	8.2767827
LAADT2	.5570308012	.12029364	4.631	.0000	7.3880662
FLASH	.4105328780	.18085654	2.270	.0232	.64935065
	Overdispersion parameter for negative binomial model				
Alpha	.2139836054	.46966503E-01	4.556	.0000	

```
+-------------------------------------------+
| Negative Binomial Regression              |
| Maximum Likelihood Estimates              |
| Dependent variable                   INJ  |
| Weighting variable                   ONE  |
| Number of observations               154  |
| Iterations completed                   9  |
| Log likelihood function      -270.1871    |
```

```
               | Restricted log likelihood     -341.1156      |
               | Chi-squared                    141.8571      |
               | Degrees of freedom                    1      |
               | Significance level             .0000000      |
               +----------------------------------------------+
+---------+--------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+--------------+----------------+--------+---------+----------
+
 Constant -6.156798052      2.2751712       -2.706   .0068
 LAADT1    .6995134446      .20434961        3.423   .0006  8.2767827
 LAADT2    .6529973195E-01  .27923136         .234   .8151  7.3880662
 FLASH     .5170479475      .35525546        1.455   .1456  .64935065
          Overdispersion parameter for negative binomial model
 Alpha     1.211488840      .24649446        4.915   .0000
```

Limdep output for Equation 3.6

$\overline{A} = e^{K} \left(Q_1 Q_2\right)^{\beta} e^{\gamma F}$

Two–way stop-controlled intersections

```
               +-----------------------------------------------+
               | Negative Binomial Regression                  |
               | Maximum Likelihood Estimates                  |
               | Dependent variable                  TOT       |
               | Weighting variable                  ONE       |
               | Number of observations               85       |
               | Iterations completed                  8       |
               | Log likelihood function       -203.0618       |
               | Restricted log likelihood     -222.4282       |
               | Chi-squared                    38.73281       |
               | Degrees of freedom                    1       |
               | Significance level             .0000000       |
               +-----------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -7.211859073      1.2988879       -5.552   .0000
 LPROAADT  .5437489942      .87353015E-01    6.225   .0000  15.413816
 FLASH     .5394831602      .20760785        2.599   .0094  .52941176
         Overdispersion parameter for negative binomial model
 Alpha     .1918647533      .57099125E-01    3.360   .0008


               +-----------------------------------------------+
               | Negative Binomial Regression                  |
               | Maximum Likelihood Estimates                  |
               | Dependent variable                  PDO       |
               | Weighting variable                  ONE       |
               | Number of observations               85       |
               | Iterations completed                  8       |
               | Log likelihood function       -162.3221       |
               | Restricted log likelihood     -166.1731       |
               | Chi-squared                    7.702018       |
               | Degrees of freedom                    1       |
               | Significance level             .5515914E-02   |
               +-----------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -7.876276336      1.5829543       -4.976   .0000
 LPROAADT  .5490123990      .10440554        5.258   .0000  15.413816
 FLASH     .5120265483      .22358713        2.290   .0220  .52941176
         Overdispersion parameter for negative binomial model
 Alpha     .1267320848      .53622846E-01    2.363   .0181

               +-----------------------------------------------+
               | Negative Binomial Regression                  |
               | Maximum Likelihood Estimates                  |
               | Dependent variable                  INJ       |
               | Weighting variable                  ONE       |
               | Number of observations               85       |
```

```
               | Iterations completed                   8      |
               | Log likelihood function        -161.0674      |
               | Restricted log likelihood      -180.0608      |
               | Chi-squared                     37.98687      |
               | Degrees of freedom                     1      |
               | Significance level              .0000000      |
               +-----------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -7.972800805      2.2173442       -3.596   .0003
 LPROAADT  .5392008114      .14541356        3.708   .0002  15.413816
 FLASH     .5925311894      .28222533        2.099   .0358  .52941176
          Overdispersion parameter for negative binomial model
 Alpha     .4549024702      .13961969        3.258   .0011
```

All-way stop-controlled intersections

```
                +---------------------------------------------+
                | Negative Binomial Regression                |
                | Maximum Likelihood Estimates                |
                | Dependent variable                 TOT      |
                | Weighting variable                 ONE      |
                | Number of observations              69      |
                | Iterations completed                 8      |
                | Log likelihood function      -165.4505      |
                | Restricted log likelihood    -200.3813      |
                | Chi-squared                   69.86166      |
                | Degrees of freedom                   1      |
                | Significance level            .0000000      |
                +---------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -8.842337274      1.8967999       -4.662   .0000
 LPROAADT  .6109943060      .11783814        5.185   .0000  15.974092
 FLASH     .4692779281      .34166375        1.374   .1696  .79710145
         Overdispersion parameter for negative binomial model
 Alpha     .4433520165      .91640455E-01    4.838   .0000

                +---------------------------------------------+
                | Negative Binomial Regression                |
                | Maximum Likelihood Estimates                |
                | Dependent variable                 PDO      |
                | Weighting variable                 ONE      |
                | Number of observations              69      |
                | Iterations completed                 8      |
                | Log likelihood function      -146.0462      |
                | Restricted log likelihood    -159.8298      |
                | Chi-squared                   27.56732      |
                | Degrees of freedom                   1      |
                | Significance level            .0000000      |
                +---------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -10.10672772      2.1611904       -4.676   .0000
 LPROAADT  .6742923649      .12789593        5.272   .0000  15.974092
 FLASH     .4374686182      .36049144        1.214   .2249  .79710145
         Overdispersion parameter for negative binomial model
 Alpha     .2839462941      .78635855E-01    3.611   .0003


                +---------------------------------------------+
                | Negative Binomial Regression                |
                | Maximum Likelihood Estimates                |
                | Dependent variable                 INJ      |
                | Weighting variable                 ONE      |
                | Number of observations              69      |
                | Iterations completed                 8      |
                | Log likelihood function      -89.84712      |
```

```
                | Restricted log likelihood     -114.4829      |
                | Chi-squared                    49.27158      |
                | Degrees of freedom                    1      |
                | Significance level             .0000000      |
                +------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -6.090763056      4.3706859       -1.394   .1635
 LPROAADT  .3422330311      .28675250        1.193   .2327  15.974092
 FLASH     .6077737913      .79380910         .766   .4439  .79710145
         Overdispersion parameter for negative binomial model
 Alpha     1.992157808      .62671660        3.179   .0015
```

Stop-controlled intersections

```
               +--------------------------------------------+
               | Negative Binomial Regression               |
               | Maximum Likelihood Estimates               |
               | Dependent variable                  TOT    |
               | Weighting variable                  ONE    |
               | Number of observations              154    |
               | Iterations completed                  8    |
               | Log likelihood function       -381.2934    |
               | Restricted log likelihood     -455.5808    |
               | Chi-squared                    148.5748    |
               | Degrees of freedom                    1    |
               | Significance level             .0000000    |
               +--------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -7.066703213      1.1078465       -6.379   .0000
 LPROAADT  .5266668677      .74035602E-01    7.114   .0000  15.664849
 FLASH     .3822539431      .19864805        1.924   .0543  .64935065
          Overdispersion parameter for negative binomial model
 Alpha     .3742129328      .60322341E-01    6.204   .0000


               +--------------------------------------------+
               | Negative Binomial Regression               |
               | Maximum Likelihood Estimates               |
               | Dependent variable                  PDO    |
               | Weighting variable                  ONE    |
               | Number of observations              154    |
               | Iterations completed                  8    |
               | Log likelihood function       -311.6077    |
               | Restricted log likelihood     -329.6716    |
               | Chi-squared                    36.12775    |
               | Degrees of freedom                    1    |
               | Significance level             .0000000    |
               +--------------------------------------------+
+---------+-------------+----------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+----------------+--------+---------+----------
+
 Constant -8.416871926      1.1279102       -7.462   .0000
 LPROAADT  .5808142016      .72586563E-01    8.002   .0000  15.664849
 FLASH     .4032913643      .18223451        2.213   .0269  .64935065
          Overdispersion parameter for negative binomial model
 Alpha     .2147252945      .47035739E-01    4.565   .0000

               +--------------------------------------------+
               | Negative Binomial Regression               |
               | Maximum Likelihood Estimates               |
               | Dependent variable                  INJ    |
               | Weighting variable                  ONE    |
               | Number of observations              154    |
               | Iterations completed                  8    |
               | Log likelihood function       -271.8122    |
               | Restricted log likelihood     -348.9460    |
```

```
               | Chi-squared                      154.2676     |
               | Degrees of freedom                      1     |
               | Significance level               .0000000     |
               +-------------------------------------------+
+---------+-------------+---------------+--------+---------+----------
+
|Variable | Coefficient  | Standard Error |b/St.Er.|P[|Z|>z] | Mean of
X|
+---------+-------------+---------------+--------+---------+----------
+
 Constant -6.343505097      2.3254070       -2.728   .0064
 LPROAADT  .4189351383      .15313570        2.736   .0062  15.664849
 FLASH     .3882726239      .34316211        1.131   .2579  .64935065
          Overdispersion parameter for negative binomial model
 Alpha     1.275025435      .25619643        4.977   .0000
```

Final Report

FHWA/IN/JTRP-2003/19

HAZARD ELIMINATION PROGRAM - MANUAL ON IMPROVING SAFETY OF INDIANA ROAD INTERSECTIONS AND SECTIONS

Volume 2
Guidelines for Highway Safety Improvements in Indiana

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16. Abstract

The Hazard Elimination Program (HEP) is the section of the Safety Management System that focuses on road improvements and includes analytical tools for identification of safety problems and their remedies. This research project reviews the results of the past research for Indiana and other states and to develop guidelines that present a set of tools for hazard elimination through road improvements. It also includes developing regression models for predicting crash frequencies at all-way and two-way stop-controlled intersections.

Negative Binomial regression was used to develop separate models for two-way and all-way stop controlled intersections. These models predict typical frequency of all crashes, PDO crashes, and injury/fatal crashes at unsignalized intersections. In addition, improved criteria have been proposed for screening the Indiana road network for high-crash locations. The proposed criteria incorporate the level of uncertainty present in the process and consider severity of crashes.

The primary outcome of the project is the "Guidelines for Highway Safety Improvements in Indiana," which comprises the second volume. Within this volume, the research results are compiled with other components selected after critical analysis of the present state-of-the-art and state-of-the-practice safety management methods. The Guidelines are ready to use by safety engineers and may also serve as a textbook for inexperienced users. The Guidelines include all required equations, tables with required default values, and calculation forms that organize the HEP process. The calculation forms can be used as an interface design for a computerized version. All major computational steps are illustrated with examples and a comprehensive example is included to demonstrate the entire HEP process.

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CHAPTER 1

Introduction

The road network is the backbone of the U.S. economy that facilitates the transportation of goods and people. It is imperative to identify and improve high crash locations in the road network in order to reduce crashes that cause economic and emotional hardship. The Intermodal Surface Transportation Efficiency Act (ISTEA) of 1991 triggered development of the Safety Management System (SMS) in various states. The Transportation Equity Act for the 21st Century (TEA 21) of 1997 encouraged further development of the SMS.

1.1 Safety management system

The primary aim of the SMS is to reduce the number and severity of traffic crashes by ensuring that all opportunities to improve safety are identified, considered, implemented, and evaluated. The SMS serves as a tool to make informed decisions regarding proper allocation of transportation resources. Its potential benefits include improving relationships among various disciplines involved in highway safety, improving analytical tools for problem identification, and providing decision-support tools for policymakers and managers to direct limited resources to solve safety problems.

The Hazard Elimination Program (HEP) focuses on road improvements and provides analytical tools for identification of safety problems and their remedies. It provides a systematic approach to find, analyze, and improve high crash locations. The program aims at identifying high crash locations, conducting safety reviews to find the causes of crashes and corresponding road deficiencies, suggesting appropriate countermeasures, grouping countermeasures to form projects, determining the economic feasibility of projects, and conducting an evaluation of the implemented safety project to provide feedback to the program.

1.2 Purpose and content of the guidelines

The guidelines provide a description of the HEP process and analytical methods to facilitate the HEP. The guidelines may serve as a textbook for inexperienced users and as a reference for experienced users. The guidelines have a complete set of equations, tables, forms, and reference material for all components of the HEP process. For example, the guidelines contains equations and tables to calculate the indices of crash frequency and crash cost, with suitable examples to illustrate the step wise calculation of these indices. Also a form is provided to illustrate the stepwise procedure for calculating these indices.

1.3 Organization of the guidelines

The guidelines consist of eight chapters and several appendices. Chapter 1 gives an overview of the guidelines, a brief description of the SMS and a brief description of the HEP. Chapter 2 describes the HEP and its components in more detail. Chapter 3 describes data acquisition and management in the HEP and information available in the databases used in safety management in Indiana. Chapter 4 describes criteria that can be used in identifying high crash locations and how the data extracted from the databases referenced in Chapter 3 are used to check the degree of hazard noted at various road locations. Chapter 5 provides tools to analyze sites that are identified as high crash locations in Chapter 4 and suggest countermeasures for identified safety deficiencies. Chapter 6 outlines a methodology to perform an economic analysis of countermeasures selected in Chapter 5. A method for evaluating projects after they have been implemented is provided in Chapter 7, as well as a method for updating crash reduction factors. Chapter 8 provides a comprehensive example illustrating the entire analysis process.

CHAPTER 2

THE Hazard elimination program (HEP)

The key elements of the HEP are data acquisition and management, analysis of data, and project implementation and evaluation, which form a cyclic process. Figure 2.1 shows the relationship of these components, which are briefly described in this chapter.

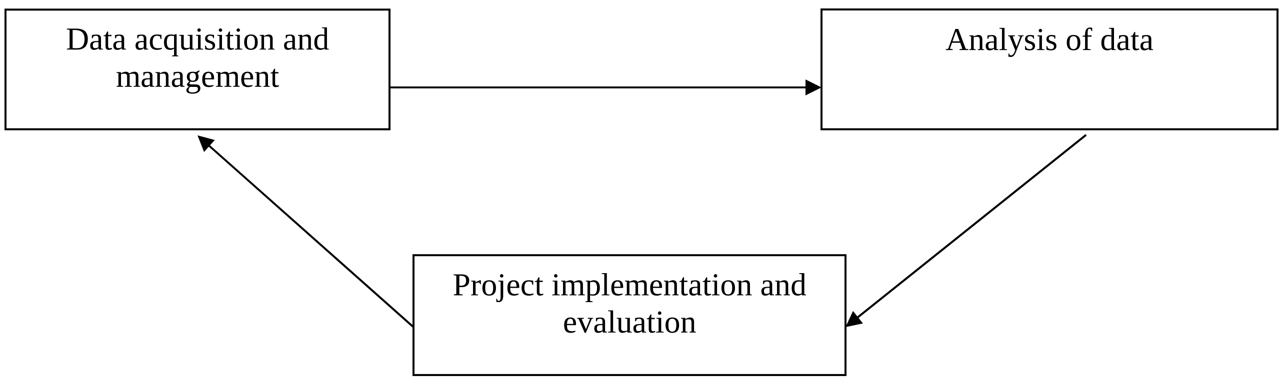

Figure 2.1 Cycle of the HEP

2.1 Data acquisition and management

Data acquisition and management includes collecting, filing, sharing, and summarizing data used in the HEP, which is comprised of crash data, traffic data, and road inventory data. When at a crash scene, police officers collect crash data, which is then sent to the state police department and entered in a crash database. Indiana Department of Transportation (INDOT) collects and maintains the road inventory data for Indiana. INDOT shares this data with other agencies involved in road safety management. The Indiana Bureau of Motor Vehicles and insurance companies also have data that although not used in the current HEP, may be used in the future.

2.2 Analysis of data

The components of a process that form the core of the HEP, are shown in Figure 2.2. They are explained in detail in the coming chapters.

2.2.1 Identifying high crash locations

Sites that have safety problems are selected from thousands of candidates. Typically, a small scope of data is available for all sites, which includes the type of location (intersection, segment), basic geometric characteristics, traffic volume, and crash records. A priority list of sites for further investigation is prepared using a specific criterion. Site selection should be done carefully as selecting safe locations incur unjustified costs for their detailed analysis, while not selecting high crash locations defeats the purpose of the program as these sites would not be considered in the current program cycle.

2.2.2 Determining causes

After high crash locations are selected, safety reviews are conducted to determine the cause of crashes at these locations. Crash data are analyzed to identify predominant crash patterns and to determine probable causes of crashes. Consequently, on-site visits, including safety checks and engineering studies, are conducted to identify the safety deficiencies.

2.2.3 Determining countermeasures

A countermeasure is a specific road improvement or set of road improvements that contribute to the solution of an identified safety problem at a road location (FHWA,1981). After safety reviews are conducted and a list of possible causes of crashes is prepared, the suitable countermeasures addressing these causes are pointed out.

2.2.4 Developing safety projects

Various countermeasures may be grouped together to form safety projects that are believed to be feasible and effective in improving safety.

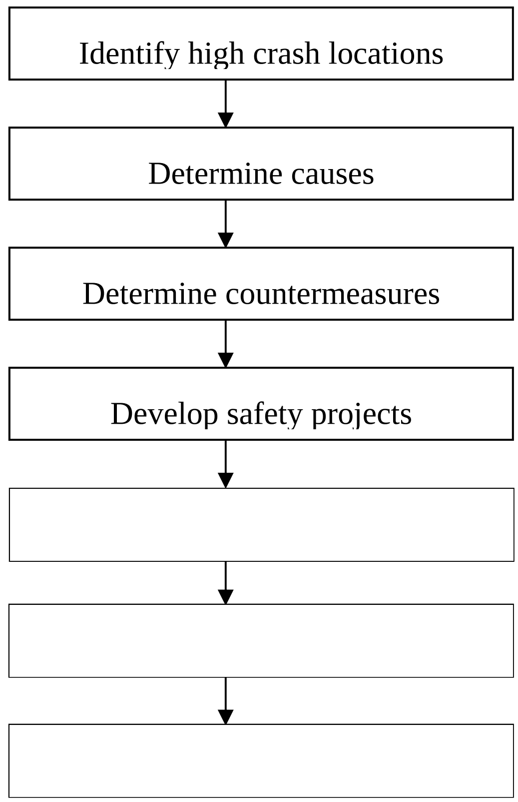

Figure 2.2 Process of the HEP

2.2.5 Selecting projects for implementation

The next step includes selecting safety projects based on priority ranking obtained from an economic evaluation of safety projects. Restricted budgets demand achieving the greatest overall safety benefit from choices made. From potential projects for multiple high crash locations, the selected projects are expected to be cost effective and maximize overall safety benefit.

2.3 Project implementation and evaluation

The effectiveness of an implemented safety project in reducing the number of crashes should be evaluated. These results can be used to update crash reduction factors and determine whether the safety project was statistically significant in reducing the number of crashes.

CHAPTER 3

Data Acquisition and Management

The need for data that is accurate and complete is imperative in the HEP. This chapter describes the HEP relevant information available in the Indiana databases.

3.1 Crash database

The Indiana State Police Accident Information System Accidents Master Files, which will be referred to as the crash database, contains information about crashes reported in Indiana. The information is gathered by police officers at the crash scene using the officer standard crash report form shown in Appendix A. Familiarity of the guidelines users with the form will help in understanding the meaning and appropriate use of the crash data.

Data for each crash is coded in a set of records containing information about the environment, vehicles, and drivers involved in the crash. The details of the fields in these records are given in the Trans Master Code Book (Automotive Transportation Center, 1993).

Each crash is described with a set of records. The set of records begins with an environment record which describes the location of a crash, the circumstances, and the surrounding conditions. The crash location is described by the pseudo number of the road on which the crash occurred, the pseudo number of the reference road (crossing road), and the distance and direction from the reference road. Pseudo numbers are six digits long and are assigned to road names. A police officer at the crash scene enters the names of roads and other location information on the crash report, and the road names are then converted to pseudo numbers when data from the crash report is entered into the crash database. Starting 2003, the crash locations are represented in the crash database with pairs of GIS coordinates that are obtained by converting the location information in crash reports through the use of digital maps.

The information on the circumstances of a crash includes the primary contributing reason for the crash, the type of crash, collision diagram information, the light and weather conditions, and the type and character of road surface. Other information in environment records contains the date of the crash, the number of vehicles involved, the number of people injured or dead, the severity of crash, the township and city, the traffic flow direction, the damage estimate for non-vehicular property, the response time, and the investigating agency.

The fields in vehicle records include crash id, vehicle year, vehicle type, vehicle use, speed limit, direction of travel, number of occupants, number of axles, crash contributing circumstances, pre-crash vehicular action, people involved in the crash, traffic control at the crash site, and whether the control devices were operational.

The driver records describe the driver, license number, injury, and alcohol or drug test information for each driver. The records also include the age and gender of the driver, the location and nature of injury, type of driver license, and whether safety equipment was used by the driver.

3.2 Road inventory database

INDOT's most extensive database is the Road Inventory Database (RIDB). Details of the fields in these records are given in the INDOT Road Inventory (INDOT Road Inventory). The database is divided into two parts: description files (DES) and detail files (DET). One pair of these files exists for each county in Indiana.

The DES file contains records defining the beginnings and ends of road sections (links), segment lengths, and other information. Road link endpoints are defined at crossing roads, bottleneck bridges, county lines, urban area boundaries, and any other break points that necessitate an information change in either the DET or DES file. The DES file records the beginning of the inventory road (the road that is being traveled) at its starting point in the county. The successive records code every cross street or other significant point along the traveled inventory road. The end of the inventory road is then coded again at its endpoint in the county. Data in the DES file is coded in a manner to conveniently handle many cases, including divided highways and travel-over sections. A divided road is traversed in one direction and then the segments not covered in the first pass are traversed in the opposite direction. The DES file contains information about the beginning and the end of travel-overs. A travel-over section is a portion of an INDOT highway, which has two or more INDOT highway numbers assigned to it. This occurs when two INDOT routes overlap for some length.

The DET file contains information such as the number of lanes, the presence of turning lanes, the AADT, the shoulder and median widths, and the pavement data for every road link coded in the DES file. The link between the DET and DES files is provided through a number in the *drk* field, which is common to both fields. This number is unique in the DET file; however, if consecutive links in the DES file share similar characteristics, their *drk* numbers may refer to the same record in the DET file.

The RIDB contains data for almost all road sections administered by INDOT. Highways under this jurisdiction are State Routes, US Routes, and Interstates. Outside this group, the completeness of the database records decreases as the classification of road decreases. Data for local, county, and city roads may be present but may be not as complete as data for INDOT highways.

3.3 Pseudo number reference list

The pseudo number reference list is a file that lists road names and corresponding pseudo numbers. This list is used to convert road names in crash reports into the pseudo numbers used in the Indiana crash database. The list is updated each year.

3.4 Other sources of data

Useful information can be retrieved from other sources such as the Indiana Bureau of Motor Vehicles, hospitals, and insurance companies. Although this data is not used in the current HEP, the availability of this data should be kept in mind.

CHAPTER 4

Identification of High Crash Locations

Sites are selected from thousands of candidates that may have safety problems. A priority list for sites that need improvement is prepared using a specific criterion. The scope of data for locations under consideration is limited. It should be remembered that if the locations with serious safety problems are not identified during the identification phase, they are not considered again in the current cycle of the Hazard Elimination Program. In order to use resources efficiently, only high crash locations should be selected for safety reviews.

4.1 Identification criteria

Various ways of identifying high crash locations (HCL) are presented below, and the criteria recommended for Indiana are described in the next section. The recommended criteria can be used for two purposes: to develop a prioritization list of locations according to the level of hazard and to confirm the safety hazards at individual locations.

Two general criteria used in identification of a HCL are a system wide perspective and an individual user perspective. The systems perspective criterion aims at reducing as many crashes as practical and promoting the most cost-effective method for mitigation of hazard. The user perspective criterion aims at reducing excessive risk faced by individual users, which promotes fairness of the highway system by equalizing the risk faced by users. These two criteria typically point out different locations as hazardous (Tarko and Kanodia, 2004).

Crash frequency is a system perspective criterion. It is a basic measure of crash experience and easy to use as it requires only crash data. The crash frequency is estimated by dividing the number of crashes by the number of years. Selecting locations with a high crash frequency does not consider exposure to risk, i.e. does not take into account volume or vehicle miles traveled (VMT). Locations with high exposure to risk tend to occupy higher positions on a prioritization list. Crash frequencies can be compared with a critical crash frequency to determine which locations are high crash locations.

Crash rate is a user perspective criterion. It is the number of crashes divided by the amount of exposure to risk at the location. For an intersection, a crash rate is recommended to be the annual number of crashes per million vehicles passing the intersection. For a roadway segment, a crash rate is recommended to be the annual number of crashes per 100 million vehicle-miles traveled (VMT). Crash rates can be compared with a critical crash rate to determine which locations are high crash locations.

Crash frequencies and crash rates can be estimated for all crashes or for each crash severity separately. Another way of considering severity is applying weights that depend on crash severity. Combined, fatal (F) and injury (I) crashes have a weight higher than property damage only (PDO) crashes. For instance, a local policy may apply a weight of 6 to each fatal or injury crash and a weight of 1 to PDO crashes. The weighted number of fatal and injury crashes, when added to the number of PDO crashes gives the equivalent property damage only (EPDO) number of crashes. The EPDO value is used to calculate the equivalent crash frequency or the equivalent crash rate.

Selection of period length for analysis is an important decision. The period should be short to ease quick identification of changes in crash frequency or rate, however, the period should be long enough to enable confident identification of HCL. Generally, the recommended time is three years, and multiples of one year are preferred to avoid bias caused by seasonal fluctuations.

When identifying high crash locations, fatal crashes should be analyzed for longer periods (for example, ten years) to counteract the highly random nature of fatal crashes. A high number of fatal crashes could also serve as a complimentary criterion to the criteria mentioned above. Long periods should be used with caution because significant changes in geometry and traffic volumes can occur during these periods.

4.2 Index of crash frequency

A crash frequency and a crash rate explained in Section 4.1 do not consider uncertainty caused by random variability in number of crashes. Consequently, a high value of crash frequency or crash rate may be caused by randomness and not by high hazard. To incorporate consideration of random crash variability, an index of crash frequency should be used. This measure combines the system and user perspectives with a stronger emphasis on the system perspective.

The index of crash frequency (I_{CF}) measures the difference between expected and reported number of crashes divided by the standard deviation of the difference estimate. For example, I_{CF} =2 indicates that the number of crashes at the location exceeds the expected number of crashes for that location by two standard deviations. A set of predictive equations is presented in Table 4.1 for calculating the expected number of crashes at a particular location (Lamptey et al, 2004; Tarko et al., 2000). These equations ensure fairness of the system by the equalization of risk experienced by users. Index of crash frequency is calculated using Eq 4.1.

$$I_{CF} = \frac{A - a \times Y}{\sqrt{A + a^2 \times Y^2 \times D}} \qquad \text{Eq 4.1}$$

where :

A = number of crashes during Y years,

a = typical crash frequency calculated using Table 4.1,

Y = number of years in analyzed period, in years, and

D = over-dispersion parameter taken from Table 4.1. The smaller the factor, the better the typical crash frequency estimate.

The index of crash frequency can be used in two different ways. In the first method, a number of locations can be ranked using the index of crash frequency. The sorted locations form a priority list for safety reviews, starting with the location for which the evidence of a high crash location is strongest. In the second method, a location may be singled out by public complaints or prior knowledge. In such cases the I_{CF} can be used to determine whether this location is actually a high crash location. If the location has an I_{CF} value greater than 2, then the location may be considered a high crash location. The higher the I_{CF} value, the stronger is the evidence for the location being a high crash location.

Table 4.1 Safety performance functions

Facility	**Safety Performance Functions**	**Over-dispersion parameter (*D*)**
Signalized intersection	$a = 0.30 \times Q^{0.953}$	0.655
Two-way stop-controlled intersection	$a = 0.522 \times Q^{1.093}$	0.359
All-way stop-controlled intersection	$a = 0.274 \times Q^{1.324}$	0.447
Rural two-lane road segment	$a = 0.922 \times L \times Q^{0.598}$	0.427
Rural multilane road segment	$a = 0.737 \times L \times Q^{0.654}$	0.473
Urban two-lane road segment	$a = 0.733 \times L \times Q^{0.917}$	1.459
Urban multilane road segment	$a = 2.641 \times L \times Q^{0.458}$	2.095
Rural interstate	$a = 0.212 \times L \times Q^{0.939}$	1.642
Urban interstate	$a = 0.0056 \times L \times Q^{2.016}$	2.819

a = typical crash frequency in Indiana , in crashes per year,

Q = AADT entering the intersection or along the road segment, in thousand vehicles per day,

D = over-dispersion parameter, and

L = road segment length, in miles.

The following steps summarize the procedure to identify high crash locations.

Step 1. Classify the locations in one of the nine categories: signalized intersection, two-way stop-controlled intersection, all-way stop-controlled intersection, rural multilane road segment, rural two-lane road segment, urban multilane road segment, urban two-lane road segment, rural interstate, and urban interstate.

Step 2. Collect the data as required for each category, which includes the number of crashes at the location, the number of years for which crash data is collected, the AADT entering the intersection or along the road segment, and the length for segments.

Step 3. Calculate the typical crash frequency, *a*, using the safety performance functions in Table 4.1.

Step 4. Calculate the indices of crash frequency I_{CF} using Eq 4.1.

Step 5. Sort the list of locations by I_{CF}.

EXAMPLE 4.1 Comparing two locations using index of crash frequency

From two locations: signalized intersection and urban two-lane segment, select the one with the stronger evidence of hazard. Use the index of crash frequency as a criterion.

Signalized intersection

Step 1. Classify the location in one of the nine categories. The location is a signalized intersection.

Step 2. Collect the data required for the signalized intersection. The schematic of the signalized intersection with AADT values is shown in Figure 4.1. The AADT is obtained from the flow maps provided by INDOT.

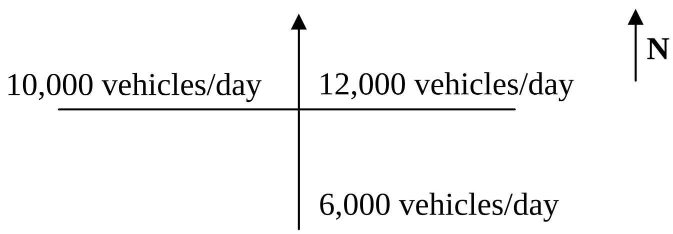

Figure 4.1 Schematic diagram of the intersection showing the AADT values

The east bound and west bound legs are two-way and the north bound leg is one-way. The total traffic entering this intersection is: Q= (10+12)/2+6 = 17 thousand veh/ day. Twenty-eight crashes were reported (A=28) over two years (Y=2). The crash data is extracted from the crash database.

Step 3. Calculate, a, using the safety performance function for signalized intersections from Table 4.1. The required input is Q =17 thousand veh/day.

$a = 0.30 \times 17^{0.953} = 4.46$ crashes/year

Step 4. Calculate I_{CF} using Eq 4.1. The required input is: A = 28 crashes, a = 4.46 crashes/year, Y = 2 years, D = 0.655 (Table 4.1).

$$I_{CF} = \frac{28 - 4.46 \times 2}{\sqrt{(28 + 4.46^2 \times 2^2 \times 0.655)}} = 2.13$$

Urban two-lane segment

Step 1. Classify the location in one of the nine categories. The location is an urban two-lane segment.

Step 2. Collect the data required for the segment. AADT for the segment is 2000 vehicles/day, (Q=2 thousand veh/day), and the length of the road section is 2.5 miles, (L=2.5). Thirty two crashes were reported over two years, (A= 32, Y=2).

Step 3. Calculate, a, using the safety performance functions for an urban two-lane segment from Table 4.1. The required input is shown in Step 2.

$a = 0.733 \times 2.5 \times 2^{0.917} = 3.46$ crashes/ year

Step 4. Calculate I_{CF} using Equation 4.1. The required input is shown in Steps 2 and 3. The required input is: A = 32 crashes, a = 3.46 crashes/year, Y = 2 years, D = 1.459 (Table 4.1).

$$I_{CF} = \frac{32 - 3.46 \times 2}{\sqrt{(32 + 3.46^2 \times 2^2 \times 1.459)}} = 2.48$$

Discussion of the results

The indication of being a high crash location is stronger for the urban two-lane segment than for the intersection as the index of crash frequency for the urban two-lane segment is greater than that for the signalized intersection. It should also be noted, though, that I_{CF} is greater than 2 in both cases, which indicates that both locations are likely to be high crash locations.

EXAMPLE 4.2 Analyzing an extended road section with index of crash frequency

An extended road segment shown in Figure 4.2 is comprised of three intersections and two segments. The second segment was too long, so it was divided into two sub segments, B and C. The intersections are named 1, 2, and 3. From the six locations A, B, C, 1, 2, and 3 in Figure 4.2, select two locations with the strongest evidence of being high crash locations. The I_{CF} is used to rank the locations.

The calculations for the segments and intersections follow steps 1 – 5 described earlier, and the calculations are similar to those given in Example 4.1 so are thus not repeated here. The required inputs and results are given in Table 4.2.

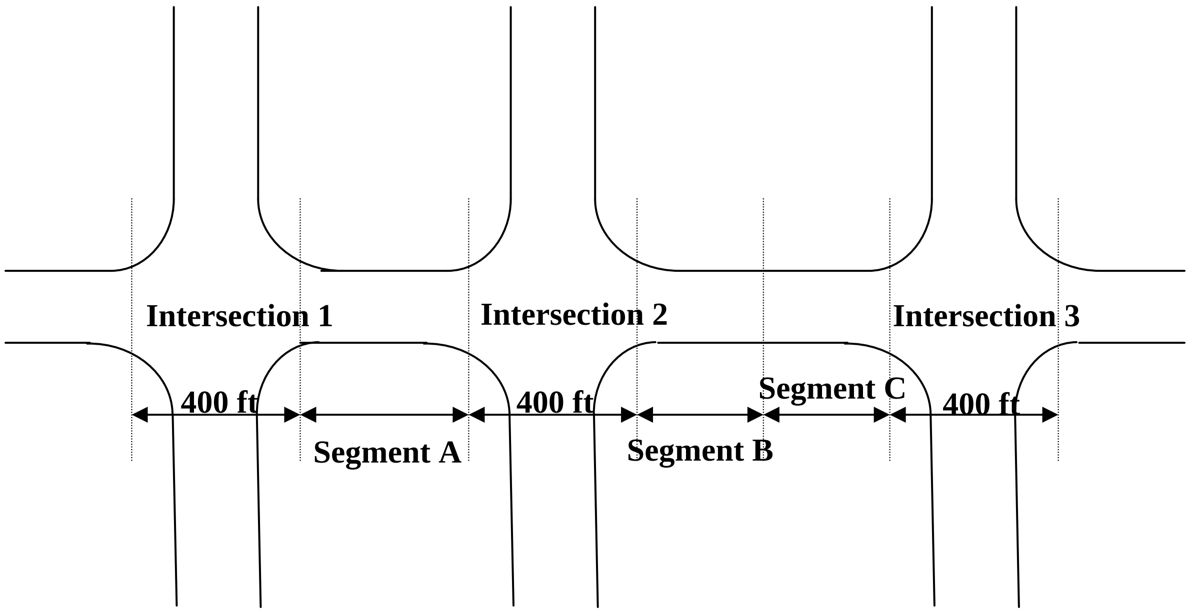

Figure 4.2 Schematic drawing of extended road section

Table 4.2 Index of crash frequency for the intersections and segments in Example 4.2

Location	Q (thousand veh/day)	L (miles)	A (crashes)	Y (years)	D	a (crashes/ year)	I_{CF}	Rank
Intersection 1 (two-way stop controlled)	1.0	NA	4	2	0.359	0.522	1.41	4
Intersection 2 (signalized)	8.0	NA	22	2	0.655	2.18	3.00	1
Intersection 3 (signalized)	10.0	NA	14	2	0.655	2.69	1.50	3
Segment A (urban two-lane)	4.0	2.5	46	2	1.459	6.53	1.92	2
Segment B (urban two-lane)	7.0	2	42	2	1.459	8.73	1.11	5
Segment C (urban two-lane)	7.0	2	36	2	1.459	8.73	0.85	6

Discussion of the results

The I_{CF} for segments and intersections is listed in Table 4.2. Intersection 2 and segment A rank as first and second respectively and appear to be likely candidates for being high crash locations. This example provides an illustration of comparing segments and intersections on the basis of index of crash frequency.

EXAMPLE 4.3 Sorting intersections by index of crash frequency

In the following example, a number of four-leg signalized intersections in two Indiana counties are to be ranked according to the index of crash frequency. The required inputs are shown in Table 4.3 and the results are shown in Table 4.4.

The calculations are similar to those given in Example 4.2 and are again skipped for brevity. *a* is calculated using the safety performance function for signalized intersections from Table 4.1. Index of crash frequency is calculated using Eq 4.1.

Table 4.3 Data for Example 4.3

Intersections	County	AADT (veh/day)	AADT (veh/day)	Crashes '97	Crashes '96
US 31 and SR31	Hamilton	11445	44790	48	34
SR 431 and 116th St.	Hamilton	16454	49719	39	34
US 31 and 116th St.	Hamilton	20815	56865	39	38
US 31 and 106th St.	Hamilton	6523	40783	29	Not available
SR 32 and Cumberland Rd.	Hamilton	4205	17678	19	29
US 31 and 151 St.	Howard	7386	39416	34	35
US 31 and Markland Ave.	Howard	16510	45124	47	39
US 31 and Southway Blvd.	Howard	9192	37806	25	Not available
US 31 and Lincoln Rd.	Howard	13615	45594	22	Not available
US 31 and Boulevard St.	Howard	12928	42542	24	Not available
US 31 and Vaile St.	Howard	2368	30982	38	25
US 31 and Carter St.	Howard	4494	33108	33	0
US 31 and Jefferson St.	Howard	2220	30834	5	8

Discussion of the results

After calculating the I_{CF} for each intersection, the intersections were ranked accordingly and the results listed in Table 4.4. The I_{CF} is higher than 2 for SR 32 and Cumberland Road, US 31 and Vaile Street, US 31 and SR 31, US 31 and 151st Street, US 31 and Markland Avenue, and these are ranked as first, second, third, fourth, and fifth respectively. These locations show strong evidence of being high crash locations and qualify for a safety review. The locations that have an I_{CF} of less than 1, for example, US 31 and Jefferson Street, US 31 and Lincoln Road, and US 31 and Boulevard Street should not be considered for safety reviews. When the I_{CF} is greater than 1 and less than 2, for example, US 31 and Southway Boulevard, and US 31 and 106th Street, there is uncertainty about the location being a high crash location and it will depend on the professional judgment of the safety engineer whether the location should be considered for further investigation.

Table 4.4 Results for Example 4.3

Intersections	Q (thousand vehicles / day)	A (crashes)	Y (years)	a (crashes / year)	I_{CF}	Rank
US 31 and SR31	56.2	82	2	13.95	2.22	3
SR 431 and 116th St.	66.17	73	2	16.30	1.46	7
US 31 and 116th St.	77.68	77	2	18.99	1.22	9
US 31 and 106th St.	47.31	29	1	11.84	1.56	6
SR 32 and Cumberland Rd.	21.88	48	2	5.68	3.18	1
US 31 and 151st St.	46.80	69	2	11.72	2.20	4
US 31 and Markland Ave.	61.63	86	2	15.23	2.11	5
US 31 and Southway Blvd.	47.00	25	1	11.77	1.23	8
US 31 and Lincoln Rd.	59.20	22	1	14.66	0.58	12
US 31 and Boulevard St.	54.47	24	1	13.54	0.87	10
US 31 and Vaile St.	33.35	63	2	8.48	2.90	2
US 31 and Carter St.	37.60	33	2	9.51	0.85	11
US 31 and Jefferson St.	33.05	13	2	8.41	-0.27	13

4.3 Index of crash cost

The index of crash cost (I_{CC}) measures the difference between expected and estimated crash cost at the location divided by the standard deviation of the difference. For example, I_{CC} =2 implies that the crash cost at the location exceeds the expected crash cost for that location by two standard deviations. This method uses crash cost to incorporate severity. A set of predictive equations is presented in Table 4.5 for calculating the expected number of crashes for different severities, (Lamptey et al, 2004; Tarko et al., 2000). Index of crash cost is calculated using Eq 4.2.

$$I_{CC} = \frac{C_{PD}(PD - Y \times a_{PD}) + C_{IF}(IF - Y \times a_{IF})}{\sqrt{(C_{PD}^2 \times PD + C_{IF}^2 \times IF + C_{PD}^2 \times Y^2 \times {a_{PD}}^2 \times D_{PD} + C_{IF}^2 \times Y^2 \times {a_{IF}}^2 \times D_{IF})}} \qquad \text{Eq 4.2}$$

where:

C_{PD} = average cost of PDO crash, in dollars,

C_{IF} = average cost of I/F crash, in dollars,

PD = number of PDO crashes during Y years,

IF = number of I/F crashes during Y years,

a_{PD} = typical PDO crash frequency, in PDO crashes per year,

a_{IF} = typical I/F crash frequency, in, I/F crashes per year,

Y = number of years in analyzed period, in years,

D_{PD} = over-dispersion parameter for PDO crashes, and

D_{IF} = over-dispersion parameter for I/F crashes.

Following is the procedure for identifying HCL based on the index of crash cost.

Step 1. Classify the location in one of the nine categories: signalized intersection, two-way stop-controlled intersection, all-way stop-controlled intersection, rural multilane road segment, rural two-lane road segment, urban multilane road segment, urban two-lane road segment, rural interstate, and urban interstate.

Step 2. Collect the data for each category as required, which includes the number of crashes at the location, the number of years for which crash data is collected, the AADT entering the intersection or the road segment, the length for the segment, average crash costs for the location.

Table 4.5 Safety performance functions including severity

Facility	**Safety Performance Functions**	**Over-dispersion parameter**
Signalized intersection	a_{IF} =0.1954×$Q^{0.723}$	0.639
	a_{PD} =0.1758×$Q^{1.0334}$	0.646
Two-way stop-controlled intersection	a_{IF} = 0.234 × $Q^{1.099}$	0.649
	a_{PD} = 0.307 × $Q^{1.034}$	0.292
All-way stop-controlled intersection	a_{IF} = 0.115 × $Q^{0.835}$	2.06
	a_{PD} = 0.182 × $Q^{1.434}$	0.265
Rural two-lane segment	$a_{IF} = 0.208 \times L \times Q^{0.604}$	0.420
	$a_{PD} = 0.712 \times L \times Q^{0.592}$	0.430
Rural multilane segment	$a_{IF} = 0.107 \times L \times Q^{0.814}$	0.451
	$a_{PD} = 0.634 \times L \times Q^{0.615}$	0.484
Urban two-lane segment	$a_{IF} = 0.105 \times L \times Q^{1.080}$	1.253
	$a_{PD} = 0.603 \times L \times Q^{0.896}$	1.349
Urban multilane segment	$a_{IF} = 0.674 \times L \times Q^{0.435}$	1.588
	$a_{PD} = 2.028 \times L \times Q^{0.460}$	1.946
Rural interstate	$a_{IF} = 0.044 \times L \times Q^{0.917}$	1.053
	$a_{PD} = 0.169 \times L \times Q^{0.943}$	1.604
Urban interstate	$a_{IF} = 0.00048 \times L \times Q^{2.238}$	2.383
	$a_{PD} = 0.0057 \times L \times Q^{1.954}$	2.704

a_{PD} = typical PDO crash frequency, in PDO crashes per year,

a_{IF} = typical I/F crash frequency, in I/F crashes per year,

Q = AADT entering an intersection or along the road segment, in thousand veh/day,

L = road segment length, in miles, and

D = over-dispersion parameter.

Step 3. Calculate the typical PDO crash frequency, a_{PD}, and the typical injury/fatal (I/F) crash frequency, a_{IF}, using the safety performance functions in Table 4.5.

Step 4. Calculate the indices of crash cost I_{CC} using Eq 4.2.

Step 5. Sort the locations by I_{CC}.

Table 4.6 Crash costs for Indiana, in 2001 dollars

Location type	Injury/Fatal crash ($)	Property Damage Only crash ($)
Interstate rural routes	75,000	6,500
Interstate urban routes	52,000	6,500
US/SR rural routes	78,000	6,500
US/SR urban routes	48,000	6,500
Local rural routes	56,500	6,500
Local urban routes	42,500	6,500

EXAMPLE 4.4 Sorting locations by index of crash cost

A number of signalized intersections in Indiana are to be ranked according to the index of crash cost. The required inputs are shown in Table 4.7 and the results are shown in Table 4.8. The crash data is for a one-year period.

For the illustration purpose, step-wise calculations are presented for the intersection of US 421 and SR 47.

Step 1. Classify the location in one of the six categories. The location is a signalized intersection.

Step 2. Collect the data required for signalized intersections. The AADT for the intersection is 8101 vehicles/day, (Q = 8.101 thousand veh/day). Four PDO crashes and eight I/F crashes were reported in one year, (PD = 4, IF = 8, Y = 1, C_{PD} = \$6,500, and C_{IF} = \$48,000). The crash costs are for US/SR urban routes.

Step 3. Calculate the typical PDO crash frequency, a_{PD} **,** and the typical I/F crash frequency, a_{IF} , using the proper safety performance functions from Table 4.5. The required input is shown in Step 2.

a_{IF} =0.1954×8.101$^{0.723}$ = 0.89 I/F crashes/year,

a_{PD} =0.1758×8.101$^{1.0334}$ = 1.53 PDO crashes/year.

Step 4. Calculate the I_{CC} using Equation 4.2. The required input is shown in Steps 2 and 3.

$$I_{CC} = \frac{6500\times(4-1\times1.53)+48000\times(8-1\times0.89)}{\sqrt{(6500^2\times4+48000^2\times8+6500^2\times1^2\times1.53^2\times0.646+48000^2\times1^2\times0.89^2\times0.639)}} = 2.54$$

Calculations for other intersections are performed in a similar step-wise procedure.

Table 4.7 Data for Example 4.4

Intersection	Number of crashes		AADT (veh/day)
	PDO	I/F	
US 231 and South St.	25	3	27950
US 231 and Columbia St.	18	2	22340
US 421 and SR 47	4	8	8101
SR 267 and I-70 Ramps	14	10	18630
SR 26 and 9th St.	28	2	24818
US 231 and SR 26	15	2	26985
US 52/ SR 25 and SR 38	43	8	48474
US 41/150 and Maragret Ave	32	8	38778
SR 26 and Creasy Lane	31	14	44394
SR 26 and Earl Ave.	31	10	42529
US 52/ SR 25 and SR 26	44	8	56290
SR 26 and 18th St.	22	2	26886

Discussion of the results

After calculating the I_{CC} for each intersection, the intersections were ranked accordingly and the results listed in Table 4.8. The I_{CC} is higher than 2 for SR 26 and Creasy Lane, SR 267 and I-70 Ramps, US 421 and SR 47, SR 26 and Earl Avenue, US 52/ SR 25 and SR 38, US 41/150 and Maragret Avenue, and US 52/ SR 25 and SR 26 which are ranked as first, second, third, fourth, fifth, sixth, and seventh respectively. These locations show strong evidence of being high crash locations and qualify for safety review. The locations which have an I_{CC} less than 1, for example, US 231 and SR 26, SR 26 and 18th Street, and US 231 and Columbia Street should not be considered for safety review. When the I_{CC} is greater than 1 and less than 2, there is uncertainty about the location being a high crash location and the location may or may not be considered for further investigation, depending on the professional judgment of the safety engineer.

Table 4.8 Results for Example 4.4

Intersection	Crashes		Q (thousand veh/day)	$\overline{PD}$ (crashes/year)	$\overline{IF}$ (crashes/year)	I_{CF}	Rank
	PDO	I/ F					
US 231 and South St.	25	3	27.95	5.49	2.17	1.33	9
US 231 and Columbia St.	18	2	22.34	4.36	1.85	0.92	10
US 421 and SR 47	4	8	8.101	1.53	0.89	2.54	3
SR 267 and I-70 Ramps*	14	10	18.63	3.61	1.62	2.69	2
SR 26 and 9th St.	28	2	24.818	4.86	1.99	1.36	8
US 231 and SR 26	15	2	26.985	5.30	2.12	0.51	12
US 52/ SR 25 and SR 38	43	8	48.474	9.70	3.23	2.28	5
US 41/150 and Maragret Ave	32	8	38.778	7.70	2.75	2.27	6
SR 26 and Creasy Lane	31	14	44.394	8.86	3.03	3.02	1
SR 26 and Earl Ave.	31	10	42.529	8.48	2.94	2.46	4
US 52/ SR 25 and SR 26	44	8	56.29	11.32	3.60	2.05	7
SR 26 and 18th St.	22	2	26.886	5.28	2.11	0.91	11

a_{PD} = typical PDO crash frequency,

a_{IF} = typical I/F crash frequency,

* Rural Route

The crash costs are taken from Table 4.6.

4.4 Seasonal variations

A seasonal variation is exhibited in the monthly shares of crashes as is evident in the values shown in Table 4.9. These values are proportions of crashes occurring in various months derived from the crash statistics for 1997 – 1999 for Indiana. Although it is recommended that the period of analysis, *Y*, should be a multiple of one year to avoid the seasonal variation, I_{CF} or I_{CC} can be used even when the period of analysis is not a multiple of one year. In such cases, the value of *Y* in Eq 4.1 and Eq 4.2 should be the sum of the number of entire years and the equivalence factors from Table 4.9 of the remaining months as is illustrated in the next paragraph.

If the crash data is from the months of January, February and March, the value of *Y* in Eq 4.1 is 0+0.096+0.066+0.076 = 0.238 (number of entire years is zero). For the same months and Eq 4.2, the value of *Y* for urban roads is 0+0.091+0.066+0.077 = 0.234, while for rural roads *Y* is 0+0.103+0.066+0.073 = 0.243.

If the crash data is from the period January 1998 through March 1999, then the period includes the full year of 1998 and the first three months of 1999. The value of *Y* in Eq 4.1 is 1+0.096+0.066+0.076 = 1.238. For the same period and Eq 4.2, the value of *Y* for urban roads is 1+0.091+0.066+0.077 = 1.234, while for rural roads *Y* is 1+.103+0.066+0.073 = 1.243.

4.5 Early warning tools

Early warning tools are useful to identify locations where safety problems have recently developed. It usually takes one or more years to identify such locations when the traditional approach is used. Early warning tools rely on crash data from periods shorter than one year and on road user feedback, which may indicate safety problems at locations before the problem results in crashes.

Telephone and written feedback are traditional ways used by road users to report safety concerns. Individuals ask transportation agencies to look into locations which they may consider hazardous. The Internet also can be used to bring complaints to INDOT about some sites, which may have developed safety problems. Recent research conducted at

Purdue University, (DeSalle, 2002) shows that locations reported by individuals as high-crash locations tend to be significantly more hazardous, and individual complaints identify high crash locations at a significantly higher rate than randomly picked locations. The locations reported by individuals should be investigated for safety deficiencies that may have come up recently and crash data should be checked for the last three to six months to determine whether there is an abnormal increase in the number of crashes.

Table 4.9 Monthly equivalence factors

Month	Total	Urban	Rural
January	0.096	0.091	0.103
February*	0.066	0.066	0.066
March	0.076	0.077	0.073
April	0.078	0.083	0.070
May	0.086	0.087	0.082
June	0.082	0.084	0.079
July	0.080	0.082	0.077
August	0.081	0.085	0.076
September	0.080	0.082	0.075
October	0.090	0.089	0.093
November	0.087	0.081	0.102
December	0.098	0.094	0.103

*A dip in monthly factor for the month of February is due to the fact that it has 28 days

An early warning may also come from short-term crash figures of various sites. If there is a sudden increase in crashes, in the last three or six month periods, it would indicate the need for a safety review at the location. The I_{CF} or I_{CC} can be used to confirm whether the location has become a high-crash location due to recent changes at the location. An investigation should be conducted regularly to identify locations that have had a sudden increase in crashes.

4.5.1 Spot maps

A spot map (Figure 4.3) is a map of the area wherein the location of each crash is identified through color spots or pins. These are particularly useful as a visual representation helps in better understanding crash patterns. Cluster of dots show the concentration of crash locations throughout the area, but this method may become quite involved and time consuming for larger areas with a large number of crashes.

Advancements in GIS applications now provide spot maps through by various software. These maps can be updated using the rolling horizon method as crash data for the following years can be added as additional layers of information. Statistics on the crashes like I_{CF} or I_{CC} can also be provided on different layers on these maps. The spot maps allow a convenient way of representing crashes or crash-related statistics and provide a quick visual picture of crash concentrations, and may help to find a spatial pattern of crashes as well, which may be predominant along a corridor in a city.

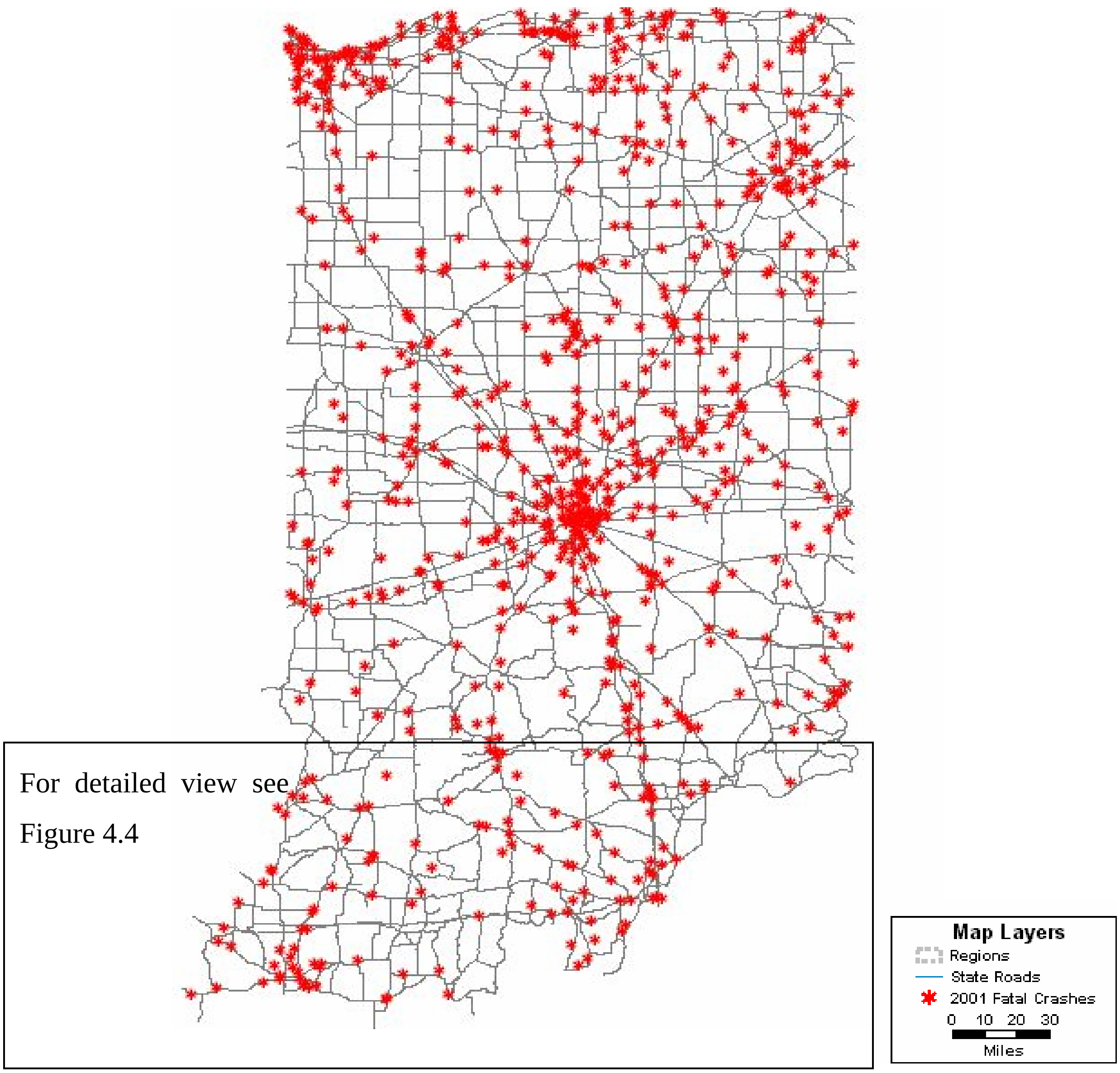

Figure 4.3 Spot map showing fatal crashes that occurred in Indiana in 2001

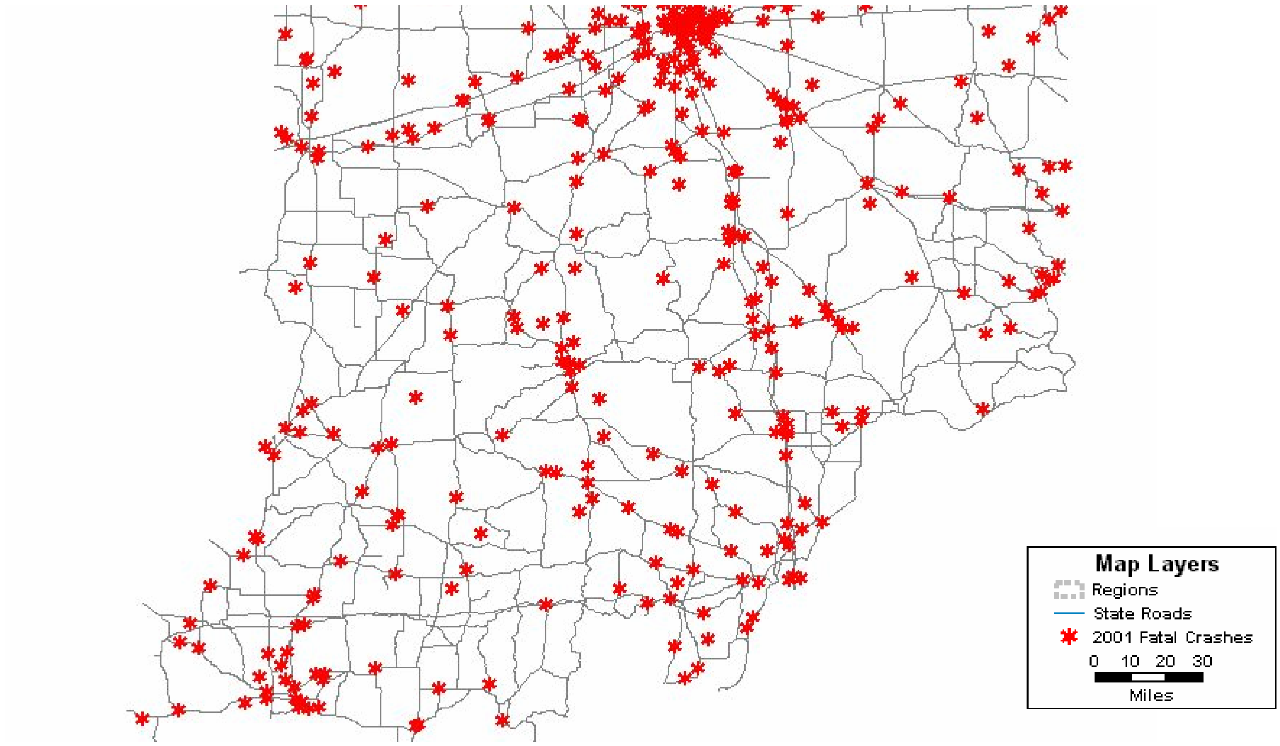

Figure 4.4 Detailed view of the area highlighted in Figure 4.3

CHAPTER 5

Safety Review of High Crash Locations

This chapter presents a methodology for analyzing sites that have been identified as high crash locations. Data is collected for these sites and analyzed to determine potential safety deficiencies and to suggest appropriate countermeasures. Guidelines are provided here, but an engineering judgment is typically needed for conducting safety reviews (See Figure 5.1):

A safety review is conducted in the following phases:

- Preliminary analysis
- Site investigation
- Post visit analysis
- Safety review documentation

Background information is collected and analyzed in the first phase before the other phases of a safety review can be conducted. Background information includes crash data for previous years, traffic data, and basic road geometry data if available. A collision diagram is prepared for the location using the crash data to check for spatial and temporal patterns in crashes. This is followed by a site investigation scheduled to coincide with the time when the majority of crashes occur. At the site, a condition diagram is prepared and various engineering studies are conducted if needed, i.e., a sight distance study or traffic volume study. Additional visits may be scheduled to aid in finding safety deficiencies if the first site visit is inconclusive. After the site investigation, a post-visit analysis is done to discuss the results of site investigation, point out safety deficiencies and suggest appropriate countermeasures for the location. The review process and its results are summarized through the safety review documentation. The entire safety review process is shown in Figure 5.1.

The safety review is typically done by a team comprised of individuals with adequate experience in safety engineering concepts and practices, crash investigation, traffic engineering, and design. The size of the team depends on the site type and size, and the expected scope of on-site data collection. The safety review is typically conducted by a team of two to five members. There should be at least two members to interact and exchange ideas. Conversely, when the team is too large, reaching a consensus may be difficult. Individuals who are not members of the review team may be a part of the team that goes to the site for data collection.

5.1 Preliminary analysis

The primary objective of a preliminary analysis is to help plan a site investigation. The preliminary analysis includes assembling available data for the site before conducting the on-site visit. The results of the preliminary analysis should help determine the proper time and scope of the site investigation.

The review team should look into crash data in the early phases of the review process as it may point out certain crash patterns indicating probable safety deficiencies. It is beneficial to have traffic volumes, design drawings, control data, and previous safety review reports available. Data collected on the site earlier should be used, if possible, to utilize resources efficiently, but the scope, time, and format of these data should be consistent with the needs of the safety study.

5.1.1 Crash data analysis

Crash data is the most important component that should be reviewed in the preliminary analysis. The crash data is used to identify periods and weather conditions when the majority of crashes occur. Driver statements from the crash records can be used in identifying the appropriate time for the visit. Input from the appropriate law enforcement and emergency response agencies can also provide useful insights in determining the causes of crashes, hence, helping in scheduling the visit. The visit should be planned so that it coincides with conditions during which the majority of crashes occur, e.g. during rush hours, wet pavement conditions, or at night. A collision diagram, which is discussed in detail in the next section, aids in finding predominant crash patterns.

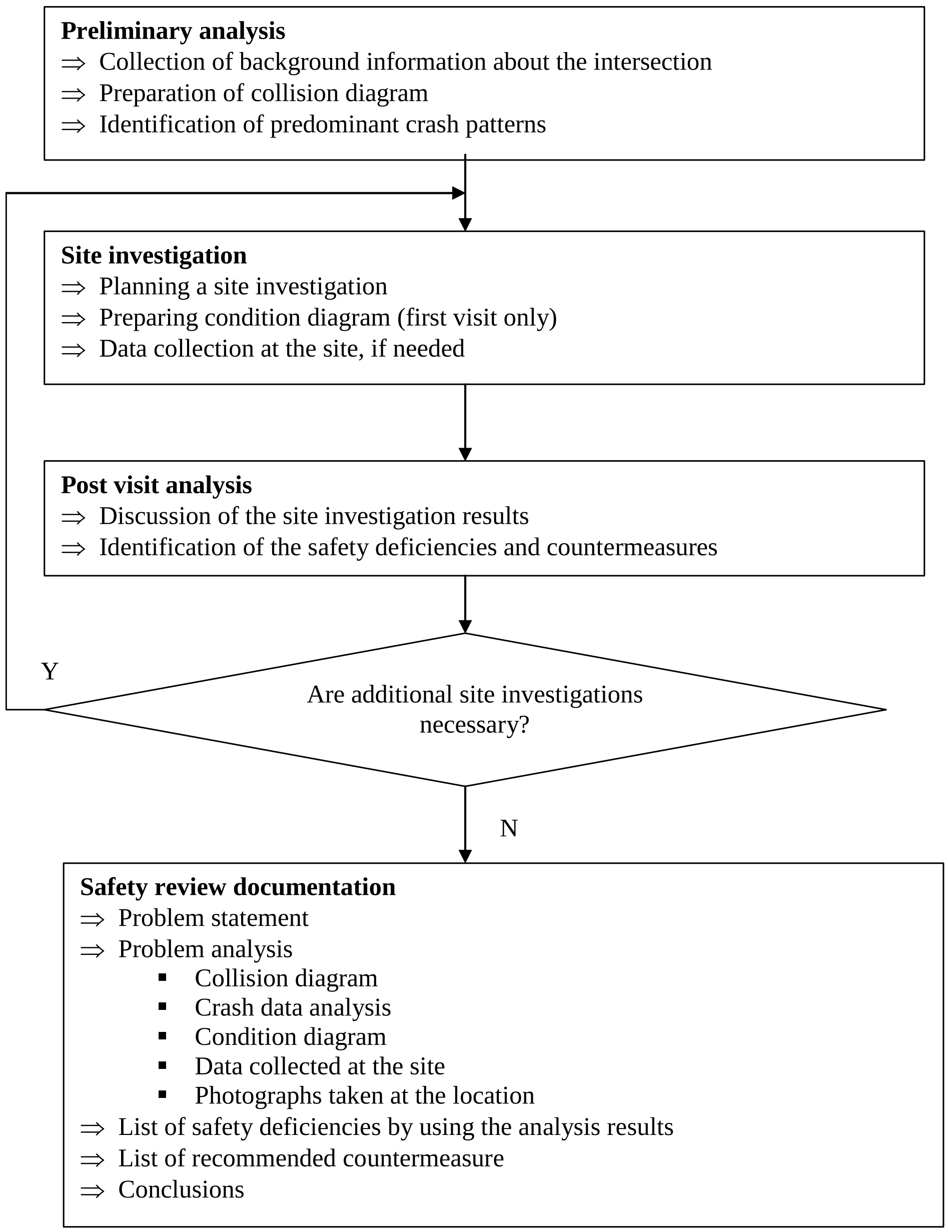

Figure 5.1 Flow chart of safety review process

Collision diagram

A collision diagram is a graphic representation of crash summaries and is a schematic drawing of the site with symbolic representation for different types of crashes and with the location of crashes indicated. Vehicles and pedestrians not involved (no physical contact) but contributing to individual crashes may be included on the diagram, (FHWA, 1981). A crash is intersection-related if the physical characteristics or operating conditions of an intersection contribute to the crash occurrence. For intersections, all intersection-related crashes should be indicated. According to Indiana standards, any crash within two hundred feet of the intersection is an intersection-related crash. Some intersection- related crashes may happen on approaches to the intersection.

A collision diagram should include the following items:

- The direction of travel of involved vehicles and pedestrians prior to impact (collision), driver and pedestrian intent, i.e., going straight, making left-turn, stopping, etc., prior to impact.
- Date, day of week, time of day
- Weather conditions (rain, snow, fog, etc.)
- Pavement conditions (wet, icy, etc.)
- Unusual operational conditions (control devices not operating properly, construction area, etc.)
- Crash severity (fatal, personal injury, property damage only)

In preparation of a collision diagram, standard symbols are used to indicate driver or pedestrian intent, direction of travel, accident severity, fixed objects etc., as shown in the legend in Figure 5.2.

A typical collision diagram, as shown in Figure 5.2, may help in finding predominant crash patterns. For example, if in a collision diagram five out of ten crashes occurred on the east-bound approach when the pavement was wet, it may be concluded that east bound approach is prone to crashes when the pavement is wet. The on-site visit should focus on this approach to confirm frequent braking maneuvers or at least to determine the potential causes of such maneuvers. In another case, a significant number of crashes at night may indicate possible lighting problems, while significant rear end crashes in rainy and icy conditions could indicate problems arising due to low skid resistance.

After collecting all available data for the site, preparing a collision diagram, and identifying the presence of any predominant crash patterns, further preparations may be continued for the site investigation.

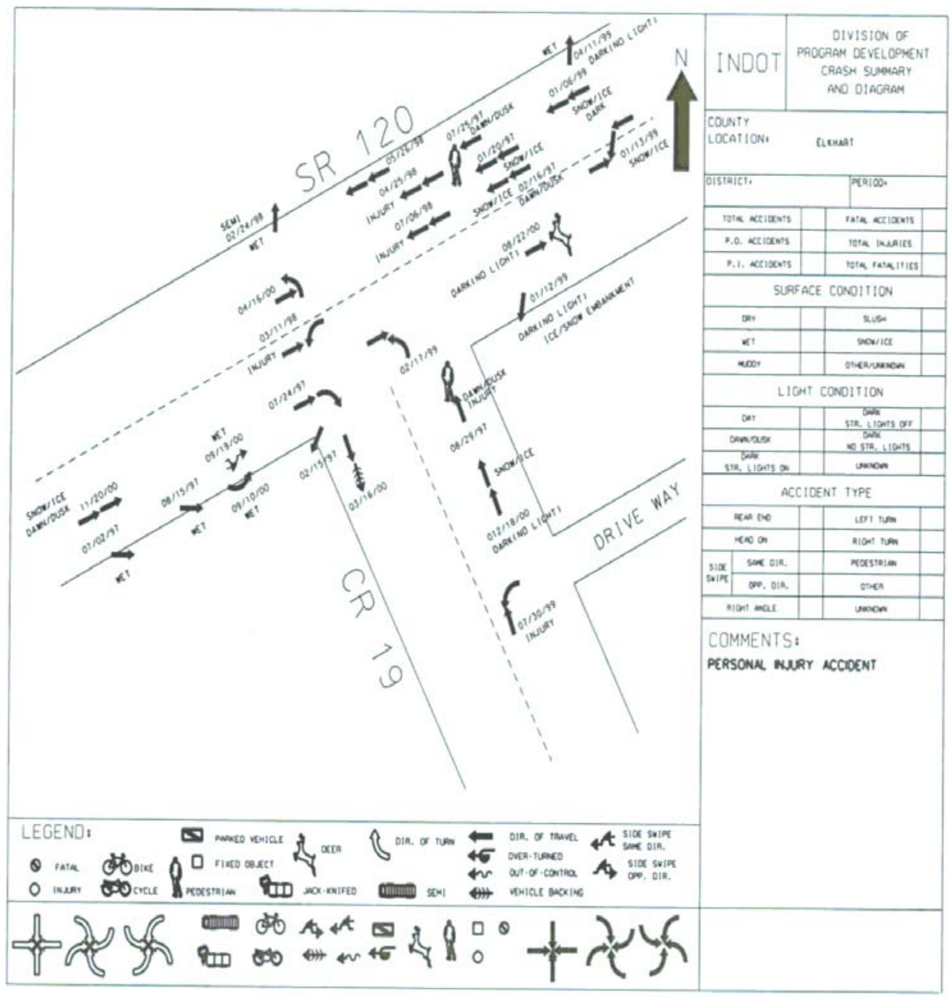

Figure 5.2 Collision diagram

5.1.2 Checklists

One of the important components in preparing for a site investigation is checklists, which are an extensive collection of possible roadway deficiencies leading to safety problems.

Checklists help organize a site investigation and assist the reviewers in ensuring that all the safety issues are addressed. However, the checklists should only serve as guidelines and should not be considered as an exhaustive list of all possible safety deficiencies.

An extensive checklist is provided in Form 4 in Appendix E (Figure 5.3). Possible causes of crashes are specific elements related to roadway deficiencies, and they can be identified on the basis of the type of facility, past experience, predominant crash trends and patterns, etc. The checklist has been built around the concept of adjusting a checklist to the facility type through checklist expansion. The entire checklist is divided into five groups. Table 5.1 explains the expansion concept by showing the applicability of each check group. The largest group, Group A, lists causes that may be applied to all locations. Group B lists additional possible causes that are unique to lane merging and diverging behavior and are more typical to interchanges. Group C lists additional possible causes that are typical to intersections. Group D adds to the three previous groups and lists additional possible causes that are unique to signalized intersections. Group E lists possible causes applicable to railroad crossings. As an example, when safety investigators are looking at a signalized intersection they would look into possible causes from Groups A, B, C, and D, or when a safety investigation is performed at an interchange, suitable possible causes are selected from Groups A and B. Furthermore, when the location is a railroad crossing appropriate checks from all groups should be considered as possible causes.

It is not expected that all items listed in Form 4 in Appendix E are to be always checked at a location. Instead, a customized checklist is prepared for the location after selecting proper groups, identifying predominant crash patterns, and then marking the relevant checks to be performed at the location. These marked checks are called possible causes. The marked checks are investigated at the location and become probable causes if during the site visit they are shown to be factors that contribute to safety deficiencies.

Safety Review Checklist	Form F4.1
Facility Type________________________**Location**__________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	**Probable causes**
Group A		
Moving lanes		
Lane widths are inadequate for vehicle classes that are common to the location	_____	_____
Number of lanes inadequate for traffic	_____	_____
Readability		
Lanes end abruptly without prior warning (lanes are not aligned)	_____	_____
Auxiliary/Turning Lanes		
Inadequate advance warning of lane drops	_____	_____
Driveways		
Improper location of driveways(e.g. driveways are too close to the intersection)	_____	_____
Driveways are closely spaced	_____	_____
Inadequate visibility of driveways	_____	_____
Shoulders		
Shoulder width inadequate for vehicle classes that are common to the intersection	_____	_____
Inappropriate shoulder surfacing	_____	_____
Rumble strips not installed where warranted	_____	_____
Shoulders are poorly maintained	_____	_____
Insufficient contrast of shoulders	_____	_____
Horizontal and vertical alignment		
Horizontal or vertical alignment affect the visibility of the intersection	_____	_____
Is location free of abrupt changes in elevation	_____	_____
Inadequate visibility at sag and crest curves	_____	_____

Figure 5.3 Safety review checklist (only first sheet)

Table 5.1 Applicability of check groups (X means applicable)

Facility	Check groups				
	A	B	C	D	E
Segments	X				
Interchanges	X	X			
Unsignalized intersections	X	X	X		
Signalized intersections	X	X	X	X	
Railroad crossings	X	X	X	X	X

5.1.3 *Planning site investigation*

Site investigations should be carefully planned and sufficient preparations should be done before conducting the investigation. The output from the preliminary phase assists in planning the site investigation. Key considerations involved in planning a visit are the time and date of the visit and personnel and equipment needed for the visit. The personnel should be told of their duties and responsibilities during the visit, and a meeting of all the personnel going to the site should be held so that everyone knows what is required of them. They should be familiar with the prepared checklists, the equipment to be used during the site investigation, and the methods of data collection.

5.2 Site investigation

The aim of site investigation is to learn about the existing local conditions, including control, geometry, and traffic characteristics. Adjoining facilities can be included if they may affect the location being studied. A schematic diagram representing the various activities involved in a site investigation is shown in Figure 5.4.

5.2.1 Documenting local conditions

The first activity to be performed at the site is to document the local conditions. The inspection should include signs, lighting, markings, delineations, and geometric features. Modern technologies provide convenient and efficient documentation methods that include videotaping from the driver's position while in motion or videotaping from an elevation (stationary) and taking still photos of the road (Figure 5.5).

A traditional and useful method of documenting the physical characteristics of the site is a condition diagram (Figure 5.6). A condition diagram is a schematic representation of the road inventory in the area. It is useful in relating crashes to physical features on and near the roadway. A condition diagram should include curbs, roadway limits, property lines, sidewalks, driveways, view obstructions on corners, physical obstructions on roadway, ditches, bridges, traffic signals, signs, pavement marking, streetlights, grades, road surface, type of adjacent property, irregularities (potholes, dips, etc.), and roadway characteristics.

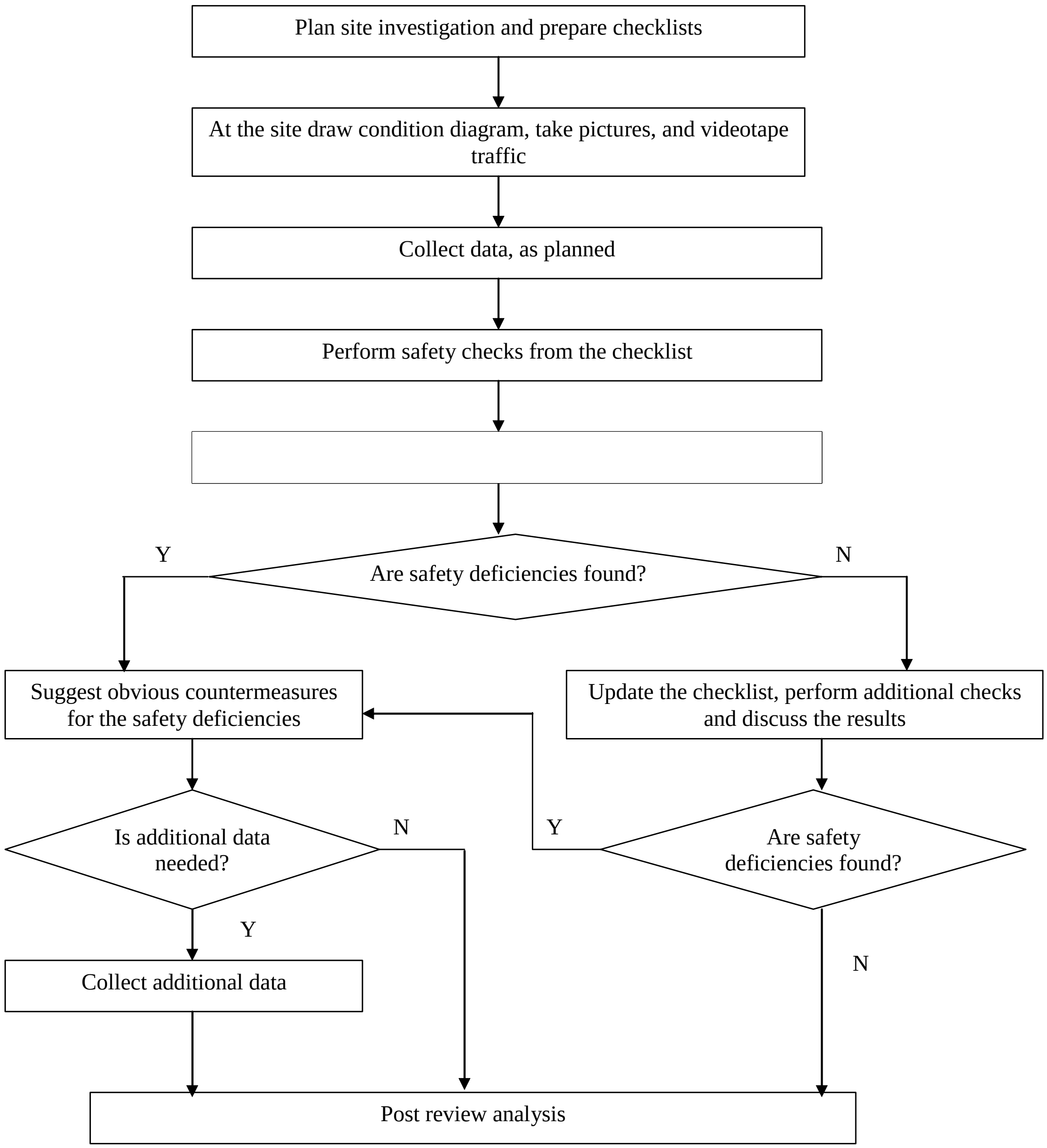

Figure 5.4 Schematic representation of on-site visit

Figure 5.5 Still picture of the location

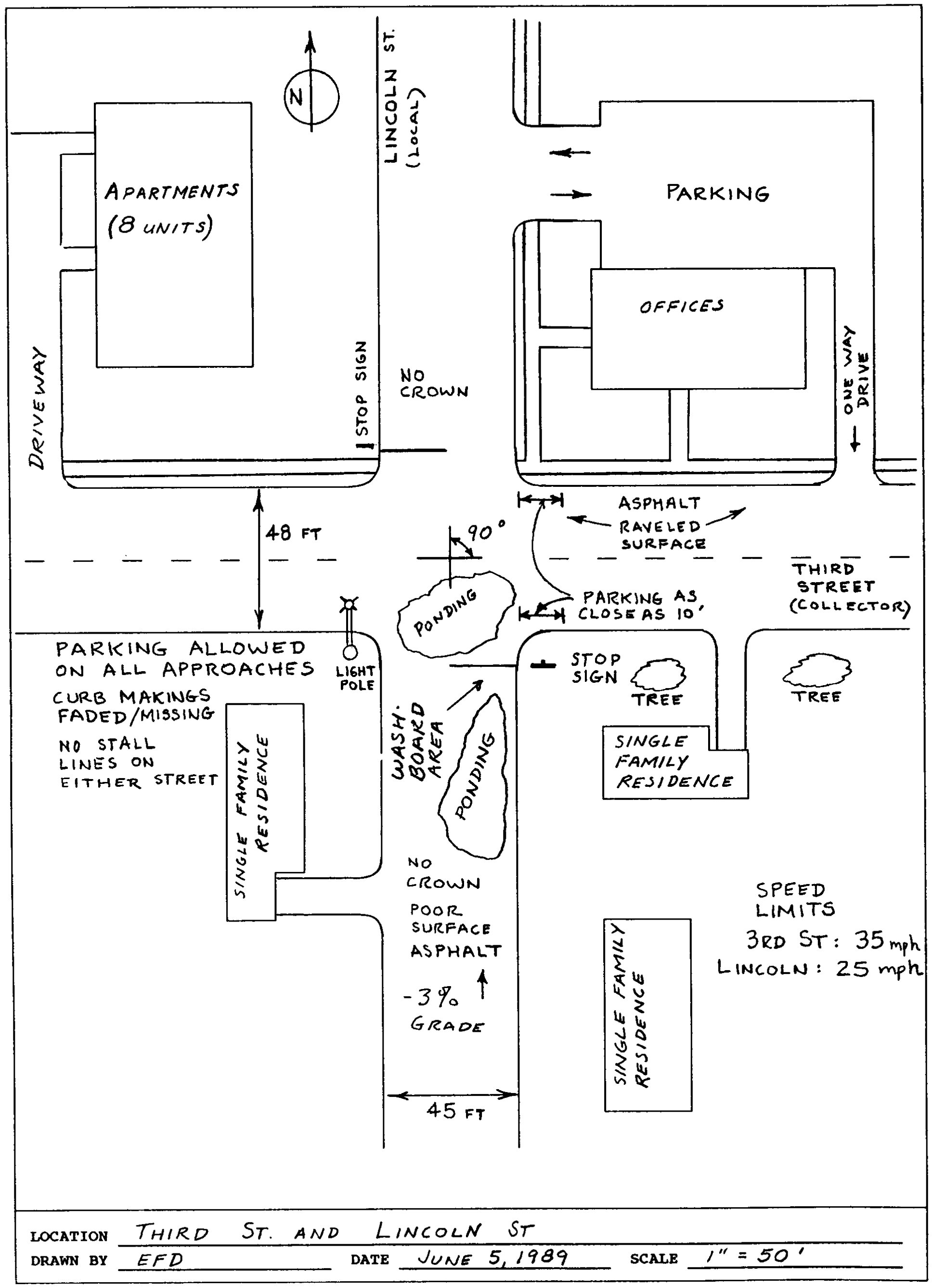

Figure 5.6 Condition diagram (Missouri Highway and Transportation Department, 1990)

5.2.2 Additional data collection

Depending upon the results of the crash analysis and inspection of the site, additional data collection may be required, which may include conducting volume studies, spot speed studies, travel and delay studies, checking signal warrants, and evaluating sight distances. Brief descriptions of some of these studies are provided in Section 5.4.

5.2.3 Safety checks

After documenting the local conditions, the location is checked for roadway deficiencies according to the checklist discussed in detail in Section 5.1.2 (Form 4, Appendix E). These checks are done to verify whether the control and geometry of the site are in accordance with the standards.

5.2.4 On-site discussion

The safety reviewers may meet after conducting the planned safety checks to briefly discuss the results. If they conclude that the safety deficiencies have not yet been found, they may propose additional checks and continue until deficiencies are successfully determined or a decision to end the site visit is made. If they are convinced that they have found the safety deficiencies, general safety countermeasures that may be appropriate for identified safety deficiencies are discussed at the site to determine if additional data could be collected. If additional data must be collected to determine appropriate countermeasures and the resources are available to do so, this data is collected during the first visit. A brief description of these studies is provided in Section 5.4.

After performing a second round of safety checks, the reviewers should discuss the results again. As in the previous discussion, if they have not found safety deficiencies, based on the results of completed checks, they should update the checklist and perform additional checks. If they are satisfied with the results of the safety checks and have found safety deficiencies, as stated earlier, they should select appropriate countermeasures. This process is repeated until the review team has either found safety deficiencies or a decision is made to end the visit.

Causes of safety deficiencies at the location can be classified into three categories: control, geometry, and road user behavior. If the location is unsafe due to road user behavior, then education and enforcement may help in reducing the number of crashes rather than engineering countermeasures. In addition, in some cases road users might be prompted to drive unsafely due to the characteristics of the system. For example, a high frequency of people running on red may indicate a short yellow phase, which, when corrected, may result in fewer people running on red.

5.3 Post visit analysis

The results of the site investigation are discussed at a review meeting to determine the safety deficiencies. If safety deficiencies have not been identified, it should be decided whether additional site visits are necessary. If additional site visits are necessary, the review process continues with planning subsequent site visits. Also, if conventional safety checks are not adequate to identify safety deficiencies, the review team can decide to conduct special studies including traffic conflict studies, which are discussed in Section 5.4.8. If the review team feels satisfied with the outcome of the first visit, specific safety deficiencies and appropriate countermeasures should be stated. The data collected, and observations made at the site and the identified safety deficiencies should be reported in the safety review documentation discussed later in the chapter.

5.3.1 Countermeasures

The purpose of the next step is to suggest candidate countermeasures. Specific candidate countermeasures should be suggested in light of the identified safety deficiencies at the location. The candidate countermeasures should be selected carefully based on knowledge of the effectiveness of similar improvements in the past. Results of past project evaluations is a very important input to this task.

A list of general countermeasures is provided in Appendix C, which consists of countermeasures that have been proven to be effective for a particular category of crashes. Specific countermeasures should be chosen after reviewing the general countermeasures, site-specific data, and applying engineering judgment. Countermeasures should not be selected without consideration of supporting data, such as traffic volumes and field observations. All practical combinations of improvements should be identified.

5.4 Engineering studies

Depending upon the results of the crash analysis for the site or/and the first on-site visit, additional engineering studies may be required for analysis of the high crash locations and for suggesting suitable countermeasures for the identified safety deficiencies. Table 5.2 lists these studies, their purpose and needs. The Manual of Transportation Engineering Studies (Hummer et al., 1994) and the Highway Safety Engineering Studies, Procedural Guide, (FHWA, 1981) describe the studies in detail. A brief description of the studies follows.

Table 5.2 Purpose and need of engineering studies in safety review (FHWA, 1981)

Study	**Purpose**	**Need**
Traffic-related studies		
Volume study	Conducted to determine the number and movement of vehicles and/or pedestrians within, through, or at selected points in an area.	Volume data is principally used as a means to describe the exposure at a location.
Spot speed study	Conducted to determine the speed distribution of a traffic stream at a spot location.	
Travel time and delay study	Conducted to obtain data on the amount of time taken to traverse a specified section of roadway and amount cause, location, duration, and frequency of delays occurring during a trip.	Crash patterns indicate the occurrence of traffic congestion, i.e. rear end, right angle, or left turn accidents along a roadway.
Roadway and intersection capacity study	Conducted to measure the ability of a highway facility to accommodate or service traffic volumes.	Crash patterns indicate the occurrence of congestion related crashes (patterns of rear end, right angle, or left turn crashes during peak traffic periods.

Gap study	Conducted to measure the time headway or gap between vehicles along a highway or an intersection to analyze the capability of a major traffic stream to accommodate a minor or alternate traffic stream.	Occurrences of crashes involving crossing or merging traffic.
Traffic lane occupancy study	Provides a measure of traffic performance of a highway facility by measuring the percent of time a point on a roadway is occupied by a vehicle.	Presence of congestion-related crashes, for example, rear end crashes.
Queue length study	Conducted to identify the number of vehicles that are stopped in a traffic lane behind the stop bar.	Presence of congestion along a intersection approach or in an individual traffic lane.
Environment-related studies		
Sight distance study	Conducted to measure sight distance at intersections along a roadway section.	Crash patterns indicate a possible sight distance problem, for example, a head-on collision on a section of a highway.
Skid resistance study	Conducted to measure the frictional properties of a pavement surface.	Crash patterns indicate the presence of wet weather or skidding crashes.
Lighting study	Conducted to determine the adequacy of existing lighting systems and the need for new, additional, or improved systems.	Crash patterns indicate predominantly night-time crashes
Other studies		
School crossing study	Provide optimal safety conditions for school age pedestrians within the roadway environment.	Complaints from school officials, students, parents, or other concerned groups.
Railroad crossing study	Performed to evaluate existing and potential conflicts between vehicular and train traffic at a railroad crossing.	Occurrence of vehicle train crashes.
Traffic control	Conducted to review the effective	Presence of

device study	application of a traffic control device.	predominantly right-angle crashes resulting from inadequate use of traffic control devices.
Bicycle or pedestrian study	Study safety situations involving bicycle or pedestrian modes.	Occurrence of bicycle/ vehicle or pedestrian/vehicle crashes.

5.4.1 Volume study

Traffic volume studies are conducted to determine the number and movement of vehicles and/or pedestrians within, through, or at selected points at a location. The resultant traffic volumes are used to identify an exposure factor for finding high crash locations. While collecting volume data, count information is classified by time period and location. The various forms of volume information classified by time period are: annual total traffic volumes, AADT, hourly volumes, peak hour volumes, and short term volumes. Similarly, volume information classified by location includes intersectional volume and mid-block volume. The use of volume data will determine the form of volume data to be collected, (FHWA, 1981).

5.4.2 Spot speed study

Spot speed data is usually necessary when crash summaries indicate safety problems that may be caused by high speeds or unusual speed distributions. They serve to estimate the speed distribution of the traffic stream during the observation period. The average speed and the 85th percentile speed should be checked. Furthermore, it should be checked whether the current speed limit is suitable for the current design of the road. If the speed limit is not appropriate for the location, a new speed limit should be proposed. The number of speed violations should be examined. If speed violations are significant, then proper enforcement may be a good safety countermeasure for the location. If there is a big variability in speed distribution, it can also be a potential safety deficiency. Spot speeds are useful in designing signals, locating signs, and determining the safe stopping sight distance.

5.4.3 Travel time and delay studies

Travel time and delay studies are useful for obtaining information on locations where crash patterns may indicate congestion-type crashes, i.e., a significant number of rear-end, right-angle, or left-turn accidents. These crashes occur when motorists are surprised by other stopped vehicles or the tendency to accept short gaps when the delay is unacceptably high. Travel time and delay characteristics are indicators of the level of service at which the facility operates and can be used as a measure of traffic efficiency. They can be used to analyze locations where safety improvements may be required to increase mobility and provide improved safety conditions. Intersection delays may be handled in a fashion similar to the travel time and delay studies, (FHWA, 1981).

5.4.4 Roadway and intersection capacity study

Highway capacity studies measure the ability of a highway facility to accommodate or service traffic volumes. Capacity studies are prompted by the occurrence of congestion-related crashes (pattern of rear end crashes or right-angle crashes during peak volume periods), and these studies provide valuable information for many traffic safety engineering investigations. Typically, two types of data are collected for a capacity study, which includes roadway inventory data and volume data. Collection of roadway inventory data can be performed under varying traffic conditions, but volume data is typically collected during peak volume periods, (FHWA, 1981).

5.4.5 Gap study

Gap studies are used to measure the time headway or gap between vehicles at an intersection to analyze the capability of a major traffic stream to accommodate a minor traffic stream. The need for a gap study is indicated by the presence of crashes involving crossing or merging traffic. Gap characteristics can be defined by the gap accepted by half of the drivers; the gap for which the number of accepted gaps shorter is equal to the number of rejected gaps longer, defined as critical gap; the average gap; and the lag between side street and main street traffic such that the number of rejected lags larger and accepted lags smaller will be equal, defined as critical gap. Gap studies are used to determine the safety of an intersection for crossing, merging, or weaving traffic and assessing the need for additional traffic controls. Gap studies are typically performed under good weather conditions, (FHWA, 1981).

5.4.6 Traffic lane occupancy study

A traffic lane occupancy study provides a measure of traffic performance of a location by measuring the percent of time a point on a roadway is occupied by vehicles. Lane occupancy is defined as the ratio of time vehicles are present at a station for a specific traffic lane. This data is used to identify the traffic performance of a location. The need for a lane occupancy study is identified by the presence of congestion at a location. The study is typically performed during peak volume periods. The lane occupancy study includes defining the levels of operation, identifying the location of bottlenecks, and determining the effects of traffic control changes, (FHWA, 1981).

5.4.7 Queue length study

Queue length studies are conducted to identify the number of vehicles that are stopped in a traffic lane behind the stop line at an intersection. Queue length studies are performed when crashes are attributed to congestion, i.e., rear-end, right angle, or side swipe crashes during peak volume periods. Queue length studies determine the level of operation of a location and identify the bottlenecks of a location. The study is performed during peak traffic volume periods under good weather conditions (FHWA, 1981).

5.4.8 Traffic conflict studies

Traffic conflict is a "traffic event involving two or more road users, in which one user performs some atypical or unusual action, such as change in direction or speed, that places another user in jeopardy of a collision unless an evasive maneuver is undertaken," (Migletz, J. et. al. 1980). A traffic conflict can be described operationally as an event that has the following distinct stages:

1. A vehicle makes some sort of unusual, atypical, or unexpected maneuver.
2. Another vehicle is in danger of collision with this vehicle due to this maneuver.
3. This vehicle reacts by taking evasive action such as braking or swerving.
4. The vehicle then continues to proceed on its normal course.

Traffic conflict studies may be useful when crash data is not available or when the safety deficiencies cannot be found after the first site investigation. Traffic conflict studies may be justified by motorist complaints about current safety at locations that have undergone recent changes of geometry, control, or traffic.

Traffic conflict studies can assist in the diagnosis of safety and operational problems at a highway location and in the evaluation of the effectiveness of improvements at a location.

Traffic conf1icts are classified based on maneuvers performed by involved vehicles. A traffic conflict study at an intersection is performed by human observers. Typically, two observers for 16 hours or four observers for eight hours are required at an intersection. More information about data collection and training procedures can be found in Traffic Conflict Characteristics Accident Potential at Intersections, (Perkins et. al., 1967) and the Traffic Conflict Procedure Manual (Ho et. al., 1996). Proper training of individuals participating in a traffic conflict study is important for obtaining accurate results. The collected data is checked for errors and analyzed to determine safety deficiencies. A conflict diagram, similar to a collision diagram, can be useful in this task.

Traffic conflict studies are believed to be useful in determining the potential for crashes at a site. Traffic conflicts can be used to estimate the frequency of crashes at a location. They can provide a useful insight to the causes of crashes. The frequency of conflicts, circumstances leading to conflicts, and comments made by observers can be useful in determining safety deficiencies.

5.5 Safety review documentation

The review process, the identified safety problems and the recommended countermeasures should be properly documented in a report, which should include the following components.

5.5.1 Introduction

In this section a brief description of the location, where the safety project is to be implemented, should be provided. It should briefly describe the methodology adopted in undertaking the project.

5.5.2 Crash data analysis

This section would include a summary of the crash data. The crash history should also be presented in a table that shows the crash history by severity and crash type. It would list any predominant patterns found in the crash history of the location. Also a collision diagram should also be included to highlight predominant crash patterns.

5.5.3 Safety review

This section explains the procedure adopted in finding safety deficiencies at the location. It should include condition diagrams, photographs taken at the location, the checklists used in the site investigation, and summaries of site data collection, if any.

5.5.4 Safety deficiencies and countermeasures

This section lists the safety deficiencies and countermeasure found by the reviewers after conducting the on-site visit.

5.5.5 Conclusion

This section would summarize the entire process and list the merits of the safety project.

CHAPTER 6

Economic evaluation of projects

After all feasible countermeasures are identified for a high crash location; some of them are combined to form a project, and one location may have several alternative projects. The projects are evaluated to select the one which provides maximum economic benefit. The objective of the evaluation is to compare the overall user benefits with the overall agency costs to determine the economic feasibility of the proposed project. Methods used to evaluate safety projects include benefit/cost ratio (*B/C* ratio) and net annual benefit (*NAB*). The *B/C* ratio represents an amount saved per dollar spent. Calculating net annual benefit along with the *B/C* ratio provides a better understanding of the economic outcome. For example, a *B/C* ratio of 2.0 may be associated with a net annual benefit of one thousand dollars or ten thousand dollars. Knowledge of both the *B/C* ratio and the net annual benefit helps in making an informed decision.

6.1 Overall procedure

The proposed method estimates the total user benefits and agency costs for a safety project. User benefits are the savings due to the crashes saved by implementation of the safety project. Project costs include the construction cost and maintenance costs. A brief introduction of the terms used in the chapter is as follows. The before period would indicate the years for which the crash data were analyzed. All the user benefit and agency cost would be brought to the dollar value of the present year. The present year is the year directly proceeding the first service year. The crash cost values provided in Chapter 4 are in 2001 dollars, which needs to be brought to the dollar value of the present year using the equations described in this chapter. For example, as shown in Figure 6.1, the crash data was collected at a location during the years 2004 – 2006. The analysis was done in 2009 which is the present year and the service life starts from 2010.

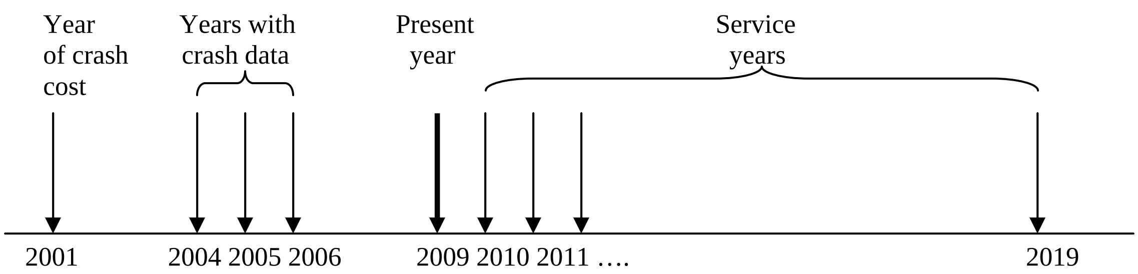

Figure 6.1 Time components of economic evaluation

The following steps summarize the procedure for economic evaluation of safety projects.

Step 1. Collect the required input. All relevant data used in calculating *B/C* ratio and *NAB* is collected in this step. The collected data is used in steps 5 and 6 to estimate the user benefits and the agency costs.

Step 2. Estimate the crash frequency for the present year. In this step the reported crashes are combined with the typical crash frequency at the location to improve the estimate. This estimate is adjusted to determine the crash frequency in the present year.

Step 3. Determine the crash reduction factors (*CRF*) and the service life of the safety improvement. The crash reduction factor (*CRF*) is the expected percent reduction in crashes caused by the safety project. The service life is the time period that the improvement can be reasonably expected to impact crash experience.

Step 4. Estimate the exposure adjustment factor. This step estimates the exposure adjustment factor (*EAF*) which is used in predicting the crash frequency during the service life of the project.

Step 5. Calculate the present worth of crash reduction benefits. A present worth dollar value is assigned to the number of crashes saved due to the implementation of the safety project. This estimate applies to the entire service life of the project.

Step 6. Calculate the present worth of total agency costs.

Step 7. Calculate the *B/C* ratio and the *NAB*.

Step 8. Conclusions. The *B/C* ratio and the *NAB* of the project are considered to determine the economic feasibility of the project. When the *B/C* ratio is greater than one, the safety project is economically prudent.

The following part of this section provides details of the procedure with all needed calculations, default values and equations.

6.1.1 Collect the required input

Identify the proposed safety improvement, collect crash data, traffic volumes, traffic growth factor, construction cost, salvage value, change in annual maintenance cost, and service life of a proposed safety improvement. Change in annual maintenance cost is the difference in maintenance cost before and after implementation of the safety project. Construction cost, salvage value, and change in annual maintenance cost are calculated from previous knowledge on similar projects.

6.1.2 Estimate the crash frequency before implementation of a safety project

The number of crashes at a location before implementation of a safety project can be obtained from the crash database discussed in Chapter 3. If possible, the number of reported crashes should be combined with the typical crash frequency at the location calculated using the safety performance functions given in Chapter 4. Combining reported crashes and values obtained from a safety performance function increases the accuracy of the calculations. Equation 6.1 estimates the crash frequency for the present year by combining the reported crashes and the typical crash frequency and by adjusting the crash frequency estimate for the change in exposure. This equation can be used for both PDO and I/F crashes as well.

$$a_P = \frac{\frac{1}{D} + A}{\frac{1}{D \times a} + Y} \times \left(1 + \frac{R}{100}\right)^{Z \times Y_2} \qquad \text{Eq 6.1}$$

where:

a_P = crash frequency in the present year,

a = typical crash frequency (crashes / year) calculated using safety performance functions (Table 4.1),

D = over-dispersion parameter, (Table 4.1),

A = number of crashes during Y years,

Y = number of years for which crash data is available,

R = exposure change rate in percent; default value is 2% (Table 6.1)

Z = constant taken from Table 6.2, and

Y_2 = number of years between the midpoints of the before period and the present year.

For example if the before period is 1998 – 2000 and the present year is 2004,

$$Y_2 = 2004 - \frac{1998 + 2000}{2} = 5.0$$

Table 6.1 Default values of constants used in economic evaluation

Constant	Default value
Interest rate (I)	4%
Inflation rate (F)	2%
Exposure change rate (R)	2%

Table 6.2 Z values for road facilities

Facility	PDO	I/F
Signalized intersection	1.033	0.723
Two-way stop controlled intersection	1.034	1.099
All-way stop controlled intersection	1.434	0.835
Rural multi-lane segment	0.615	0.814
Rural two-lane segment	0.592	0.604
Urban multi-lane segment	0.460	0.435
Urban two-lane segment	0.896	1.080
Rural interstate	0.943	0.917
Urban interstate	1.954	2.238

If the volumes at the subject site are not known, then the safety performance cannot be used. Eq 6.2 is used in such a case.

$$a_P = \frac{A}{Y} \times \left(1 + \frac{R}{100}\right)^{Z \times Y_2} \qquad \text{Eq 6.2}$$

EXAMPLE 6.1 Calculating annual number of PDO crashes in analysis year

A rural two-lane segment with AADT of 6,000 (vehicles/day) and a length of 2.5 miles experienced 17 PDO crashes in three years 1998-2000. Estimate the annual number of PDO crashes for the present year 2004.

The safety performance function for PDO crashes on a rural two-lane segment is $a_{PD} = 0.712 \times L \times Q^{0.592}$ with an over-dispersion parameter D = 0.430 and where L = road segment length in miles and Q = AADT along the road segment, in thousand vehicles per day, see Table 4.5. The typical crash frequency of PDO crashes for the rural two lane segment is $a_{PD} = 0.712 \times 2.5 \times 6^{0.592}$ = 5.14 PDO crashes / year

The average annual number of crashes in the present year, 2004, is calculated using Eq 6.1, assuming the exposure change rate as two percent and Z=0.592 from Table 6.2.

$$Y_2 = 2004 - \frac{1998 + 2000}{2} = 5$$

$$a_{PD,P} = \frac{\frac{1}{0.430} + 17}{\frac{1}{0.430 \times 5.14} + 3} \times \left(1 + \frac{2}{100}\right)^{0.592 \times 5} = 5.93 \text{ PDO crashes/year}$$

6.1.3 Determine the crash reduction factors and the life of the safety improvement

The crash reduction factor is the expected percent reduction in crashes caused due to the implementation of the safety project. The recommended crash reduction factors for Indiana are listed in Appendix C. The crash reduction factors may be different for a PDO and I/F crash. For improvements that involve multiple alternatives, Eq 6.3 should be used to calculate the total percent crash reduction due to implementation of multiple safety improvements.

$$CRF = 100 - \prod_{k=1}^{m} (100 - CRF_k) \, , \qquad \text{Eq 6.3}$$

where:

CRF = total percent crash reduction factor for multiple improvements, and

CRF_k = crash reduction factor for the k^{th} improvement.

Service life is the time period that the improvement can be reasonably expected to impact crash experience. The expected service life should reflect this time period and is not necessarily the physical life of the improvement (Appendix D).

6.1.4 Estimate the exposure adjustment factors

The exposure adjustment factor (*EAF*) is used in calculating the PDO and I/F crash frequency during the service life of the safety improvement. It is assumed that the change in the crash frequency calculated in step 2 is proportional to the *EAF*, which depends on the change in exposure to risk (AADT for intersections and VMT for sections). The exposure change rate (*R*) should be assumed as 2% unless better data or method of projection is available. *EAF* for a service year after the implementation of safety project can be calculated using Eq 6.4. This equation can be used for both PDO and I/F crashes as well. *EAF* is calculated for each year of the service life.

$$EAF = \left(1 + \frac{R}{100}\right)^{Z \times Y_1} , \qquad \text{Eq 6.4}$$

where:

R = exposure change rate in percent, assumed to be 2% unless otherwise specified (Table 6.1),

Z = constant taken from Table 6.2, and

Y_1 = number of years between the present year and the future year of service.

For example, if the present year is 2004 and the service year is 2011,

$Y_1 = 2011 - 2004 = 7.0.$

EXAMPLE 6.2 Calculating the exposure adjustment factor

A safety project is analyzed for a rural two-lane segment. Calculate the *EAF* for PDO crashes at this location for the year 2011, if the present year is 2004. R is assumed to be 2%.

The time between present year and the service year is $Y_1 = 2011 - 2004 = 7$. The exposure adjustment factor for PDO crashes is calculated using Eq 6.4 and Z = 0.592 (From Table 6.2)

$$EAF_{PD} = (1 + \frac{2}{100})^{0.592 \times 7} = 1.086.$$

6.1.5 Calculate the present worth of total crash benefits

Crash history is usually the best indicator of future crash experience. The crash frequency before the improvement is multiplied with the *EAF* for each service year to determine the expected number of crashes in the analysis period after the implementation of the safety project. Annual crash reduction (*CR*), and annual benefits (*AB*) in present year dollars should be calculated separately for PDO and I/F crashes as follows:

$$CR = a_P \times EAF \times CRF \,, \qquad \text{Eq 6.5}$$

$$AB = CR \times C_P \times PWF_{SP}, \qquad \text{Eq 6.6}$$

where:

CR = annual crash reduction,

a_P = average annual number of crashes in the present year, calculated in step 2,

EAF = exposure adjustment factor,

CRF = crash reduction factor (from existing records and judgment). Same value of CRF is used for PDO and I/F crashes if separate values are not available.

AB = annual benefits,

C_P = estimated cost of the crash in the present year, explained in the next section, and

PWF_{SP} = present worth factor (single payment). PWF_{SP} is used to determine the present value of a future single payment. PWF_{SP} can be calculated using Eq 6.7.

$$PWF_{SP} = \frac{1}{(1+I)^{Y_1}}, \qquad \text{Eq 6.7}$$

where:

I = interest rate, assumed to be 4% unless otherwise specified, and

Y_1 = number of years between the present year and the future year of service.

The result of this step is the gross dollar value for the total annual benefits for each year of the service life of the safety project calculated in the dollar value of the present year. Annual benefits (*AB*) are summed for the entire service life of the project to obtain the total crash benefit in present dollars (*PWB*) as shown in Eq 6.8. *PWB* is multiplied by capital recovery factor to obtain equivalent uniform annual benefit (*EUAB*) as shown in Eq 6.9.

$$PWB = \sum_{k=1}^{T} AB_k , \qquad \text{Eq 6.8}$$

$$EUAB = PWB \times CF \qquad \text{Eq 6.9}$$

$$CF = \frac{I}{1-(1+I)^{-T}} \qquad \text{Eq 6.10}$$

where:

PWB = present worth benefit,

AB = annual benefit, calculated using Eq 6.6,

$EUAB$ = equivalent uniform annual benefit,

CF = capital recovery factor,

I = interest rate, and

T = service life of the improvement, determined in step 3.

6.1.5.1 Crash cost

Crash cost values are of major importance in computing the expected crash benefits. The most commonly used sources of information about crash costs are the National Safety Council (NSC) and the National Highway Traffic Safety Administration (NHTSA). The NSC cost estimates include wage losses, medical expenses, insurance administrative costs, and property damage. The NHTSA cost estimates includes the calculable costs associated with each fatality and injury plus the costs to society. INDOT recommends NSC crash cost values. In 2001, NSC proposed a value of $6,500 for a PDO crash, $36,500 for an injury crash, and $104,000 for a fatal crash. In order to find the cost of an injury/fatal crash, number of injury and fatal crashes occurring on various road facilities was determined from the Indiana crash database. The number of injury crashes was taken as the weight for injury crashes and number of fatal crashes was taken as the weight for fatal crashes. The resulting weighted average gave the crash cost values in 2001 dollars, which are listed in Table 4.6.

The crash costs are in 2001 dollars so they need to be updated to the present worth of dollar using the following equation:

$$C_P = \left(1 + \frac{F}{100}\right)^{Y_3} \times C_{01}, \qquad \text{Eq 6.11}$$

where:

C_P = crash cost in dollar value of present year,

F = inflation rate, assumed to be 2% unless otherwise specified,

Y_3 = number of years between the year in which crash cost values are computed and the present year, and

C_{01} = crash cost in 2001 dollars.

This equation is used for calculating the crash cost for both I/F and PDO crashes.

EXAMPLE 6.3 Calculating crash costs for analysis year

Calculate the crash cost in 2004 dollars for a rural two-lane segment on a state road, where crash data was collected for the period 1998 – 2000 and the present year is 2004.

The crash cost in 2004 dollars is calculated using Eq 6.11. Inflation rate is assumed to be 2% and $Y_3 = 2004 - 2001 = 3$.

$$C_{PDP} = \left(1 + \frac{2}{100}\right)^3 \times 6{,}500 = \$6{,}898$$

$$C_{IFP} = \left(1 + \frac{2}{100}\right)^3 \times 78{,}000 = \$82{,}774$$

6.1.6 Calculate the present worth of total agency costs

The present worth of total agency costs, (*PWC*), and equivalent uniform annual cost, (*EUAC*) can be calculated using Eq 6.12 and Eq 6.13.

$$PWC = PC + M \times PWF_{EPS} - S \times PWF_{SP}, \quad \text{Eq 6.12}$$

$$EUAC = PWC \times CF \quad \text{Eq 6.13}$$

where:

PC = project cost,

M = change in annual maintenance cost,

PWF_{EPS} = present worth factor (equal payment series), calculated using Eq 6.15,

S = salvage value,

PWF_{SP} = present worth factor (single payment), calculated using Eq 6.14, and

CF = capital recovery factor, calculated using Eq 6.10.

PWF_{SP} is used to determine the present value of future single payments. PWF_{SP} can be calculated using Eq 6.14.

$$PWF_{SP} = \frac{1}{(1+I)^T}, \quad \text{Eq 6.14}$$

where:

I = interest rate, assumed to be 4% unless otherwise specified (Table 6.1), and

T = service life of the safety improvement.

PWF_{EPS} is used to determine the present value of future equivalent uniform annual payments. PWF_{EPS} can be calculated using Eq 6.15.

$$PWF_{EPS} = \frac{(1+I)^T - 1}{I(1+I)^T}, \quad \text{Eq 6.15}$$

where:

I = interest rate, assumed to be 4% unless otherwise specified (Table 6.1), and

T = service life of the safety improvement.

6.1.7 Calculate B/C ratio and NAB

Calculate the *B/C* ratio by dividing the equivalent uniform annual benefit by the equivalent uniform annual cost shown in Eq 6.16.

$$B/C = \frac{EUAB}{EUAC}, \quad \text{Eq 6.16}$$

Calculate the *NAB* by subtracting the equivalent uniform annual cost from the equivalent uniform annual benefit as shown in Eq 6.17.

$$NAB = EUAB - EUAC, \quad \text{Eq 6.17}$$

6.1.8 Conclusions

When the B/C ratio is greater than one, the improvement could be economically prudent. When the B/C ratio is less than one, the proposed improvement is generally not economically prudent but when the B/C ratio is less than one but very close to one, then the secondary benefits resulting from the proposed improvement should be analyzed before abandoning the proposed improvement.

Secondary benefits such as improved capacity or other economic benefits will not be included in the final computed B/C ratio of the selected safety project. Secondary benefits may be used in computing B/C ratios of the alternative improvements studied in determining the selection of the preferred alternative but should not be used for the final B/C ratio.

6.2 Example

Calculate the B/C ratio for a rural two-lane segment on a state road that experienced 17 PDO and seven I/F crashes during the years 1998 – 2000. The length for the segment is 2.5 miles and has an AADT of 6000 vehicles/day. The improvement being considered is the realignment of the horizontal curve. The present year is 2004 and the service life starts in 2005.

Step 1. Collect the required input

Collect crash data, traffic volumes, and determine the traffic growth factor. Identify the proposed safety improvement and estimate the construction cost, salvage cost, change in annual maintenance costs, and the service life of the safety improvement.

The selected safety improvement is to realign the horizontal curve and from similar projects the construction costs are estimated to be $750,000 with a change in annual maintenance cost to be $3,000 after realignment. After 20 years, the salvage value is expected to be $20,000. The exposure change rate is assumed to be 2 percent.

Step 2. Estimate the crash frequency before implementation of the safety project

The location had 17 PDO crashes and seven I/F crashes during 1998 - 2000. The crash frequency before improvement is calculated as follows.

The safety performance function for PDO and I/F crashes for rural two-lane segment from Table 4.5 are a_{IF} = 0.208×L×$Q^{0.604}$ with an over-dispersion parameter D = 0.420, and a_{PD} = 0.712×L×$Q^{0.592}$ with an over-dispersion parameter D = 0.430, where L = road section length, in miles and Q = AADT entering along the road segment, in thousand vehicles per day.

a_{PD} = 0.712×2.5×$6^{0.592}$ = 5.14 crashes / year

a_{IF} = 0.208×2.5×$6^{0.604}$ = 1.53 crashes / year

The crash frequency in the present year 2004 is calculated using Eq 6.1 and assuming the exposure change rate as 2 percent.

$$Y_2 = 2004 - \frac{1998 + 2000}{2} = 5,$$

$$a_{PD,P} = \frac{\frac{1}{0.430} + 17}{\frac{1}{0.430 \times 5.14} + 3} \times \left(1 + \frac{2}{100}\right)^{0.592 \times 5} = 5.93 \text{ PDO crashes/year}$$

$$a_{IF,P} = \frac{\frac{1}{0.420} + 7}{\frac{1}{0.420 \times 1.53} + 3} \times \left(1 + \frac{2}{100}\right)^{0.604 \times 5} = 2.18 \text{ I/F crashes/year}$$

Step 3. Determine the crash reduction factor and the service life of the safety improvement

The expected service life of the proposed improvement is 20 years, taken from Appendix D. Appendix C is used to determine the CRF for the proposed improvement. The CRF for both PDO and I/F crashes is 50%.

Step 4. Estimate the exposure adjustment factor.

R is assumed to be 2% per year (Table 6.1).

For illustration purposes, the *EAF* for PDO and I/F crashes is calculated for sixth service year which is 2010 as follows.

$Y_2 = 2010 - 2004 = 6$; Z_{PD}= 0.592; Z_{IF}=0.604 (From Table 6.2)

$$EAF_{PD} = (1 + \frac{2}{100})^{0.592 \times 6} = 1.072$$

$$EAF_{IF} = (1 + \frac{2}{100})^{0.604 \times 6} = 1.074$$

EAF for other years is calculated in a similar way, which is shown in Table 6.3, Column 2 and Column 3.

Step 5. Calculate the present worth of total crash benefits

Table 6.3 presents the detailed calculations for calculating present worth total crash benefits. Columns 4 and 5 of Table 6.3 present the number of PDO and I/F crashes saved, which is calculated by multiplying the crash frequency by the crash reduction factor. The benefits of saving PDO crashes is calculated by multiplying the value in Column 4 by $6,898, the cost of a PDO crash in 2004 dollars on a rural road. Similarly the benefits of reducing I/F crashes is calculated by multiplying the value in Column 5 by $82,774, the cost of an I/F crash in 2004 dollars on a rural road. The crash cost values in 2004 dollars are calculated in Example 6.3. The total benefit of reducing the crashes due to implementation of the safety project is obtained by adding Column 6 and 7 which is shown in Column 8. PWF_{SP} is listed in Column 9. The present worth of the benefits obtained by preventing crashes is determined by multiplying Column 8 and Column 9, and the result is shown in Column 10. The sum of annual present worth benefits (*PWB*) is determined by summing the values in Column 10. *EUAB* is calculated by multiplying *PWB* by *CR* using Eq 6.9.

PWB = $1,681,255

$$CR = \frac{0.04}{(1 - (1 + .04)^{-20}} = 0.0736$$

EUAB = $1,681,255 × 0.0736 = $123,740

Table 6.3 Crash reduction benefits

Service year (1)	EAF_{PD} (2)	EAF_{IF} (3)	PDO saved (4)	I/F saved (5)	Annual benefits ($) PDO benefits (6)	I/F benefits (7)	Total benefit (8)	PWF_{SP} (9)	Annual present worth benefits (10)
1	1.01	1.01	3.00	1.10	20,694	91,306	111,999	0.9615	107,692
2	1.02	1.02	3.04	1.12	20,938	92,401	113,338	0.9246	104,788
3	1.04	1.04	3.07	1.13	21,185	93,509	114,693	0.8890	101,962
4	1.05	1.05	3.11	1.14	21,434	94,630	116,065	0.8548	99,213
5	1.06	1.06	3.14	1.16	21,687	95,765	117,452	0.8219	96,537
6	1.07	1.07	3.18	1.17	21,943	96,913	118,856	0.7903	93,934
7	1.09	1.09	3.22	1.18	22,202	98,076	120,277	0.7599	91,401
8	1.10	1.10	3.26	1.20	22,464	99,252	121,715	0.7307	88,936
9	1.11	1.11	3.29	1.21	22,728	100,442	123,171	0.7026	86,538
10	1.12	1.13	3.33	1.23	22,996	101,647	124,643	0.6756	84,204
11	1.14	1.14	3.37	1.24	23,268	102,866	126,133	0.6496	81,934
12	1.15	1.15	3.41	1.26	23,542	104,099	127,641	0.6246	79,724
13	1.16	1.17	3.45	1.27	23,820	105,348	129,167	0.6006	77,575
14	1.18	1.18	3.49	1.29	24,101	106,611	130,712	0.5775	75,483
15	1.19	1.20	3.54	1.30	24,385	107,890	132,274	0.5553	73,447
16	1.21	1.21	3.58	1.32	24,672	109,184	133,856	0.5339	71,467
17	1.22	1.22	3.62	1.33	24,963	110,493	135,456	0.5134	69,540
18	1.23	1.24	3.66	1.35	25,258	111,818	137,076	0.4936	67,664
19	1.25	1.25	3.70	1.37	25,555	113,159	138,714	0.4746	65,840
20	1.26	1.27	3.75	1.38	25,857	114,516	140,373	0.4564	64,064
Sum of annual present worth benefit (PWB)									1,681,255

$a_{PD,P}$ = 5.93 crashes/year

$a_{IF,P}$ = 2.18 crashes/year

PDO saved = $a_{PD,P} \times EAF \times CRF_{PD}$; I/F saved = $a_{IF,P} \times EAF \times CRF_{IF}$

PDO benefits = PDO saved × $C_{PD,P}$; I/F benefits = I/F saved × $C_{IF,P}$

Annual present worth benefits = (PDO benefits + I/F benefits) × PWF_{SP}

Step 6. Calculate the present worth of total agency costs.

Equivalent uniform annual cost is calculated using Eq 6.13.

PWC = \$750,000 + \$3,000 ×13.5903 - \$20,000 × 0.4654 = \$781,463

$EUAC$ = \$781,463 × 0.0736 = \$57,515

where:

PC = Project cost = \$750,000,

PWF_{EPS} = Present worth factor for equal payment series, calculated using Eq 6.15, $PWF_{EPS} = \frac{(1+I)^T - 1}{I(1+I)^T}$ = 13.590 for T =20 years and I = 4 %,

PWF_{Sp} = Present worth factor for single payment series, calculated using Eq 6.14, $PWF_{SP} = \frac{1}{(1+I)^T}$ = 0.4564 for T =20 years and I= 4 %,

M = Increase in annual maintenance cost = \$3,000,

S = Salvage value = \$20,000.

Step 7. Calculate *B/C* ratio and *NAB*

The *B/C* ratio and *NAB* are calculated using Eq 6.16 and Eq 6.17.

$$B/C \text{ ratio} = \frac{EUAB}{EUAC} = \frac{\$123{,}740}{\$57{,}515} = 2.15,$$

$$NAB = EUAB - EUAC = \$123{,}740 - \$57{,}515 = \$66{,}244.$$

Step 8. Conclusions

The *NAB* is positive as expected because the *B/C* ratio is more than one. This means that if the proposed improvement was implemented, the annual benefit would be $66,244. As the *B/C* ratio is greater than one, this project would be cost-effective.

6.3 Application for funds

The following is taken from the "Proposed Policy for the Indiana Highway Safety Improvement Program" and appropriately modified.

A listing of eligible projects will be developed by the INDOT Central Office Division of Program Development that will establish priorities for implementing specific projects. Benefit/Cost ratios will be used to select the final projects that will be eligible for Surface Transportation Program safety funding.

The local agency will be required to provide to the INDOT Division of Local Transportation sufficient engineering and crash data that would indicate the priority ranking of a particular project compared to other locations within their jurisdiction. The Division of Local Transportation will determine which projects will be submitted based upon availability of funds.

The safety project should be requested through the Program Development process when a call for projects is requested. As part of the application and approval process, each project application should contain the following:

1. Problem statement and proposed solution
2. Crash analysis
    a. Why the project area is considered as a high crash location (through a severity index, index of crash cost, index of crash frequency, comparison to statewide averages, etc.)
    b. The three-year history of crashes by type and severity
    c. Traffic data
    d. Design standard deficiencies
    e. Potential for crash reduction
    f. Collision diagram

3. The proposed project's cost and schedule
4. Justification
   a. Economic Analysis – Benefit/Cost Ratio (Include calculations in appendix)
   b. Secondary benefits and consideration
   c. Certain types of safety improvement projects that have been shown to be cost-effective by previous nationwide studies can be implemented without reporting the cost benefit and other considerations. The report on actual crash reductions realized will still be needed.
5. Priority recommendations
6. Commitment to provide the FHWA Safety Report on actual crash reductions realized by the safety improvement. This report is an after-improvement crash study, which when compared with the before-improvement crash history would document any crash reduction realized. The study should be completed within one year from the time the data is available from the Indiana State Police vehicle crash records.

6.3.1 Funding

The amount of funds that can be spent on any given project will not be limited, but the intent is to fund as many projects as possible with the funds available. The funds shall be used only for construction activities.

Approval will be only for the amount requested for a particular project. If there are any cost overruns, the applicant must reapply or pay for the increase from other funds.

Applications for funding for construction activities are encouraged for any existing project that meets the application requirements and whose completion might be advanced, thus avoiding potential crashes.

A selection committee will be formed to review projects and recommend them for funding. This committee would be made up of representatives from INDOT and FHWA.

A list of INDOT projects will be prepared annually. The list will include the following information for each project:

Project number

Location

County or city

INDOT district

Crash rate

Anticipated letting date

Project cost

Federal safety funds

CHAPTER 7

Post implementation study

The effectiveness of a safety project should be reevaluated after its implementation to provide feedback to the safety management process. Crash data collected before and after the project's implementation is used. Although the recommended periods before and after the implementation are three years for each period, longer periods increase the confidence of the results and should be considered. In all cases, the periods should be multiples of full years to eliminate the undesirable effect of seasonal variations of crashes. Other data needed for a post-implementation study include actual project costs, annual maintenance costs, traffic growth rate, and average daily traffic volumes.

7.1 Calculating and updating crash reduction factors

The crash reduction factors listed in Appendix D are used in calculating the benefits provided by the safety project. It is the percent of original crashes reduced by the implementation of the safety project. The crash reduction factor for the project is calculated using crash data before and after implementing the safety project and the equations presented in this chapter. Expected crash frequency a_{0A} in the period after implementation of a safety project, had the safety project not been implemented, is calculated using Eq 7.1, which accounts for the "regression-to-mean effect" and for the change in exposure. CRF_2, the crash reduction factor for the implemented safety project and its standard deviation is calculated using Eq 7.5 and Eq 7.6. Crash reduction factors can be estimated for all crashes, PDO crashes, and I/F crashes.

$$a_{0A} = \frac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \times \left(\frac{E_A}{E_B} \right)^Z , \qquad \text{Eq 7.1}$$

$$a_A = \frac{A_A}{Y_A} , \qquad \text{Eq 7.2}$$

$$Var(a_{0A}) = \frac{\frac{1}{D} + A_B}{\left(\frac{1}{D \times a_B} + Y_B\right)^2} \times \left(\frac{E_A}{E_B}\right)^{2Z}, \qquad \text{Eq 7.3}$$

$$Var(a_A) = \frac{A_A}{Y_A^{\ 2}}, \qquad \text{Eq 7.4}$$

$$CRF_2 = \left(1 - \frac{a_A}{a_{0A}} - \frac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100, \qquad \text{Eq 7.5}$$

$$SD_2 = \sqrt{\frac{Var(a_A)}{(a_{0A})^2} + \frac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100, \qquad \text{Eq 7.6}$$

where:

a_{0A} = expected crash frequency in the period after the implementation of safety project, had the safety project not been implemented,

a_B = typical crash frequency (crashes / year) for the location calculated using safety performance functions,

D = over-dispersion parameter,

A_B = number of crashes during the period before the implementation of safety project,

Y_B = years for which crash data is analyzed before the implementation of safety project,

E_B = average daily exposure during the period before the implementation of safety project (exposure for intersections is the average AADT entering the intersection whereas for segments it is the product of AADT and the length of the segment),

E_A = average daily exposure during the period after before the implementation of safety project,

Z = constant taken from Table 7.1,

a_A = crash frequency during the period after the implementation of safety project,

A_A = number of reported crashes during the period after the implementation of safety project,

Y_A = years for which crash data is analyzed after the implementation of safety project,

CRF_2 = crash reduction factor calculated using the crash data obtained after the implementation of safety project, in percent,

$Var(a_{0A})$ = variance of a_{0A},

$Var(a_A)$ = variance of a_A, and

SD_2 = standard deviation of the crash reduction factor for the implemented safety project, in percent.

Appendix F presents calculations of the crash reduction factor based on multiple locations where the same safety project was applied and with the use of, so called control group. The use of multiple locations increases the accuracy of *CRF* estimation. The use of control group allows for adjusting for changes in safety that cannot be attributed to safety project or to the changes in exposure.

Table 7.1 Z values for different road facilities

Facility	All crashes	PDO	I/F
Signalized intersection	0.953	1.033	0.723
Two-way stop-controlled intersection	1.093	1.034	1.099
All-way stop-controlled intersection	1.324	1.434	0.835
Rural multilane road segment	0.654	0.615	0.814
Rural two-lane road segment	0.598	0.592	0.604
Urban multilane road segment	0.458	0.460	0.435
Urban two-lane road segment	0.917	0.896	1.080
Rural interstate	0.939	0.943	0.917
Urban interstate	2.016	1.954	2.238

EXAMPLE 7.1 Calculating crash reduction factor and its standard deviation

Calculate the crash reduction factor and its standard deviation for a 2.5 mile long rural two-lane segment that has been improved by widening its traveled way by two feet. The crash data for the segment is given in Table 7.2.

Table 7.2 Crash data for urban two-lane segment

Year	Crashes	AADT
1993	18	10,100
1994	12	10,300
1995	25	10,500
1996	16	11,100
1997	11	11,300
1998	Year of modernization	
1999	11	12,000
2000	8	12,300
2001	16	12,400

Average daily exposure in the period before project implementation:

$$E_B = \left(\frac{10100 + 10300 + 10500 + 11100 + 11300}{5}\right) \times 2.5 = 26650 \text{ veh miles/day.}$$

Average daily exposure in the period after project implementation:

$$E_A = \left(\frac{12000 + 12300 + 12400}{3}\right) \times 2.5 = 30583 \text{ veh/day.}$$

A_B = 82 crashes, Y_B = 5, A_A = 35 crashes, Y_A = 3.

Typical crash frequency (crashes / year) calculated using safety performance functions for rural two-lane segments from Table 4.1; $a = 0.922 \times L \times Q^{0.598}$ with an over-dispersion parameter $D = 0.427$. Length for the segment is 2.5 miles and average AADT = 10,660.

$a_B = 0.922 \times 2.5 \times 10.66^{0.598} = 9.49$ crashes / year

The expected crash frequency in the period after implementation of safety project, had the safety project not been implemented, is calculated using Eq 7.1,

$$a_{0A} = \frac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \times \left(\frac{E_A}{E_B}\right)^Z = \frac{\frac{1}{0.427} + 82}{\frac{1}{0.427 \times 9.49} + 5} \times \left(\frac{30583}{26650}\right)^{0.598} = 17.45 \text{ crashes/year}$$

$$a_A = \frac{A_A}{Y_A} = \frac{35}{3} = 11.66 \text{ crashes / year}$$

$$Var(a_{0A}) = \frac{\frac{1}{D} + A_B}{\left(\frac{1}{D \times a_B} + Y_B\right)^2} \times \left(\frac{E_A}{E_B}\right)^{2Z} = \frac{\frac{1}{0.427} + 82}{\left(\frac{1}{0.427 \times 9.49} + 5\right)^2} \times \left(\frac{30583}{26650}\right)^{2 \times 0.598} = 3.61$$

$$Var(a_A) = \frac{A_A}{Y_A^{\ 2}} = \frac{35}{3^2} = 3.88$$

CRF_2 is calculated using Eq 7.5, $CRF_2 = \left(1 - \frac{a_A}{a_{0A}} - \frac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100$

$$= \left(1 - \frac{11.66}{17.45} - \frac{2 \times 11.66 \times 3.61}{17.45^3}\right) \times 100 = 31.6\%$$

Standard deviation of the new crash reduction factor is calculated as follows.

$$SD_2 = \sqrt{\frac{Var(a_A)}{(a_{0A})^2} + \frac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100 = \sqrt{\frac{3.88}{17.45^2} + \frac{11.66^2 \times 3.61}{17.45^4}} \times 100 = 13\% .$$

The crash reduction factor for the implemented safety project was 32% with a standard deviation of 13%.

Data collected after the implementation of a safety project and its evaluation can be used to update crash reduction factors. Let CRF_1 stand for the old crash reduction factor taken from Appendix D, while CRF_2 is calculated using Eq 7.5.

Then, the updated crash reduction factor, *CRF*, is calculated using the CRF_1 and CRF_2 estimates and their standard deviations SD_1 and SD_2 respectively using Eq 7.7.

$$CRF = \frac{SD_1^2 \times CRF_2 + SD_2^2 \times CRF_1}{SD_1^2 + SD_2^2}, \qquad \text{Eq 7.7}$$

where:

CRF = updated crash reduction factor, percent,

SD_1 = standard deviation of the old crash reduction factor (assume 25% if not available), in percent, and

SD_2 = standard deviation of the new crash reduction factor for the implemented safety project, in percent.

The standard deviation of the updated crash reduction factor is calculated using Eq 7.8, which uses standard deviations SD_1 and SD_2,

$$SD = \sqrt{\frac{SD_2^4 \times SD_1^2 + SD_1^4 \times SD_2^2}{(SD_1^2 + SD_2^2)^2}}, \qquad \text{Eq 7.8}$$

where:

SD = Standard deviation of updated crash reduction factor

The calculated *SD* becomes SD_1 when the crash reduction factor has to be updated again.

EXAMPLE 7.2 Updating crash reduction factor and its standard deviation

A crash reduction factor of 20% is listed in Appendix D for widening a rural two-lane segment by two feet. After implementing a safety project, which involves addition of one foot to both lanes, the new crash reduction factor was estimated as 32%. The standard deviation of the old crash reduction factor was not known and assumed to be 25%, the standard deviation for the new factor was estimated as 13%. Update the crash reduction factor for adding two feet to a rural two-lane segment.

Known: $CRF_1 = 20$, $CRF_2 = 32$, $SD_1 = 25$, $SD_2 = 13$.

Updated crash reduction factor and its standard deviation are calculated using Eq 7.7 and Eq 7.8,

$$CRF = \frac{SD_1^2 \times CRF_2 + SD_2^2 \times CRF_1}{SD_1^2 + SD_2^2} = \frac{25^2 \times 32 + 13^2 \times 20}{25^2 + 13^2} = 29\%$$

$$SD = \sqrt{\frac{SD_2^4 \times SD_1^2 \;\; + SD_1^4 \times SD_2^2}{(SD_1^2 + SD_2^2)^2}} \;\; = \sqrt{\frac{13^4 \times 25^2 + 25^4 \times 13^2}{(25^2 + 13^2)^2}} = 12\%$$

The updated crash reduction factor for the addition of two feet to a rural two-lane segment is 29% with a standard deviation of 12 %.

7.2 Significance of crash reduction

The agency must test the statistical significance of the effectiveness of a safety project to determine whether the reduction in crashes is large enough to reject the possibility that the reduction was caused solely by random fluctuations of crashes. Negative binomial distribution is used in the test.

The number of crashes expected in the period after implementation if the safety project were not implemented is calculated using Eq 7.9 and compared to the actual number of crashes that occurred during the same period, A_A. The significance for the safety change is performed at a user selected significance level. The choice of significance level depends on the project size (cost). A significance level of 5% can be used for large and expensive projects, while 10% or even 20% may be used for small projects. The 10% significance level is considered typical in post-implementation studies.

$$\overline{A_{0A}} = Y_A \times a_{0A}, \qquad \text{Eq 7.9}$$

$$Var\left(\overline{A_{0A}}\right) = Y_A{}^2 \times Var(a_{0A}), \qquad \text{Eq 7.10}$$

$$D_A = \frac{Var\left(\overline{A_{0A}}\right)}{\left(\overline{A_{0A}}\right)^2}. \qquad \text{Eq 7.11}$$

where :

$\overline{A_{0A}}$ = expected number of crashes at the location had the safety project not been implemented, during the after period,

$Var(\overline{A_{0A}})$ = variance of $\overline{A_{0A}}$, and

D_A = over-dispersion for $\overline{A_{0A}}$.

Figure 7.1 and Figure 7.2 help determine whether the reduction in crashes is significant at the10% significance level. Figure 7.1 is used when D_A is greater than 0.01 and Figure 7.2 is used when D_A is less than 0.01. The value of D_A is calculated using Eq 7.11 and it reflects the estimation accuracy of the expected number of crashes, $\overline{A_{0A}}$, calculated using Eq 7.9. For D_A greater than 0.01, using D_A and corresponding $\overline{A_{0A}}$, critical number of crashes is determined from the Y axis of Figure 7.1. For D_A less than 0.01, using $\overline{A_{0A}}$, the critical number of crashes is determined from the Y axis of Figure 7.2. If the number of crashes in the period after the project implementation is less than the critical number of crashes, then the safety improvement is statistically significant at 10% level of significance.

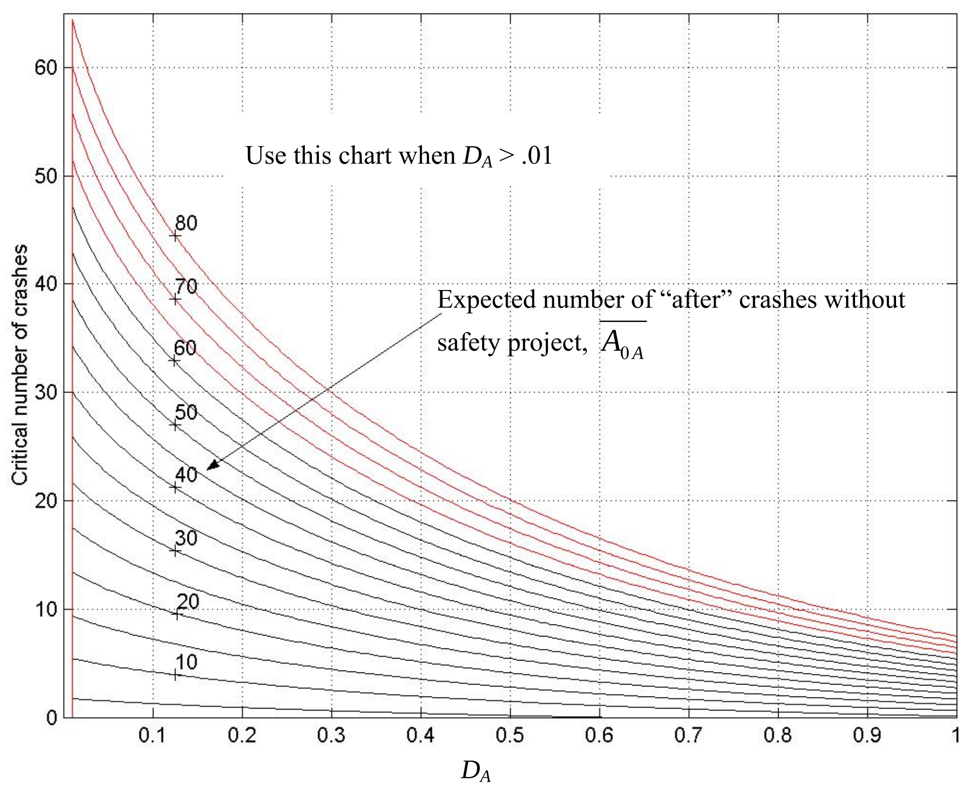

Figure 7.1 Critical number of crashes for D_A greater than 0.01, at a significance level of 10%

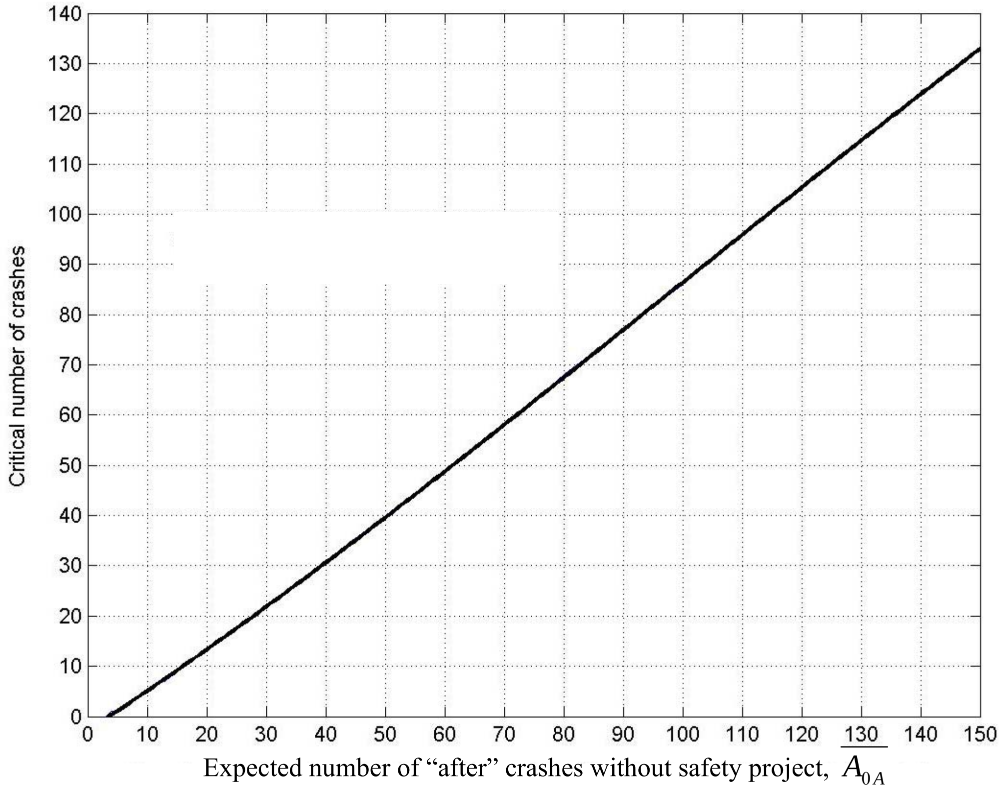

Figure 7.2 Critical number of crashes for D_A less than 0.01, at a significance level of 10%

EXAMPLE 7.3 Checking significance of crash reduction

A rural two-lane segment has been improved by widening its traveled way by two feet. The crash data for the segment is given in Table 7.1. Determine whether the reduction in crashes is significant at a 10% significance level.

In this example, the expected number of crashes at the location had the project not been implemented during the after period is calculated using Eq 7.9 and the value of a_{0A} is taken from Example 7.1.

$$\overline{A_{0A}} = Y_A \times a_{0A} = 3 \times 17.45 = 52.35$$

$$Var\left(\overline{A_{0A}}\right) = Y_A{}^2 \times Var(a_{0A}) = 3^2 \times 3.61 = 32.49$$

$$D_A = \frac{Var\left(\overline{A_{0A}}\right)}{\left(\overline{A_{0A}}\right)^2} = \frac{32.49}{(52.35)^2} = 0.012$$

As D_A is greater than 0.01, Figure 7.1 is used to determine the critical number of crashes. From Figure 7.3 the critical number of crashes for D_A equal to .012 and $\overline{A_{0A}}$ equal to

52.35 is 38. As the crash count after the improvement is 35, which is less than the critical crash count, the safety project was statistically significant in reducing the number of crashes.

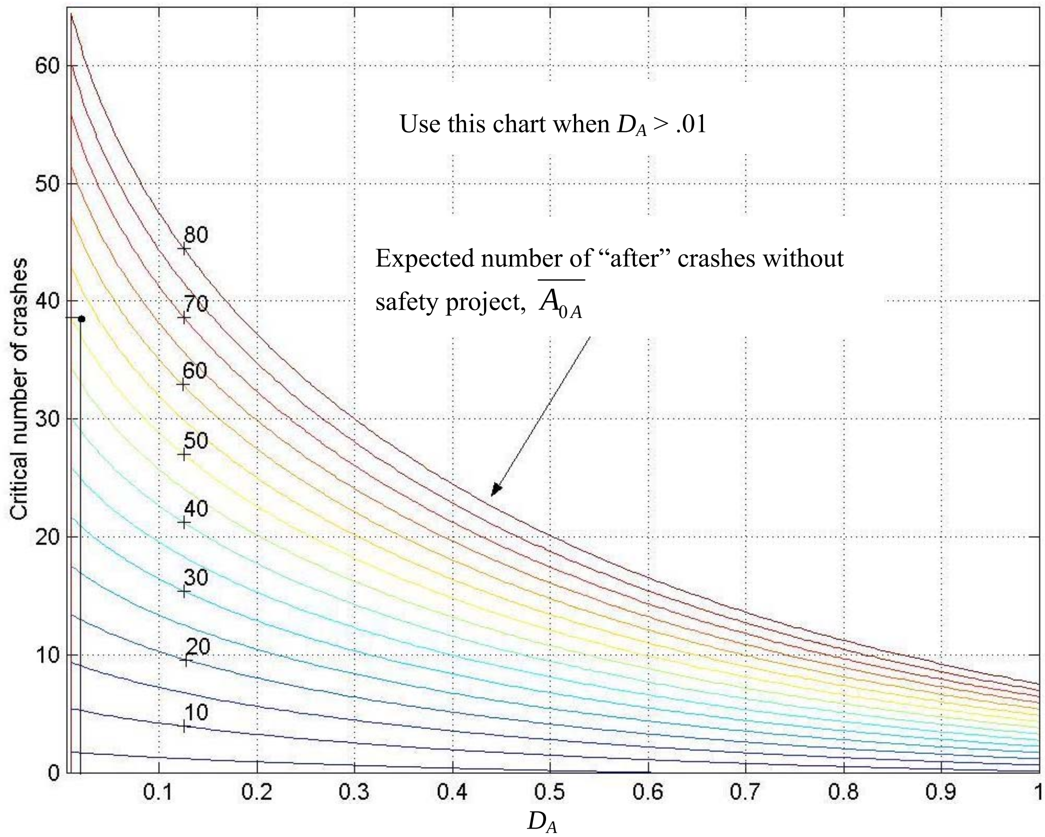

Figure 7.3 Determining the critical number of crashes for Example 7.2

7.3 Benefit and cost analysis revision

The benefit and cost analysis is done after the safety project is implemented to determine whether the project met the expectations. This would give a feedback to the HEP as to whether or not the improvement was effective. The actual project costs and updated crash reduction factors are used in the benefit and cost analysis. All information regarding the actual incurred costs should be stored to use in the future for suitable projects if needed.

CHAPTER 8

Example

This chapter applies the key analytical components presented in the earlier chapters to an example intersection that is suspected to be a high crash location. The example includes checking whether the location is indeed a high crash location, and performing a safety review, an economic analysis, and a post-implementation study.

8.1 Site location and reason for analysis

Safety studies in Pleasantville dating back to 1991 have consistently found State Street, and particularly the intersection of State and Main Streets, to have the highest crash rates and severity ratios in town. In the last three years (1998-2000), there have been 40 crashes at the intersection. The analysis aims to confirm the need for safety improvement and to propose adequate safety projects for the subject intersection if needed.

8.2 Confirming crash hazard

The purpose of this step is to check if the intersection State Street and Main Street can be considered a high crash intersection according to the statewide standards. A total of 40 crashes were reported at the intersection during 1998-2000. A summary of the crashes is presented in Table 8.1.

Table 8.1 Crash summary for State and Main street during 1998 - 2000

Crash Type	Property Damage Only (PDO)	Injury / Fatal (I/F)	Total
Right Angle	1	2	3
Rear End	6	3	9
Sideswipe	6	0	6
Right Turn-related	3	0	3
Left Turn –related	10	9	19
Total	26	14	40

8.2.1 Index of crash frequency

Step 1. Classify the location in one of the nine categories. The location is a signalized intersection.

Step 2. Collect the data needed for signalized intersections. The number of vehicles entering the intersection is 25,600 veh/day, Q = 25.6 thousand veh/day. Forty crashes were reported over three years, A = 40, Y = 3.

Step 3. Calculate a using safety performance functions for signalized intersections from Table 4.1 : $a = 0.30 \times Q^{0.953}$

$a = 0.30 \times 25.6^{0.953}$ = 6.59 crashes/year

Step 4. Calculate the index of crash frequency using Eq 4.1, (Figure 8.2):

$$I_{CF} = \frac{A - a \times Y}{\sqrt{A + a^2 \times Y^2 \times D}},$$

$$I_{CF} = \frac{40 - 6.59 \times 3}{\sqrt{(40 + 6.59^2 \times 3^2 \times .655)}} = 1.18$$

The **index of crash frequency** for the intersection is **1.18** and compared to a statewide average for similar locations, a value of I_{CF} = 1.18 implies that the number of crashes at the location exceeds the expected number of crashes for that location by 1.18 standard deviations.

8.2.2 Index of crash cost

Step 1. Classify the location in one of the nine categories. The location is a signalized intersection.

Step 2. Collect the data needed for signalized intersections. The number of vehicles entering the intersection 25,600 veh/day, Q=25.6 thousand veh/day. Twenty-six PDO crashes, PD = 26, and fourteen I/F crashes were reported, IF = 14. Crash data was analyzed for three years, Y=3.

Step 3. Calculate the typical property-damage-only crash frequency, a_{PD}, and the typical injury/fatal crash frequency, a_{IF}, using the proper safety performance functions from Table 4.5.:

$$a_{PD} = 0.1758 \times Q^{1.0334}, \; a_{IF} = 0.1954 \times Q^{0.723}$$

$$a_{PD} = 0.1758 \times 25.6^{1.0334} = 5.02 \text{ crashes / year}$$

$$a_{IF} = 0.1954 \times 25.6^{0.723} = 2.04 \text{ crashes / year}$$

Step 4. Calculate the index of crash cost I_{CC} using Eq 4.2, the reported number of crashes property damage only, injury/fatal crashes, typical property damage only crash frequency, a_{PD}**,** typical injury/fatal crash frequency, a_{IF}**,** over-dispersion parameters, D_{PD}, D_{IF}, cost of a property damage only crash, and cost of an injury/fatal crash.

$$I_{CC} = \frac{C_{PD}(PD - Y \times a_{PD}) + C_{IF}(IF - Y \times a_{IF})}{\sqrt{(C_{PD}^2 \times PD + C_{IF}^2 \times IF + C_{PD}^2 \times Y^2 \times a_{PD}^2 \times D_{PD} + C_{IF}^2 \times Y^2 \times a_{IF}^2 \times D_{IF})}}$$

$$\frac{6500 \times (26 - 3 \times 5.02) + 42500 \times (14 - 3 \times 2.04)}{\sqrt{(6500^2 \times 26 + 42500^2 \times 14 + 6500^2 \times 3^2 \times 5.02^2 \times 0.646 + 42500^2 \times 3^2 \times 2.04^2 \times 0.639)}} = 1.47$$

The **index of crash cost** for the intersection is **1.47**, and compared to the statewide average for similar locations, a value of I_{CC} = 1.47 implies that the cost of crashes at the location exceeds the expected cost of crashes for that location by 1.47 standard deviations. As the index of crash cost is more than the index of crash frequency it signifies that the severity of crashes is a bigger problem than frequency at this location. When the indices are greater than one and less than two then there is uncertainty about the location being a high crash location, whereas if the indices are greater than two the probability of the location being a high-crash location is very high. As the location has both an index of crash frequency and crash cost greater than 0, it signifies that the number of crashes and the severity of crashes at the location are greater than the statewide average. However, there is uncertainty about the location being a high-crash location so a safety review may be conducted at the location.

8.3 Safety review

Collision diagrams have been prepared using the crash statistics. A collision diagram, (Figure 8.4) for the period January 1998 – December 2000 prepared for the intersection shown in Figure 8.1. A careful analysis of the crash statistics reveal that 19 out of 40 crashes (47.5%) are related to left turns and 22% of crashes (nine crashes) are rear end crashes. Twenty-one crashes occurred during the months of June, July, and August; 34 crashes (85%) occurred between 7 a.m. to 7 p.m; and 29 crashes (72.5%) crashes occurred during dry pavement conditions.

Using the above statistics, the following inferences are made about the safety deficiencies of the location. As a predominant number of crashes are related to left turns, maneuvers for the left turns should be investigated at during the site visit. As most of the crashes occur during the day, the site investigation should be conducted during the day, and it should be scheduled during peak hours to observe the maximum number of left turns.

8.3.1 Checklist

Before visiting the site, a checklist is prepared based on the inferences made by observing the crash statistics for the intersection. The checklist prepared for the intersection (Figure 8.5) will assist the reviewers in ensuring that all the safety issues are addressed and will serve as a guideline.

8.3.2 Site investigations

After arriving at the intersection, the local conditions are documented by the review team. The signs, lighting, markings, delineation, traffic signals, and geometric features are inspected. The location is videotaped from the driver's position while in motion and from an elevation (stationary), and still pictures are taken for the intersection.

A condition diagram of the location is shown in Figure 8.6. After inspecting the intersection, no deficiencies where found in the sight distances. The traffic signals satisfied the minimum clearance and green phases. However, the main problem could be seen in frequent lane changes by vehicles going through when the left lane was blocked by left-turning vehicles (see Figure 8.1). Also, during peak periods the right lane had significant queues compared to the left lane as the left lane was frequently blocked by left-turning vehicles. The capacity at the intersection was not utilized fully due to absence of an exclusive left turning lane. It was also determined that the lenses of the traffic signal were not large enough to be observed from a safe distance from the intersection.

8.3.3 Post review analysis

The intersection of State and Main Street is a signalized intersection, and there are no existing deficiencies in the geometric design of the intersection and the signal is operating efficiently. The primary reason for the predominant left turn crashes was found to be absence of exclusive left turn lanes, which leads to erratic maneuvers by vehicles going through (see Figure 8.1) and rear end collisions.

8.3.4 Countermeasures

The safety investigation of the State and Main Street intersection indicates the need for an exclusively left turn lane. The existing traffic signal could be modified and a signal pole and a mast arm could be installed to provide an exclusive left turn phase. The diameter of the lenses could be increased and the lenses could be cleaned for better visibility of the signals. Suitable changes would be made in geometry of the intersection to accommodate the exclusive left turn lane. Due to the addition of an exclusive left turn lane, the traffic flow would not be obstructed in the through lanes and this would lead to a reduction in the erratic maneuvers of vehicles going through the intersection. It would also provide a clearer view of the oncoming traffic for left turning drivers. The addition of a left turn signal would not create capacity problems at the intersection as the volumes on the side street are low and are not expected to rise dramatically in the near future. The next section will show the benefit/cost analysis for the proposed countermeasure.

Figure 8.1 Frequent lane changing due to blocking of lanes by left turning vehicles

8.4 Economic evaluation of the project

Step 1. Collect the required input.

The crash data is provided in Table 8.1. The location experienced 26 PDO and 14 I/F crashes during 1998-2000. The proposed safety improvement is the construction of opposing exclusive left turn lanes on State Street at the intersection of State and Main Streets. From similar past project information, the construction costs are estimated to be $400,000 with an increase in annual maintenance costs of $4000. After 10 years, the salvage value is expected to be $2,000. The exposure change rate is assumed to be 2 percent. The present year is 2004 and the service year starts from 2005.

Step 2. Estimate the crash frequency for the present year.

The location had 26 PDO crashes and 14 I/F crashes during 1998 - 2000. The average annual number of crashes is calculated as follows:

The safety performance function for PDO and I/F crashes for signalized intersections from Table 4.5 are $a_{PD} = 0.1758 \times Q^{1.0334}$ with an over-dispersion parameter $D_{PD} = 0.646$, and $a_{IF} = 0.1954 \times Q^{0.723}$ with an over-dispersion parameter $D_{IF} = 0.639$, where Q = AADT entering the intersection, in thousand vehicles per day.

$a_{PD} = 0.1758 \times 25.6^{1.0334} = 5.02$ crashes / year, $a_{IF} = 0.1954 \times 25.6^{0.723} = 2.04$ crashes / year

The crash frequency in the present year 2004 is calculated using Eq 6.1 and assuming the exposure change rate as 2 percent and $Z_{PD} = 1.033$ and $Z_{IF} = 0.723$ from Table 6.2.

$$Y_2 = 2004 - \frac{1998 + 2000}{2} = 5$$

$$a_{PD,P} = \frac{\frac{1}{0.646} + 26}{\frac{1}{0.646 \times 5.02} + 3} \times \left(1 + \frac{2}{100}\right)^{1.033 \times 5} = 9.22 \text{ crashes/year}$$

$$a_{IF,P} = \frac{\frac{1}{0.639} + 14}{\frac{1}{0.639 \times 2.04} + 3} \times \left(1 + \frac{2}{100}\right)^{0.723 \times 5} = 4.44 \text{ crashes/year}$$

Step 3. Determine the crash reduction factor and the service life of the safety improvement.

The expected service life of the proposed improvement is 10 years, (Appendix E). The Crash Reduction Factor (*CRF*) for the proposed development of both PDO and I/F crashes are 35% (Appendix D).

Step 4. Estimate the exposure adjustment factor.

R is assumed to be 2% per year.

For example *EAF* is calculated for 6th service year which is 2010 as follows.

$$Y_1 = 2004 - 2010 = 6$$

$$EAF_{PD} = (1 + \frac{2}{100})^{1.033 \times 6} = 1.13$$

$$EAF_{IF} = (1 + \frac{2}{100})^{0.723 \times 6} = 1.09$$

The *EAF* for other years is calculated in a similar manner. Table 8.2 shows these values in Column 2 and Column 3.

Step 5. Calculate the present worth of total crash benefits

Table 8.2 presents the detailed calculations for calculating the present worth of total crash benefits. Column 4 and 5 of Table 8.2 present the expected number of PDO and I/F crashes saved, which are calculated by multiplying the crash frequency by the crash reduction factor. The benefits of reducing PDO crashes is calculated by multiplying the value in Column 4 by $6,898, the cost of a PDO crash in 2004 dollars on local urban routes. Similarly, the benefit of reducing I/F crashes is calculated by multiplying the value in Column 5 by $45,101, the cost of an I/F crash in 2004 dollars on local urban routes. The crash cost values in 2004 dollars are calculated using Eq 6.11 as follows.

Inflation rate is assumed to be 2% and $Y_3 = 2004 - 2001 = 3$

$$C_{PDP} = \left(1 + \frac{2}{100}\right)^3 \times 6{,}500 = 6{,}898$$

$$C_{IFP} = \left(1 + \frac{2}{100}\right)^3 \times 42{,}500 = 45{,}101$$

The total benefit of the reduced number of crashes is obtained by adding Column 6 and Column 7, which is shown in Column 8. PWF_{SP} is listed in Column 9. The present worth of the benefits from the crashes saved is determined by multiplying Column 8 and Column 9 and the results are shown in column 10. The sum of annual present worth benefit (*PWB*) is determined by summing the values in Column 10, which is $813,784. *EUAB* is calculated by multiplying *PWB* by CF using Eq 6.9.

PWB = $813,784

$$CF = \frac{I}{1-(1+I)^{-10}} = 0.123$$

EUAB = \$813,784 × 0.123 = \$100,095

Step 6. Calculate the present worth of total agency costs

Equivalent uniform annual cost is calculated using Eq 6.13.

PWC = 400,000 + 4000×8.111 - \$2,000×0.6756 = \$431,093

EUAC = \$431,093 × 0.123 = \$53,024

where:

PC = Project Cost = \$400,000

PWF_{EPS} = Present worth factor for equal payment series = 8.111 @ 10 years

PWF_{Sp} = Present worth factor for single payment series = 0.6756 @ 10 years

M = Change in annual maintenance cost = \$4,000

S = Salvage Value = \$2,000

Step 7. Calculate *B/C* ratio and *NAB*, (Figure 8.7, Figure 8.8).

B/C ratio and *NAB* are calculated using Eq 6.16 and Eq 6.17.

$$B/C \text{ Ratio} = \frac{EUAB}{EUAC} = \frac{\$100,095}{\$53,024} = 1.88$$

NAB = *EUAB – EUAC* = \$100,095- \$53,024 = \$47,071

Step 8. Conclusions

The *NAB* is a positive value, as expected, because the *B/C* ratio is more than one, which means that if the proposed improvement were constructed, the net annual benefit would be $47,071. Since the *B/C* Ratio is greater than one, this project would be cost-effective to construct.

Table 8.2 Crash reduction benefits

Service year (1)	EAF_{PD} (2)	EAF_{IF} (3)	PDO saved (4)	I/F saved (5)	Annual benefits ($): PDO benefits (6)	I/F benefits (7)	Total benefit (8)	PWF_{SP} (9)	Annual present worth benefits (10)
1	1.02	1.01	3.29	1.58	22,720	71,098	93,818	0.9615	90,209
2	1.04	1.03	3.36	1.60	23,189	72,123	95,312	0.9246	88,122
3	1.06	1.04	3.43	1.62	23,669	73,163	96,832	0.8890	86,083
4	1.09	1.06	3.50	1.65	24,158	74,218	98,376	0.8548	84,092
5	1.11	1.07	3.57	1.67	24,657	75,288	99,945	0.8219	82,148
6	1.13	1.09	3.65	1.69	25,167	76,374	101,541	0.7903	80,249
7	1.15	1.11	3.72	1.72	25,687	77,475	103,162	0.7599	78,395
8	1.18	1.12	3.80	1.74	26,218	78,592	104,810	0.7307	76,584
9	1.20	1.14	3.88	1.77	26,759	79,726	106,485	0.7026	74,815
10	1.23	1.15	3.96	1.79	27,313	80,875	108,188	0.6756	73,088
Sum of annual present worth benefit (PWB)									813,784

$a_{PD,P}$ = 9.22 crashes/year

$a_{IF,P}$ = 4.43 crashes/year

PDO saved = $a_{PD,P} \times EAF \times CRF_{PD}$; I/F saved = $a_{IF,P} \times EAF \times CRF_{IF}$

PDO benefits = PDO saved × C_{PDP} ; I/F benefits = I/F saved × C_{IFP}

Annual present worth benefits = (PDO benefits + I/F benefits) × PWF_{SP}

Secondary Benefits

As the intersection is less than a half mile from Getwell Hospital, the reduction of congestion and improving safety on the intersection would be important in expediting the passage of emergency vehicles to the hospital.

8.5 Post implementation study

After the implementation of the safety project, a "before and after study" is conducted to determine the effectiveness of the safety project. Crash data is collected for two years after the project's implementation. There were 22 crashes in two years in years 2002-2003 after implementing the safety project. Table 8.3 compares the crash statistics for the two year period.

Table 8.3 Crashes and AADT before and after safety improvement

Year	Crashes	Average AADT
1998-2000	A_B = 40	25,600
2002-2003	A_A = 22	27,000

The expected number of annual crashes in the period after implementation of safety project, had the safety project not been implemented, is calculated using Eq 7.1,

$$a_{0A} = \frac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \times \left(\frac{E_A}{E_B}\right)^Z = \frac{\frac{1}{0.655} + 40}{\frac{1}{0.655 \times 9.22} + 3} \times \left(\frac{27000}{25600}\right)^{0.953} = 13.80 \text{ crashes/year}$$

$$a_A = \frac{A_A}{Y_A} = \frac{22}{2} = 11 \text{ crashes / year}$$

$$Var(a_{0A}) = \frac{\frac{1}{D} + A_B}{\left(\frac{1}{D \times a_B} + Y_B\right)^2} \times \left(\frac{E_A}{E_B}\right)^{2Z} = \frac{\frac{1}{0.655} + 40}{\left(\frac{1}{0.655 \times 9.22} + 3\right)^2} \times \left(\frac{27000}{25600}\right)^{2\times 0.953} = 4.59$$

$$Var(a_A) = \frac{A_A}{{Y_A}^2} = \frac{22}{2^2} = 5.50$$

CRF_2 is calculated using Eq 7.3, $CRF_2 = \left(1 - \frac{a_A}{a_{0A}} - \frac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100$

$$= \left(1 - \frac{11}{13.80} - \frac{2 \times 11 \times 4.59}{13.80^3}\right) \times 100 = 16.45\%$$

Standard deviation of the new crash reduction factor is calculated as follows.

$$SD_2 = \sqrt{\frac{Var(a_A)}{(a_{0A})^2} + \frac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100 = \sqrt{\frac{5.50}{13.80^2} + \frac{11^2 \times 4.59}{13.80^4}} \times 100 = 21\% .$$

The crash reduction factor for the implemented safety project was 16.5% with a standard deviation of 21%.

Based on the new crash reduction factor, the old crash reduction factor is updated for future use using Eq 7.7.

As the standard deviation for the old crash reduction factor is not given, SD_1 is assumed to be 25%.

CRF_1 = 35 %, CRF_2 = 16.5 %, SD_1 = 25%, SD_2 = 21%

$$CRF = \frac{SD_1^2 \times CRF_2 + SD_2^2 \times CRF_1}{SD_1^2 + SD_2^2} = \frac{25^2 \times 16.5 + 21^2 \times 35}{25^2 + 21^2} = 24\%$$

$$SD = \sqrt{\frac{SD_2^4 \times SD_1^2 + SD_1^4 \times SD_2^2}{(SD_1^2 + SD_2^2)^2}} = \sqrt{\frac{21^4 \times 25^2 + 25^4 \times 21^2}{(25^2 + 21^2)^2}} = 16\%$$

The updated crash reduction factor is 24% with a standard deviation of 16%.

The expected number of crashes at the location had the project not been implemented during the after period is calculated using Eq 7.9 and the value of a_{0A} is taken from previous calculations.

$$\overline{A_{0A}} = Y_A \times a_{0A} = 2 \times 13.80 = 27.60$$

$$Var\left(\overline{A_{0A}}\right) = Y_A^{\ 2} \times Var(a_{0A}) = 2^2 \times 4.59 = 18.36$$

$$D_A = \frac{Var\left(\overline{A_{0A}}\right)}{\left(\overline{A_{0A}}\right)^2} = \frac{18.36}{(27.60)^2} = 0.024$$

From the graph in Chapter 7 it is observed that the critical number of crashes for D_A = .024 and $\overline{A_{0A}}$ =27.6 is 18. As the number of crashes after improvement is 22, which is greater than the critical number of crashes, the safety improvement was not statistically significant at the 10% level of significance.

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APPENDIX A
Indiana Officer's Standard Crash Report

Indiana Officer's Standard Crash Report

State Form: 23558 (Revised 9/4/01) Stock 302

Mail to: Indiana State Police, Crash Records Section, 100 North Senate Avenue, Indianapolis, IN 46204

2 4 6 8 0 1 3 5 7

Report: Original / Supplemental

Page ___ of ___

Local ID

Date/Location

Date of Crash (Month / Day / Year)	Day of Week	Actual Local Time (AM / PM)	County	County #	Township	No. Motor Vehicles	No. Injured	No. Dead	No. Trailers

Road Crash Occurred On | Intersecting Road/Mile Marker/Interchange | City/Town or Nearest City/Town | Inside Corporate Limits? Yes / No | Property? DNR / Private / Other

If not an intersection, number of feet from | Direction | Nearest Intersecting Road/Mile Marker/Interchange | Distance and Direction from Corporate Limits: ___ Miles North ___ Miles East ___ Miles South ___ Miles West | Road Classification: Interstate / US Route / State Road / County Road / Local/City Road / Unknown

Crash Latitude | Crash Longitude

A

Fill in only one primary cause for the crash.

Fill in up to two ovals per vehicle for Driver Contributing Circumstance.

Fill in one oval per vehicle for Vehicle and Environment Contributing Circumstance.

(Primary Cause / Vehicle 1 / Vehicle 2)

Driver Contributing Circumstance
- Alcoholic Beverages
- Illegal Drugs
- Driver Apparently Asleep
- Prescription Drugs
- Driver Illness
- Unsafe Speed
- Failure to Yield Right of Way
- Disregard Signal/Regulatory Sign
- Left of Center
- Improper Passing
- Improper Turning
- Improper Lane Usage
- Following Too Closely
- Unsafe Backing
- Overcorrecting/Oversteering
- Ran Off Road Right
- Ran Off Road Left
- Wrong Way on One Way
- Pedestrian's Action
- Passenger Distraction
- Violation of License Restriction
- Jackknifing
- Cell Phone Usage
- Other Telematics in Use
- Other (Explain in Narrative)
- None

Vehicle Contributing Circumstance
- Engine Failure or Defective
- Accelerator Failure or Defective
- Brake Failure or Defective
- Tire Failure or Defective
- Headlight(s) Defective or Not On
- Other Lights Defective
- Steering Failure
- Window/Windshield Defective
- Oversize/Overweight Load
- Insecure/Leaky Load
- Tow Hitch Failure
- Other (Explain in Narrative)
- None

Environment Contributing Circumstance
- Glare
- Roadway Surface Condition
- Holes/Ruts in Surface
- Shoulder Defective
- Road Under Construction
- Severe Crosswinds
- Obstruction Not Marked
- Lane Marking Obscured
- View Obstructed
- Animal on Roadway
- Traffic Control Inoperative/Missing/Obscured
- Other (Explain in Narrative)
- None

B

Fill in only one oval per vehicle per category.

(Vehicle 1 / Vehicle 2)

Pre-Crash Vehicle Action
- Going Straight
- Backing
- Changing Lanes
- Overtaking/Passing
- Turning Right
- Turning Left
- Making U Turn
- Merging
- Entering Traffic Lane
- Leaving Traffic Lane
- Parked
- Slowing or Stopped in Traffic
- Unattended Moving Vehicle
- Avoiding Object in Roadway
- Starting in Traffic
- Driving Left of Center
- Crossing the Median

Traffic Controls
- Officer/Crossing Guard/Flagman
- *RR Crossing Gate/Flagman
- *RR Crossing Flashing Signal
- RR Crossing Sign
- *Traffic Control Signal
- *Flashing Signal
- Stop Sign
- Yield Sign
- Lane Control
- No Passing Zone
- Other Regulatory Sign/Markings (Explain in Narrative)
- None

*Was traffic control operational? Yes / No

Was this crash a result of aggressive driving? Yes / No / Not Applicable

C

Fill in only one oval per category.

Hit and Run: Yes / No

Locality: Rural / Urban

School Zone: Yes / No

Rumble Strips: Yes / No

Construction: Yes / No

Construction Type: Lane Closure / X-Over/Lane Shift / Work on Shoulder / Intermittent or Moving Work

Light Condition: Daylight / Dawn/Dusk / Dark (Lighted) / Dark (Not Lighted) / Unknown

Weather Conditions: Clear / Cloudy / Rain / Snow / Sleet/Hail/Freezing Rain / Fog/Smoke/Smog / Severe Cross Wind / Blowing Sand/Soil/Snow

Surface Condition: Dry / Wet / Muddy / Snow/Slush / Ice / Loose Material on Road (Gravel, etc.) / Water (Standing or Moving)

Type of Median: Drivable / Curbed / Barrier Wall

Type of Roadway Junction: No Junction Involved / Four-Way Intersection / T-Intersection / Y-Intersection / Traffic Circle/Roundabout / Five Point or More / Interchange / Ramp

Road Character: Straight/Level / Straight/Grade / Straight/Hillcrest / Curve/Level / Curve/Grade / Curve/Hillcrest / Non-Roadway Crash

Drivers

Drv # | Driver's Name (Last, First, MI)

Address (Street, City, State, Zip)

Age | Date of Birth (Month / Day / Year)

Driver's License No. | Lic. Type | CDL Class | Lic. State

Drv # | Driver's Name (Last, First, MI)

Address (Street, City, State, Zip)

Age | Date of Birth (Month / Day / Year)

Driver's License No. | Lic. Type | CDL Class | Lic. State

D

Fill in only one oval per driver per category.

(Driver 1 / Driver 2)

Gender: Male / Female / Unknown

Ejected/Trapped: Not Ejected or Trapped / Partially Ejected / Ejected / Trapped In / Pinned Under / Unknown

Safety Equipment Used: No Restraint / Lap Belt Only / Harness / Helmet / Airbag Deployed (No Restraint) / Airbag Deployed + Harness / Unknown / Other (Explain in Narrative)

Safety Equipment Effective?: Yes / No / Not Applicable

E

Fill in all that apply.

(Driver 1 / Driver 2)

Apparent Physical Condition: Normal / Had Been Drinking / Handicapped / Ill / Fatigued / Asleep / Drugs/Medication

If Cited?: Infraction / Misdemeanor / Felony

Restrictions: Glasses/Contact Lenses / Outside Rearview Mirror / Daylight Driving / Automatic Transmission / Special Controls / Employment Only / Motorcycle Only / To/From Employment Only / Employers Vehicle Only / Authorized State-Owned Vehicles Only / P.P. Chauffeurs Restricted to Taxi Only / Power Steering / Special Restrictions / Probation DWI / Probation HTO

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2 4 6 8 0 1 3 5 7

Vehicles

Veh #	Color	Vehicle Year	Make	Model Name
No. Occupants	Lic. Year	License No.		License State
No. Axles	Speed Limit	Insured By		Phone No.

Registered Owner's Name (Last, First, MI)

Address (Street, City, State, Zip)

Towed? ◯ Yes ◯ No | Towed To | Towed By

Veh #	Color	Vehicle Year	Make	Model Name
No. Occupants	Lic. Year	License No.		License State
No. Axles	Speed Limit	Insured By		Phone No.

Registered Owner's Name (Last, First, MI)

Address (Street, City, State, Zip)

Towed? ◯ Yes ◯ No | Towed To | Towed By

Fill in only one oval for each vehicle category. F

Vehicle 1 / Vehicle 2

Vehicle Use
- Personal (Farm, Company)
- Commercial (Buses, Taxis, Common and Contract Carriers)
- Rental, not leased
- School
- Police
- Fire
- Ambulance
- Military
- Highway Department
- Other Government (Postal, etc.)
- Public Utilities (Gas, Electric, etc.)
- Other (Explain in Narrative)

Type of Primary/Secondary Roadway at Scene of Crash

One Way Traffic
- One Lane
- Two Lanes
- Multi-Lanes (3 or more)

Two Way Traffic
- Two Lanes
- Multi-Lane Undivided (3 or more)
- Multi-Lane Undivided, 2-way left turn
- Multi-Lane Divided (3 or more)
- Alley
- Private Drive

Vehicle Type
- Passenger Car/Station Wagon
- Pickup
- Van
- Sport Utility Vehicle
- Truck (Single Unit 2 Axle, 6 Tires)
- Truck (Single Unit 3 or more Axles)
- Truck/Trailer (not semi)
- Tractor/One Semi Trailer
- Tractor/Double Trailers
- Tractor/Triple Trailers
- Tractor (Cab Only, No Trailer)
- Motor Home/Recreational Vehicle
- Motorcycle
- Bus/Seats 9-15 Persons including Driver
- Bus/Seats 15 + Persons including Driver
- School Bus
- Unknown Type (Not Classified)
- Farm Vehicle
- Combination Vehicle

Direction of Travel
- North
- South
- East
- West
- Northwest
- Northeast
- Southwest
- Southeast

Emergency Run?
- Yes
- No

Fire?
- Yes
- No

Fill in only one oval for each vehicle. G

Vehicle 1 / Vehicle 2

Collision with Vehicle/Person/ Non-Fixed Object
- Another Motor Vehicle
- Pedestrian
- Bicycle
- Railway Vehicle/Train/Engine
- Deer
- Animal Other Than Deer
- Animal Drawn Vehicle

Non-Collision Crash
- Overturn/Rollover
- Fire/Explosion
- Immersion
- Jackknife
- Cargo/Equipment Shift or Loss
- Off Roadway

Collision with Fixed Object
- Impact Attenuator/Crash Cushion
- Bridge Overhead Structure
- Bridge Pier or Abutment
- Bridge Parapet End
- Bridge Rail
- Guardrail Face
- Guardrail End
- Median Barrier
- Highway Traffic Sign Post
- Overhead Sign Post
- Light/Luminaire Support
- Utility Pole
- Other Post/Pole or Support
- Wall/Building/Tunnel, etc.
- Work Zone Maintenance Equipment
- Embankment
- Curb
- Ditch
- Culvert
- Fence
- Mailbox
- Tree
- Other (Explain in Narrative)

Injured 1 Name (Last, First, MI), Address, etc. | Age | Date of Birth: Month Day Year

Gender: ◯ Male ◯ Female ◯ Unknown

Injured 2 Name (Last, First, MI), Address, etc. | Age | Date of Birth: Month Day Year

Gender: ◯ Male ◯ Female ◯ Unknown

Injured 3 Name (Last, First, MI), Address, etc. | Age | Date of Birth: Month Day Year

Gender: ◯ Male ◯ Female ◯ Unknown

Injured

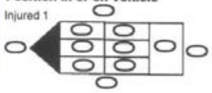
Fill in only one oval for each driver/other injured category. H

Injured 1 / Injured 2 / Injured 3

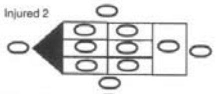
Injured
- Vehicle 1
- Vehicle 2
- Pedestrian
- Pedalcyclist
- Other (Explain in Narrative)

Position in or on Vehicle

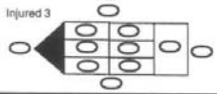
Injured 1



Injured 2



Injured 3



Safety Equipment Used
- No Restraint
- Lap Belt Only
- Harness
- Child Restraint
- Helmet
- Airbag (No Restraint)
- Airbag + Harness
- Unknown
- Other (Explain in Narrative)

Safety Equipment Effective?
- Yes
- No
- Not Applicable

Ejected/Trapped
- Not Ejected or Trapped
- Partially Ejected
- Ejected
- Trapped In
- Pinned Under
- Unknown

Driver 1 / Driver 2 / Injured 1 / Injured 2 / Injured 3

Victim's Injury Status
- Fatal Injury
- Nonfatal Injury
  - Incapacitating
  - Non-incapacitating
  - Possible
- Not Reported
- Unknown

Nature of Most Severe Injury
- Severed
- Internal
- Minor Burn
- Severe Burn
- Abrasion
- Minor Bleeding
- Severe Bleeding (Arterial)
- Fracture/Dislocation
- Contusion/Bruise
- Complaint of Pain
- None Visible
- Other (Explain in Narrative)

Location of Most Severe Injury
- Chest
- Neck
- Eye
- Face
- Head
- Back
- Shoulder/Upper Arm
- Elbow/Lower Arm
- Abdomen/Pelvis
- Hip/Upper Leg
- Knee/Lower Leg/Foot
- Entire Body

EMS No.

Driver 1 ______

Driver 2 ______

Injured 1 ______

Injured 2 ______

Injured 3 ______

2 4 6 8 0 1 3 5 7

Trailer

Tr #	Lic. State	Lic. Year	Registered Owner's Name (Last, First, MI)
License No.			Address (Street, City, State, Zip)
Year	Make		

Tr #	Lic. State	Lic. Year	Registered Owner's Name (Last, First, MI)
License No.			Address (Street, City, State, Zip)
Year	Make		

Commercial Vehicle

Vehicle # ________ **Commercial Vehicle:** Carrier's Name and Address

HAZMAT Proper Shipping Name:

US DOT No. | ICC No. | State DOT No.

Vehicle Identification No.

HAZMAT Release of Cargo ◯ Yes ◯ No | **HAZMAT Placard** ◯ Yes ◯ No | HAZMAT 4-Digit ID No. | Hazard Class No.

Gross Vehicle Weight Rating
◯ Less than 10,000#
◯ 10,001# – 26,000#
◯ 26,001# or more

Cargo Body Type
◯ Grain, Chip, Gravel, Coal
◯ Van/Enclosed Box
◯ Cargo Tank
◯ Flatbed
◯ Garbage/Refuse
◯ Concrete Mixer
◯ Auto Transport
◯ Dump
◯ Pole
◯ Other (Explain in Narrative)

Vehicle # ________ **Commercial Vehicle:** Carrier's Name and Address

HAZMAT Proper Shipping Name:

US DOT No. | ICC No. | State DOT No.

Vehicle Identification No.

HAZMAT Release of Cargo ◯ Yes ◯ No | **HAZMAT Placard** ◯ Yes ◯ No | HAZMAT 4-Digit ID No. | Hazard Class No.

Gross Vehicle Weight Rating
◯ Less than 10,000#
◯ 10,001# – 26,000#
◯ 26,001# or more

Cargo Body Type
◯ Grain, Chip, Gravel, Coal
◯ Van/Enclosed Box
◯ Cargo Tank
◯ Flatbed
◯ Garbage/Refuse
◯ Concrete Mixer
◯ Auto Transport
◯ Dump
◯ Pole
◯ Other (Explain in Narrative)

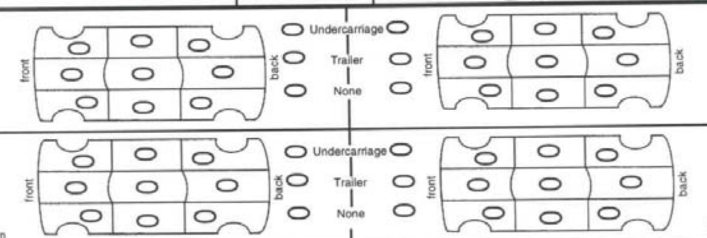
Damage

Total Estimate of Damage
◯ Under $750
◯ $750-$1000
◯ $1001-$2500
◯ $2501-$5000
◯ $5001-$10,000
◯ $10,001-$25,000
◯ $25,001-$50,000
◯ $50,001-$100,000
◯ Over $100,000

Areas Damaged (Multiples)

Vehicle 1 — Vehicle 2

Initial Impact Area
◯ Unknown



Areas Damaged (Multiples)

Initial Impact Area
◯ Unknown

Other Property Damage (Include Cargo)

Name of Object	State Property	Owner's Name and Address
(1)	◯ Yes ◯ No	
(2)	◯ Yes ◯ No	
(3)	◯ Yes ◯ No	

Tests

Driver 1 / Driver 2 / Injured 1 / Injured 2 / Injured 3

Test Given
◯◯◯◯◯ None
◯◯◯◯◯ Alcohol
◯◯◯◯◯ Drug
◯◯◯◯◯ Alcohol + Drug
◯◯◯◯◯ Refused

Type Given
◯◯◯◯◯ Blood
◯◯◯◯◯ Urine
◯◯◯◯◯ Breath
◯◯◯◯◯ Other (Explain in Narrative)

Results

Alcohol				
Dr1	Dr2	Inj1	Inj2	Inj3

Drug				
Dr1	Dr2	Inj1	Inj2	Inj3

Non-Motorists

Non-Motorist
◯ Pedestrian
◯ Pedalcyclist
◯ Other

Cited? ◯ Yes ◯ No

Direction

Street/Highway

Traffic Control? ◯ Yes ◯ No

If yes, was traffic control operational? ◯ Yes ◯ No

Apparent Physical Condition
◯ Normal
◯ Had Been Drinking
◯ Handicapped
◯ Ill
◯ Fatigued
◯ Asleep
◯ Drugs/Medication

Non-Motorist Action
◯ On designated non-motorist lane
◯ Not in roadway
◯ On shoulder
◯ On roadway
◯ With traffic
◯ Against traffic
◯ Crossing at intersection
◯ Crossing not at intersection
◯ Moving
◯ Standing
◯ Working
◯ Getting in or out of vehicle
◯ Getting off or on school bus
◯ Other (Explain in Narrative)

Name of Person Cited	IC Code
Name of Person Cited	IC Code

Other Participant(s) Name (Last, First, MI), Address, etc.

Witness No. 1 Name (Last, First, MI), Address, etc.

Location at Time of Crash | Phone #

Witness No. 2 Name (Last, First, MI), Address, etc.

Location at Time of Crash | Phone #

Page | | of | |

Local ID

2 4 6 8 0 1 3 5 7

Diagram
(Refer to Vehicle by Number)

- ○ Rear End
- ○ Head On
- ○ Rear to Rear
- ○ Same Direction Sideswipe
- ○ Opposite Direction Sideswipe
- ○ Ran Off Road
- ○ Right Angle
- ○ Left Turn
- ○ Right Turn
- ○ Left/Right Turn

NORTH

Narrative

Time Notified ○ AM ○ PM	Time Arrived ○ AM ○ PM	Other Location of Investigation		
Assisting Officer	ID No.	Agency	Investigation Complete? ○ Yes ○ No	Photos Taken? ○ Yes ○ No
Assisting Officer	ID No.	Agency	Date of Report	Driver Report Form Furnished? D1 ○ D2 ○
Investigating Officer (printed)	ID No.	Agency		
Investigating Officer's Signature				

APPENDIX B
General Countermeasures for Safety Deficiencies

Source: "Manual on Identification, Analysis and Correction of High-Accident Locations", Technology Transfer Assistance Program, Missouri Highway and Transportation Department, Second Edition, 1990.
Indiana Design Manual. Road Design, Part V, 1994.

General Countermeasures for Safety Deficiencies

Accident Patterns	Probable Cause	General Countermeasure
Right-angle crashes at unsignalized intersections	Restricted Sight Distance	Remove sight obstructions Restrict parking near corners Install warning signs Install yield signs Install Stop signs Install overhead flashing beacons Channelize intersection Reconstruct approach to improve crossing angle at intersection Install/improve street lighting Install signals Reduce speed on approaches Install stop bars
	Large total traffic volume at location	Install stop signs Install signals Add traffic lanes Reroute through traffic Increase curb radii
	High approach speed	Reduce speed limit on approaches Install rumble strip Install overhead flashing beacon Improve warning devices
Right-angle crashes at signalized intersections	Restricted sight distance	Remove sight obstructions Restrict parking near corners Install warning signs Reduce speed limit on approaches
	Poor visibility of traffic signals	Remove sight obstructions Install 305 mm signal lenses Install signal visors or back plates Install/improve advance warning devices Relocate signals Install overhead or added signals Add illuminated/reflectorized name signs Reduce speed limit on approaches

	Inadequate traffic signal timing or type of signal	Adjust yellow change interval Provide all-red clearance interval Adjust phase times and cycle time Install multi-dialer controller Install traffic actuated signal Adjust minimum green or extension time Provide/improve progression through a set of signalized intersections Install speed sign
Rear end crashes at intersections	Pedestrian crossing roadway	Improve crosswalk markings and/or signs Illuminate crosswalk Provide pedestrian "Walk" phases Relocate crosswalk
	Driver not aware of intersection	Install/improve warning signs Install overhead flashing beacon
	Slippery Surface	Overlay pavement (friction course) Chip and seal of slurry seal approaches Groove pavement Provide adequate drainage and/or crown Reduce speed limit on approaches Use "Slippery When Wet" sign
	Large volume of vehicle turning	Increase curb radii Construct left turn or right turn lanes Prohibit turns Install signal
	Poor visibility of traffic signals	Remove Sight Obstructions Install/improve advance warning devices Install 12-inch signal lenses Install additional/overhead signs Reduce speed limits on approaches
	Inadequate traffic signal timing	Adjust yellow change interval Provide all-red clearance interval Adjust phase time and cycle time Install multi-dialer controller Adjust minimum green or extension time Provide/improve signal progression
	Slippery Surface	Overlay pavement (friction course) Chip and seal of slurry seal approaches Groove pavement Provide adequate drainage and/or crown Reduce speed limit on approaches Use "Slippery When Wet" sign
	Unwarranted signals	Remove signals

	Large Volumes of vehicles turning	Increase curb radii Construct left-turn or right turn lanes Prohibit turns
Left Turn collision at intersection	Large Volume of left-turn traffic	Channelize intersection Install "Stop" signs Provide signal with left turn phase Reroute left turn traffic Prohibit left-turns Create one way streets
	Restrict sight distance	Remove sight obstructions Install warning signs Reduce speed limit on approaches
Right Turn Collision at intersections	Inadequate turning path	Increase curb radii
	Restricted sight distance	Remove sight obstructions Add "No turn of Red" signs if signalized Reduce speed limit on approaches
Pedestrians crashes at intersections	Sight distance inadequate	Remove sight obstructions Improve/install pedestrian crossings Improve/install pedestrian crossing signs Reroute pedestrian path/mid block crossing
	Inadequate protection for pedestrians	Add pedestrian refuge islands Install pedestrian signals Install pedestrian over pass or underpass
	Inadequate traffic signals	Add pedestrian "Walk" phase Improve timing of pedestrian phase
	School crossing area	Remove parking from crosswalk location Remove sight obstructions Install school zone markings Install school crossing signs Install school speed limit signs Install school crossing signals Use school crossing guards Revise school route plan map Construct overpass or underpass
	Long distance to nearest crosswalk	Install pedestrian crosswalk Install pedestrian actuated signals
Pedestrian crashes at locations between intersections	Driver has inadequate warning of frequent mid-block crossings	Prohibit parking Install warning signs Reduce speed limit
	Pedestrian walking on road or jay-walking	Install sidewalks Install "Cross only at Crosswalk" signs Install pedestrian barriers

	Excessive vehicle speed	Install proper warning signs
	Distance too long to nearest crosswalk	Install additional crosswalks and signs Install pedestrian actuated signals
Fixed Object collision	Object located too near the roadway	Remove or relocate large objects Install object marker Modify poles/posts with breakway features Eliminate poles by burying utility lines Install barrier curbs or guardrail Install crash cushions
	Inadequate lighting	Improve roadway lighting
	Inadequate pavement marking	Install reflectorized pavement marking lines/raised markers
	Inadequate signs and guardrail	Install reflectorized paint and/or reflectors on the obstruction Add special signing Upgrade barrier system
	Inadequate road design	Improve alignment/grade Provide proper superelevation Install warning signs/delineators Provide wider lanes
	Slippery pavement	Improve skid resistance Provide adequate drainage Groove existing pavement
Vehicles turning off road	Slippery pavement	Overlay pavement (friction course) Improve skid ressistance Chip and seal or slurry seal approaches Groove pavement surface Provide adequate drainage or improve crown Reduce speed limit Use “Slippery when wet” sign (temporary)
	Roadway design is no longer adequate for traffic conditions	Widen lanes and/or shoulders Relocate or remove islands Flatten side slopes/ditches Provide proper super-elevation on curve Install/improve traffic barriers Improve alignment/grade Construct more gradual horizontal curve Provide escape ramp

	Poor delineation	Improve/install pavement markings Install roadside delineators or chevron alignment signs Install advance warning lights
	Driver has inadequate warning of roadway alignment change	Install curve or turning warning sign Install advisory speed plate on curve or turning warning sign Install large arrow warning sign
	Poor visibility	Improve roadway lighting Increase sign size
	Inadequate shoulder	Upgrade roadway shoulders
	Improper channelization	Improve channelization
Sideswipe or head on collisions between vehicles traveling opposite directions	Roadway design is no longer adequate for traffic conditions	Improve alignment/grade Provide passing lines Install/improve center line markings Channelize intersections Widen lanes and/or shoulders Remove constriction as parked vehicles Install median driver Create one way streets Provide roadside delineators Sign and mark unsafe passing areas
	Inadequate shoulder	Upgrade roadway shoulders
	Excessive vehicle speed	Install median devices
	Inadequate pavement markings	Install/improve centerlines Lane lines and edgelines Install reflectorized markers
	Inadequate channelization	Install acceleration and deceleration lanes Improve/install channelization Provide turning bays
	Inadequate signing	Provide advance direction and warning signs Add illuminate name signs
Lane change, sideswipe or turning crashes between vehicles traveling in same direction	Roadway design is no longer adequate for traffic conditions	Widen lanes and/or shoulders Remove constrictions as parked vehicles Channelize intersections Provide turning bay for high volume driveway Install continuous two-way left turn lane Reduce speed limit

	Inadequate traffic control devices	Improve/install pavement lane lines Install advance route identification or street name signs
Collision with parked vehicles or vehicles being parked	High rate of parking turnover	Change from angle to parallel parking Provide short term off street parking Prohibit Parking Restrict parking during rush hour Reroute through traffic Reduce speed limit on traveled way Widen lanes
	Inadequate road design	Widen lanes/shoulder
Collision at driveways	Improperly located driveway	Regulate minimum spacing of driveways Regulate minimum corner clearance Move driveway to a side street Combine/consolidate adjacent driveways Install curbing to define driveway location
	Large volume of Left turn vehicles	Install median driver Install continuous two-way left turn lane Install protected left-turn bays
	Large volume of Right turn vehicles	Provide right turn lanes Restrict parking near driveways Increase driveway width Widen through lanes Increase driveway curb radii
	Large volume of through traffic	Move driveway to side street Construct a local service road Reroute through traffic
	Large volume of driveway traffic	Signalize driveway Provide acceleration and/or deceleration lanes Widen or channelize driveway Construct additional driveway Change to one way driveways
	Inadequate sight distance	Remove sight obstructions Restrict parking near driveway Install/improve lighting at driveway Reduce speed limit
Pedestrians crashes at driveways	Sidewalk too close to roadway	Move sidewalk laterally away from street
Wet pavement crashes	Slippery pavement	Overlay pavement (friction course) Chip and seal or slurry seal approaches Groove pavement surface Reduce speed limit Use “Slippery when wet” sign (temporary)

	Water ponding on roadway and inadequate drainage	Provide adequate drainage Improve roadway crown Remove turf or other drainage impediments from shoulder
	Install pavement markings	Install raised/reflectorized pavement markers
Night crashes	Poor visibility or lighting	Improve/install street lighting Improve/install reflectorized pavement markers Remove distracting commercial lighting of other sources of glare Install/improve delineation markings
	Poor sign quality	Upgrade signing Improve/install reflectorized signs Install/improve warning signs
	Inadequate channelization or delineation	Install pavement markings Improve channelization/delineation
Crashes at railroad grade crossings	Inadequate sight distance	Remove sight obstructions Improve/install advance warning signs Improve/install pavement markings Install train actuated signals Install overhead flashing lights Install automatic crossing gates Reconstruct crossing to provide improved crossing grade Construct grade separation
	Poor visibility	Improve/install crossing lighting Install larger reflectorized signs
	Inadequate pavement markings	Install advance markings to supplement signs Install stop bars Install/improve pavement markings
	Rough crossing grade	Improve crossing surface
	Sharp crossing angle	Rebuild crossing with proper angle
	Slippery approaches	Improve drainage Install skid resistance
	Excessive speed	Reduce speed limit on approaches Reduce train speed through community

Overturn	Roadside features	Flatten slopes and ditches Relocate drainage facilities Extend culverts Provide traversable culvert end treatments Install/improve traffic barriers
	Inadequate shoulder	Widen lane/shoulder Upgrade shoulder surface Remove curbing obstructions Revise cross slope
	Pavement feature	Eliminate dropoff Improve super-elevation/crown
Bridge	Alignment	Realign bridge/roadway Install advance warning signs Improve delineation/markings
	Narrow roadway	Widen structure Improve delineation/markings Install signing/signals
	Visibility	Remove obstruction Install advance warning signs Improve delineation and markings
	Vertical clearance	Rebuild structure/adjust roadway grade Install advance warning signs Improve delineation and markings Provide height restrictor/warning device
	Slippery Surface (Wet/Icy)	Resurface deck Improve skid resistance Provide adequate drainage Provide special signing
	Rough Surface	Resurface deck Rehabilitate joints Regrade approaches
	Inadequate barrier	Upgrade bridge rail system Upgrade approach rail/terminals Upgrade bridge approach rail connections Remove hazardous curb Improve delineation and marking

APPENDIX C
Crash Reduction Factors

Source: Tarko, A. P., Sinha, K. C., Eranky, S.,Brown, H., Roberts, E., Scinteie, R., and Islam, S., Crash Reduction Factors for Improvement Activities In Indiana, Joint Highway Research Project, final report, June 2000.

Crash Reduction Factors

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
ACCESS CONTROL			
Introduce Partial Access Control [AA][b]	77	87	74
Reduce Density of Access Points [AA][b]			
Urban Multi-Lane			
1 Access point per Mile	2	2	2
5 Access point per Mile	8	10	8
10 Access point per Mile	16	18	15
20 Access point per Mile	30	33	28
30 Access point per Mile	41	45	39
40 Access point per Mile	51	55	48
Change Access Control From No Control to Full Control [AA][b]			
Rural Multi-Lane	86	90	82
Urban Multi-Lane	95	98	93
Close Median Opening Urban Multi-Lane [AA][b]	45	39	50
BRIDGES			
Widen Bridge or Replace Two Lane Bridge [B][c]			
From 18 to 24 feet	68		
From 20 to 24 feet	56		
From 22 to 24 feet	36		
From 18 to 30 feet	93		
From 20 to 30 feet	90		
From 22 to 30 feet	86		

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
BRIDGES (Cont'd)			
Install Guardrail [C]		F:90 I:45	-110 d
Install Illumination [Z][b]	59		
Install Delineation [C][c]	40		
Repair Deck and Upgrade or Install Rails [Z][b]	13		
CHANNELIZATION			
Construct Channelization [Z][b]	17		
Construct Painted Channelization [Z][b]	18		
Install Painted or Raised Median [C]	10		
Install Raised Median at Intersections [AA]	16	29	25

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.
d An accident reduction factor presented by a minus (-) sign indicates an increase should be expected for that type of accident.

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
CHANNELIZATION (Cont'd)			
Install Painted Median at Intersections [AA]	67	75	63
Add Left-Turn Lane Where No Existing Signal [D]			
Painted Lane	32		
Protected Lane with Curb or Raised Bars	67		62
Install Left-Turn Lane at Signalized Intersection [E]			
No Left-Turn Phase	15		
Add Left-Turn Phase	35		
Install Continuous Two-WayLeft-Turn Lane in Median [AA][b]	53	58	50
Two Lanes to Three Lanes [F]	32		
Four Lanes to Five Lanes [F]	28		
CONSTRUCT/RECONSTRUCT			
Install Concrete Median Barrier [C] [c]		F: 90 I: 10	-10[d]
Install Outside Shoulders [ZA] [b]			
Adding parking Lanes Urban Multi-Lane	47	I:41	49

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.
d An accident reduction factor presented by a minus (-) sign indicates an increase should be expected for that type of accident.

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
CONSTRUCT/RECONSTRUCT (Cont'd)			
Install Inside Shoulders [AA] [b]			
a) Rural Multi-Lane			
4 feet shoulders		70	
6 feet shoulders		84	
b) Urban Multi-Lane			
4 feet shoulders		56	
6 feet shoulders		71	
Widen Lane			
a)Rural Two-Lane [AA] [b]			
Add 1 Foot to Both Lanes	16	20	12
Add 2 Feet to Both Lanes	29	37	22
b)Urban Two-Lane [AA] [b]			
Add 1 Foot to Both Lanes	16	24	12
Add 2 Feet to Both Lanes	30	12	22
Widen Median [AA][b]			
Rural Multi-Lane			
Widening 4 Feet	19	10	21
Widening 10 Feet	42	23	44
Widening 20 Feet	66	41	68
Widen Median at Intersections [AA][b]			
Widening 4 Feet	5		6
Widening 10 Feet	12		14
Widening 20 Feet	23		26
Convert Raised Median into Flushed Median at Intersections [AA]	60	65	57

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.

COUNTERMEASURE	I[a]	II	
	All	Fatal or Injury	PDO
CONSTRUCT/RECONSTRUCT (Cont'd)			
Paving Shoulders or Adding Paved Shoulders [AA] [b]			
Urban Multi-Lane	53	58	50
Improve Pavement Friction [AA] [b]			
Rural Two-Lane	13		15
Rural Multi-Lane	34	52	
Urban Two-Lane	33	18	34
Urban Multi-Lane		13	
Improve Pavement Serviceability Index [AA] [b]			
Rural Two-Lane	23	24	23
Reduce Sharpness of Curve			
For Horizontal Curve [J] [c]			
From 20 to 10 Degree	48		
From 15 to 5 Degree	63		
From 10 to 5 Degree	45		
Improve Vertical Curve [I]	45		
Improve Horizontal and Vertical Alignment [I]	50		
Install Pedestrian Grade Separation [K]	5		
Add Accel. Or Decel. Lane [I]	10		
Improve Intersection Approach Angle [L]	35		

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
DELINEATION			
Install Post Mounted Delineators or Horiz. Curve [M]	25		
Install Chevron Alignment Sign on Horiz. Curve [M]	35		
Install Raised Pavement Marker [Z] [b]	4		
FIXED OBJECTS			
Remove Fixed Objects [I] [c]		F:50 I:15	
Relocate Fixed Objects [I]		F:40 I:15	
FLASHING BEACONS			
With Warning Signs [D] Before Curve Before Intersection	 54 24		
Overhead Yellow-Red at 4-Leg Intersection [O]	36	15	50
Overhead Red-Red at 4-Leg Intersection [O]	50	40	55
Overhead Yellow-Red at 3-Leg Intersection [O]	39	7	54

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.

	I[a]	II	
COUNTERMEASURE	All	Fatal or Injury	PDO
GUARD RAIL			
Install Guardrail [Z] [b]	4		
Replace Guardrail [Z] [b]	7		
Median Barrier [C] [c] 1 to 12 Feet Median		F:75 I:2	-28
13 to 30 Feet Median		F:85 I:5	-30
Install Along Ditch [C]			-19
Install Along Embankment [C]			-47
Install at Fixed Objects as Rocks & Steel Posts [C]			-45
Install at Trees [C]		F:65 I:51	-90 [d]
ILLUMINATION			
Install Lighting [Z] [b]	37		
Modernize Lighting [Z] [b]	25		
Replace Luminaire [Z] [b]	16		

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.
d An accident reduction factor presented by a minus (-) sign indicates an increase should be expected for that type of accident.

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
PAVEMENT MARKINGS			
Center Double Yellow [A]	5		
Add Centerline [Q]	30		
Add Edgeline [R]	11	15	8
No Passing Striping [I]	40		
PAVEMENT TREATMENTS			
Deslicking [S,G]	13		
RAILROAD CROSSINGS			
Add Pavement Markings [I]	10		
Add Markings and Signs [I]	27	20	31
Surface Improvements [I]	34		39
Install Signals	15		
Replace Active WarningDevices with Grade Separation [C]	95		88
REGULATIONS			
Prohibit On-Street Parking [G] Eliminate Parking Zones [Z] [b]	90 [d] 8		
Change Angle Parking To Parallel [T] [c]	59		

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.
d Apply to parking accidents only.

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
REGULATIONS (Cont'd).			
Introduce No-Passing Zones [Z] [b]	30		
Adjust Speed Limit Increase or Decrease [M]	20	35	
Change Two-way Streeets To One-way Streets [U] Intersection Accidents Mid-Block Accidents	 26 43		
Convert Two-way Streets into One-way Streets [AA] One Street Both Streets			 23 41
SIGNALS			
Modernize Signal [Z] [b]	11		
Install, Channelize and Illuminate Signal [Z] [b]	70		
Install and Channelize Signal and Install Signs [Z] [b]	50		
Install New Signals [V] [c] From Two-Way Stop From Two-Way Stop and Add Left-Turn Lane	 28 36	 43 53	

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed in this appendix.

	I[a]	II	
COUNTERMEASURE	All	Fatal or Injury	PDO
SIGNALS			
Install New Signal and New Left-Turn Lane With [V]			
No Left-Turn Phase	53	49	
Protected Left-Turn Phase	49	66	
Protected/Permitted Left-Turn Phase	58	61	
Install Signal Heads at Intersections [AA]			
On One Pair of Approaches		31	
On Four Approaches		53	
Upgrade Pedestal Mounted to Mast Arm Mount Permitted [V]			
No Left-Turn Lane	51	52	
Existing Left-Turn Lane	44	25	
Left-Turn Lane Added	84	87	
Install 12-inch Lenses [Q]	10		
Interconnect Traffic Signals and Improve Timing [M] [b]	10	29	
SIGNS			
Warning Signs in Advance of Intersections[I]			
Urban	30		
Rural	40		
Warning Signs on Sections [I]			
Urban	15		
Rural	20		

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.

COUNTERMEASURE	I[a] All	II Fatal or Injury	PDO
SIGNS (Continued)			
Install Signs [Z] [b]	15		
Warning Signs in Advance of Curves [I]	30		
Regulatory Signs			
Yield from No Control [K]	59		
Two-Way Stop from Yield Control [K]	48		
Four-Way Stop fromTwo-way Stop [X]	47		
Lane Use Signs [Y]	30		
Install Guide Signs [Q][c]	15		

a Roman numerals designate accident reduction factor group.
b The factors apply to crashes excluding those at major intersections.
c Capital letters in brackets, such as [B], refer to the accident reduction factor sources listed below.

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APPENDIX D
Service Life of Safety Improvements

Source: Indiana Design Manual. Road Design, Part V, 1994

Service life of safety improvements

Code	Intersection Projects	Service life
10	Channelization, left turn bay	10
11	Traffic signals	10
12	Combination of 10 and 11	10
13	Sight distance improved	10
19	Other intersection except structures	10
1A	Combination of 10 and 19	10
1B	Combination of 11, 13, 19 and/or 65	10
	Cross section projects	
20	Pavement widening, no lanes added	20
21	Lanes added without new median	20
22	Highway divided, new median added	20
23	Shoulder widening or improvement	20
24	Combination of 20 and 23	20
25	Skid treatment – grooving	10
26	Skid treatment – resurfacing	10
27	Flattening, clearing side slopes	20
29	Other cross section or combination of 20 - 27	20
2A	Combination of 20 and 26	15
	Structures	
30	Widening bridge or major structure	20
31	Replacing bridge or major structure	30
32	New bridge or major structure, except 34 and 51	30
33	Minor structure	20
34	Pedestrian over - or under crossing	30
39	Other structure	20
	Alignment projects	
40	Horizontal alignment change, except 52	20
41	Vertical alignment changes	20
42	Combination of 40 and 41	20
49	Other alignments	20
	Railroad crossing projects	
50	Flashing lights replacing signs	10
51	Elimination by new or reconstructied grade seperation	30
52	Elimination by relocation of highway or RR	30
53	Illumination	10
54	Flashing lights replacing active devices	10

55	Automatic gates replacing signs	10
56	Automatic gates replacing active devices	10
57	Signing, marking	10
58	Crossing surface treatment	10
59	Other RR grade crossing	10
5A	Any combination of 50, 54, 55, 56, 57 and/or 58	10
	Roadside appurtenances	
60	Traffic signs	6
61	Breakway signs or luminaire supports	10
62	Road edge guardrail	10
63	Median barrier	15
64	Markings, delineators	2
65	Lighting	15
66	Improve drainage structures	20
67	Fencing	10
68	Impact attenuators	10
69	Other roadside	10
6A	Combination of 60 – 64	10
6B	Combination of 63 – 64	10
6C	Combination of 60 and 62	8
6D	Combination of 60 and 64	4
6E	Combination of 62 and 69	10
6F	Combination of 62, 66 and 69	10
6G	Combination of 60 and 63	10
	Other safety improvements	
90	Safety provision for roadside features and appurtenances	20
99	All projects not otherwise classified	20
9A	Combination of 11, 26 and 69	10
9B	Combination of 26 and 66	15
9C	Combination of 27, 30, 62 and 99	20
9D	Combination of 11 and 60	8
9E	Combination of 11 and 64	6
9F	Combination of 23, 26 and 62	15
9G	Combination of 27, 61, 62 and 64	10
9H	Combination of 23, 39 and 65	20
9I	Combination of 23, 61, 62, 64, 65, 66	15

APPENDIX E
Forms

Index of Crash Frequency

Form F1

INPUT		Facility Type	Safety Performance Functions	*D*
Specify the facility type		Signalized intersection	$a = 0.30 \times Q^{0.953}$	0.655
A (crashes)		Two-way stop-controlled intersection	$a = 0.522 \times Q^{1.093}$	0.359
		All-way stop-controlled intersection	$a = 0.274 \times Q^{1.324}$	0.477
L (miles)		Rural two-lane road segment	$a = 0.922 \times L \times Q^{0.598}$	0.427
		Rural multilane road segment	$a = 0.737 \times L \times Q^{0.654}$	0.473
Q (thousand vehicles/ day)		Urban two-lane road segment	$a = 0.733 \times L \times Q^{0.917}$	1.459
		Urban multilane road segment	$a = 2.641 \times L \times Q^{0.458}$	2.059
Y (years)		Rural interstate	$a = 0.212 \times L \times Q^{0.939}$	1.642
		Urban interstate	$a = 0.0056 \times L \times Q^{2.016}$	2.819

a = (crashes / year)		*D*	

$$I_{CF} = \frac{A - a \times Y}{\sqrt{(A + a^2 \times Y^2 \times D)}}$$

Comments:

Location:

Analysis Period:
Analyst:

Date:

Notation:

A = number of reported crashes during *Y* years

L = road segment length

Q = AADT entering the intersection or along the road segment, in thousands of vehicles per day

Y = number of years in analyzed period

a = typical crash frequency

D = over-dispersion parameter

I_{CF} = index of crash frequency

Index of Crash Cost

Form F2

Location:

Analysis Period:

Analyst:

Date:

INPUT	
Specify the facility type	
Q (thousand veh/day)	
L (miles)	
Y (years)	
PD (crashes)	
IF (crashes)	
C_{PD} (\$)	
C_{IF} (\$)	
D_{PD}	
D_{IF}	
a_{PD} (PDO crashes / year)	
a_{IF} (I/F crashes / year)	

Facility Type	Safety Performance Functions	*D*
Signalized intersection	$a_{IF} = 0.1954 \times Q^{0.723}$	0.639
	$a_{PD} = 0.1758 \times Q^{1.033}$	0.646
Two-way stop-controlled intersection	$a_{IF} = 0.234 \times Q^{1.099}$	0.649
	$a_{PD} = 0.307 \times Q^{1.034}$	0.292
Two-way stop-controlled intersection	$a_{IF} = 0.115 \times Q^{0.835}$	2.06
	$a_{PD} = 0.182 \times Q^{1.434}$	0.265
Rural two-lane segment	$a_{IF} = 0.208 \times L \times Q^{0.604}$	0.420
	$a_{PD} = 0.712 \times L \times Q^{0.592}$	0.430
Rural multi-lane segment	$a_{IF} = 0.107 \times L \times Q^{0.814}$	0.451
	$a_{PD} = 0.634 \times L \times Q^{0.615}$	0.484
Urban two-lane segment	$a_{IF} = 0.105 \times L \times Q^{1.080}$	1.253
	$a_{PD} = 0.603 \times L \times Q^{0.896}$	1.349
Urban multi-lane segment	$a_{IF} = 0.674 \times L \times Q^{0.435}$	1.588
	$a_{PD} = 2.028 \times L \times Q^{0.460}$	1.946
Rural interstate	$a_{IF} = 0.044 \times L \times Q^{0.917}$	1.053
	$a_{PD} = 0.169 \times L \times Q^{0.943}$	1.604
Urban interstate	$a_{IF} = 0.00048 \times L \times Q^{2.238}$	2.383
	$0.0057 \times L \times Q^{1.954}$	2.704

$$I_{CC} = \frac{C_{PD}(PD - Y \times a_{PD}) + C_{IF}(IF - Y \times a_{IF})}{\sqrt{(C_{PD}^2 \times PD + C_{IF}^2 \times IF + C_{PD}^2 \times Y^2 \times a_{PD}{}^2 \times D_{PD} + C_{IF}^2 \times Y^2 \times a_{IF}{}^2 \times D_{IF})}}$$

$I_{CC} =$

Comments

Notation:

Q = AADT entering an intersection or along a road segment, in thousands of vehicles per day

L = road segment length

Y = number of years in analyzed period

PD = number of PDO crashes during Y years

IF = number of I/F crashes during Y years

a_{PD} = typical PDO crash frequency

a_{IF} = typical I/F crash frequency

C_{PD} = average cost of PDO crash

C_{IF} = average cost of I/F crash

D_{PD} = over-dispersion parameter for PDO crashes

D_{PD} = over dispersion parameter for I/F crashes

I_{CC} = index of crash cost

COLLISION DIAGRAM

N

Form F3

Location:

Analysis Period:
Analyst:

Date:

Total crashes		Fatal crashes	
PDO crashes		Total injuries	
Injury Crashes		Total fatalities	

Surface condition

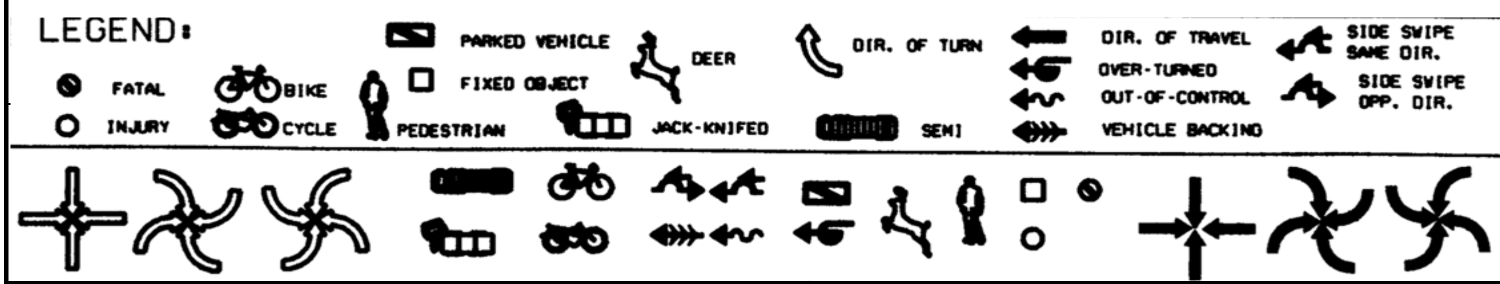
Dry		Slush	
Wet		Snow/Ice	
Muddy		Other/Unknown	

Light conditions

Day		Dark (Street lights off)	
Dawn/Dusk		Dark (No street lights)	
Dark (Street lights on)			

Crash Type
Unknown

Rear end			Left turn	
Head on			Right turn	
Side swipe	Same dir		Pedestrian	
	Opp dir		Other	
Right angle			Unknown	



Comments

Safety Review Checklist	Form F4.1
Facility Type________________________**Location**__________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	Probable causes

Group A

Moving lanes

Lane widths are inadequate for vehicle classes that are common to the location	_____	_____
Number of lanes inadequate for traffic	_____	_____

Readability

Lanes end abruptly without prior warning (lanes are not aligned)	_____	_____

Auxiliary/Turning Lanes

Inadequate advance warning of lane drops	_____	_____

Driveways

Improper location of driveways(e.g. driveways are too close to the intersection)	_____	_____
Driveways are closely spaced	_____	_____
Inadequate visibility of driveways	_____	_____

Shoulders

Shoulder width inadequate for vehicle classes that are common to the intersection	_____	_____
Inappropriate shoulder surfacing	_____	_____
Rumble strips not installed where warranted	_____	_____
Shoulders are poorly maintained	_____	_____
Insufficient contrast of shoulders	_____	_____

Horizontal and vertical alignment

Horizontal or vertical alignment affect the visibility of the intersection	_____	_____
Abrupt changes in elevation	_____	_____
Inadequate visibility at sag and crest curves	_____	_____
Location at high side/low side of superelevation	_____	_____
Excessive curves that cause sliding in adverse weather condition	_____	_____
Excessive grades present, which could be unsafe in adverse weather conditions	_____	_____

Pavement markings / Delineation

Pavement markings (center lines, edge lines etc) are not clearly visible in day or night time conditions	_____	_____

Safety Review Checklist	Form F4.2
Facility Type________________________Location__________________________________	
Date:__________________Time_________________Weather_________________________	

	Possible causes	Probable causes
All necessary pavement markings not present	_____	_____
Presence of too many markings confusing the users	_____	_____
Pavement markings are inappropriate for the location	_____	_____
Old pavement markings have not been removed which may cause safety problems	_____	_____
Inadequate retroreflectivity of existing markings.	_____	_____
Road markings do not have sufficient contrast with the surfacing	_____	_____
Light conditions		
Inadequate visibility during night time conditions	_____	_____
Severe headlight glares during night time operations	_____	_____
Luminaries create glare for road users on adjacent roads	_____	_____
Adjacent road lighting affects driver perception of road	_____	_____
Lighting interferes with traffic signs	_____	_____
Inadequate lighting for signs	_____	_____
Signs		
Inadequate visibility of necessary, regulatory, warning and guide signs in normal and adverse weather conditions	_____	_____
Incorrect location of regulatory, warning and directory signs (i.e., proper height, offset, distance in advance of hazard)	_____	_____
Signs obstruct visibility	_____	_____
Signs are missing/redundant/broken	_____	_____
Signs are not maintained properly	_____	_____
Signs contradict each other	_____	_____
Any existing signs present those are no longer applicable	_____	_____
Signs are inconsistent with respect to standard fonts and phrases	_____	_____
Signs cannot be read from adequate safe distance	_____	_____
Sight distance		
Inadequate sight distance, stopping sight distance or decision sight distance	_____	_____
Sight lines are obstructed by signs, buildings, landscaping, vegetation etc.	_____	_____

Safety Review Checklist	Form F4.3
Facility Type________________________**Location**_________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	**Probable causes**
Sight lines are obstructed temporarily by parked vehicles, snow storage, seasonal foliage, etc.	_____	_____
Opportunity for passing is insufficient	_____	_____
Pavement conditions		
Abrupt changes in pavement condition	_____	_____
Skid resistance		
Presence of locations that have inadequate skid resistance	_____	_____
Pavement defects		
Pavement has defects, which could result in safety problems(e.g. loss of steering control)	_____	_____
Pavement is not free of distresses (i.e. potholes, rutting, etc)	_____	_____
Changes in surface type (e.g. pavement ends) have drop offs / poor transitions	_____	_____
Presence of loose aggregate/gravel in pavement	_____	_____
Presence of bleeding in pavement due to excess asphalt	_____	_____
Drainage		
Presence of areas in pavement where ponding or sheet flow of water occurs resulting in safety problems	_____	_____
Drainage channel inappropriate for topography	_____	_____
Possibility of surface flooding or overflow from surrounding or intersecting drains and water courses	_____	_____
Presence of accumulated water during rainy conditions	_____	_____
Culverts are not protected	_____	_____
Embankments are too steep	_____	_____
Barriers		
Clear zone is narrow	_____	_____
Guiderails are not designed properly	_____	_____
Inappropriate transition from one barrier to another	_____	_____

Safety Review Checklist	Form F4.4
Facility Type________________________**Location**_________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	Probable causes
Inadequate retro reflectivity of barriers	______	______
Inappropriate treatment of barrier ends	______	______
Median barriers sufficiently offset from roadway	______	______
Medians		
Inappropriate spacing between median crossovers	______	______
Inadequate slopes of grass median	______	______
Special Road Users		
Travel paths for pedestrians and cyclists are not properly signed and / or marked	______	______
Bus stops are not safely located with adequate clearance and visibility from the traffic lane	______	______
Driver behavior indicating potential safety problems		
Overrepresentation of a particular age group as users raising safety concerns	______	______
Too many drivers violating the speed limit	______	______
Skid marks	______	______
Frequent off tracking	______	______
Illegal parking	______	______
Pedestrians crossing illegally (jaywalking)	______	______

Group B

Readability		
Confusing geometry which encourages wrong way entry	______	______
Layout is not consistent with adjacent interchanges	______	______
Auxiliary/Turning Lanes		
Queues stretch beyond the auxiliary lanes	______	______
Deceleration length is short	______	______
Tapers are not marked properly	______	______
Tapers are not designed properly	______	______

Safety Review Checklist	Form F4.5
Facility Type________________________Location_________________________________ ____ Date:__________________Time_________________Weather_________________________	

	Possible causes	Probable causes
Signs		
Inconsistency of signs and markings with adjacent interchanges	_____	_____
Driver behavior indicating potential safety problems		
Presence of congestion (excessive queues and delays) leading to safety problems	_____	_____
Erratic maneuvers	_____	_____
Rapid breaking	_____	_____
Traffic conflicts	_____	_____
Wrong way entry	_____	_____
Violation of right of way	_____	_____

Group C

Readability		
Intersection layout is complex (e.g. 5 leg intersection)	_____	_____
Layout is not consistent with adjacent intersections	_____	_____
Channelization		
Presence of large unused area at the intersection	_____	_____
Island required to channel traffic at the intersection	_____	_____
Inadequate dimensions of the island	_____	_____
Inadequate visibility of the island	_____	_____
Confusing layout of islands	_____	_____
Horizontal and vertical alignment		
Location of intersection (before, inside or after) a curve	_____	_____
Presence of sharp corners	_____	_____
Curvature for turning movements		
Minimum design not provided for left and right turns(Insufficient widths and curves)	_____	_____
Markings		
Stop bar not marked properly	_____	_____

Safety Review Checklist	Form F4.6
Facility Type________________________Location__________________________________	
____	
Date:__________________Time_________________Weather_________________________	

	Possible causes	Probable causes
Signs		
Inconsistency of signs and markings with adjacent intersections	_____	_____
Sight distance		
Sight triangle is insufficient	_____	_____
Median		
Excessively wide median	_____	_____
Special Road Users		
Crossing points for pedestrians and cyclists not properly signed and / or marked	_____	_____
Driver behavior indicating potential safety problems		
Violation of stop signs	_____	_____
Incorrect stopping position	_____	_____
Frequent blocking of continuous lanes by queues where auxiliary lanes do not exist	_____	_____

Group D

Light conditions		
Lighting interferes with traffic signals	_____	_____
Signals		
Inadequate warning for signals not visible from an appropriate sight distance? (i.e., signs, flashing light, etc.)	_____	_____
High intensity signals/shields are not provided where sunset and sunrise glare may be a problem	_____	_____
Inadequate visibility of signals due to presence of billboards etc. (visual clutter)	_____	_____
Traffic signals adjacent to roads affect driver perception of the intersection.	_____	_____
Primary and secondary signal heads are not properly positioned	_____	_____
Confusing signals for left turning vehicles (yellow trap, conjunction of permitted-protected phasing and lagging left-turns, lead lag phasing)	_____	_____
Auxiliary heads not provided where necessary	_____	_____
Bases not installed at the proper height	_____	_____

Safety Review Checklist	Form F4.7
Facility Type________________________**Location**________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	Probable causes
Signal Phasing		
Minimal green and clearance phases are not provided	_____	_____
Signal phasing plan inconsistent with adjacent intersections	_____	_____
A dedicated left turn signal is required	_____	_____
Light conditions		
Light interferes with traffic signals	_____	_____
Driver behavior indicating potential safety problems		
Significant number of people running on red	_____	_____

Group E

Railroad crossings		
Absence of railroad crossing signs on each approach to railroad crossings	_____	_____
Absence of advance warning signs at railroad crossing approaches	_____	_____
Presence of obstructions at rail road crossings which restrict sight distance	_____	_____
Grades of roadway approach to railroad crossings are not flat enough and encourage prevent vehicle snagging	_____	_____

Condition Diagram

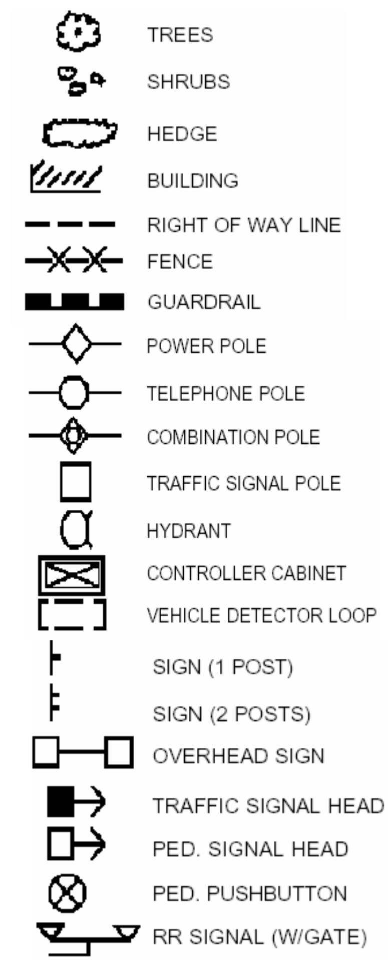
Form F5

Location:

Analysis Period:
Analyst:

Date:

Legend



Benefit Cost Analysis

Form F6.1

PD (crashes)		*IF* (crashes)	
PC ($)		*M* ($)	
S ($)		*R* (%)	
C_{PD01} ($)		C_{IF01} ($)	
F (%)		*I* (%)	
Y (years)		*T*	
CRF_{PD} (%)		CRF_{IF} (%)	
For a_{PD} and D_{PD} refer to **Form F2**		For a_{IF} and D_{IF} refer to **Form F2**	
For Z_{PD} refer to **Table 6.2**		For Z_{IF} refer to **Table 6.2**	

$PWF_{EPS} = \frac{((1+I)^T - 1)}{I(1+I)^T}$		$PWF_{SP} = \frac{1}{(1+I)^T}$		$CF = \frac{I}{1-(1+I)^{-T}}$	

Y_2 (years)		Y_3 (years)	

$$a_{PD,P} = \frac{1/D_{PD} + PD}{1/(D_{PD} \times a_{PD}) + Y} \times \left(1 + \frac{R}{100}\right)^{Z_{PD} \times Y_2}$$

(PDO crashes/year)

$$a_{IF,P} = \frac{1/D_{IF} + IF}{1/(D_{IF} \times a_{IF}) + Y} \times \left(1 + \frac{R}{100}\right)^{Z_{IF} \times Y_1}$$

(I/F crashes/year)

$C_{PDP} = \left(1 + \frac{F}{100}\right)^{Y_3} \times C_{PD01}$		$C_{IFP} = \left(1 + \frac{F}{100}\right)^{Y_3} \times C_{IF01}$	

Location:

Analysis Period:

Analyst:

Date:

Notation:

- *PD* = number of PDO crashes
- *IF* = number of I/F crashes
- *PC* = project cost
- *M* change in annual maintenance cost
- *S* = = salvage value
- *R* exposure change rate
- C_{PD01} = cost of a PDO crash in 2001 dollars
- C_{IF01} = cost of an I/F crash in 2001 dollars
- *F* = inflation rate
- *I* interest rate
- *Y* = number of years for which crash data is available
- *T* = service life of the safety improvement
- CRF_{PD} =crash reduction factor for a PDO crash
- CRF_{IF} =crash reduction factor for a I/F crash
- a_{PD} typical PDO crash frequency
- D_{PD} = =over-dispersion parameter for PDO crashes
- a_{IF} = typical I/F crash frequency
- D_{IF} =over-dispersion parameter for I/F crashes
- Z_{PD} constant taken from Table 6.2 of the guidelines
- Z_{IIF} = constant taken from Table 6.2 of the guidelines
- PWF_{EPS} =present worth factor for equal payment series
- PWF_{SP} =present worth factor for a single payment
- *CF* = capital recovery factor
- Y_2 = number of years between the before period and the present year
- Y_3 = number of years between the before period and the year in which crash cost values are given
- $a_{PD,P}$ = crash frequency of PDO crashes in the present year
- $a_{IF,P}$ = crash frequency of I/F crashes in the present year
- C_{PDP} = cost of a PDO crash in present year
- C_{IFP} = cost of an I/F crash in present year

Inputs to this form are in Form F6.1

Benefit Cost Analysis

Form 6.2

Location:

Analysis Period:
Analyst:

Date:

Y_1 = service year - present year (1)	EAF_{PD} = $(1+R/100)^{Z_{PD} \times Y_1}$ (2)	EAF_{IF} = $(1+R/100)^{Z_{PD} \times Y_1}$ (3)	PDO saved = $a_{PD,P} \times EAF_{PD} \times CRF_{PD}$ (4)	I/F saved = $a_{IF,P} \times EAF_{IF} \times CRF_{IF}$ (5)	Annual Benefits ($)				
					PDO benefits = PDO saved × C_{PDP} (6)	I/F benefits = I/F saved × C_{IFP} (7)	Total benefits = PDO benefits + I/F benefits (8)	PWF_{SP} = $1/(1+I)^{Y_1}$ (9)	Annual present worth benefits= Total benefits × PWF_{SP} (10)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

$EUAC = (PC + M \times PWF_{EPS} - S \times PWF_{SP}) \times CF$

$EUAB = PWB \times CF$

$B/C = EUAB / EUAC =$

$NAB = EUAB - EUAC =$

Notation

Y_1 = number of years between present analysis year and service year
EAF_{PD} = exposure adjustment factor for PDO crashes
EAF_{IF} = exposure adjustment factor for I/F crashes
CRF_{PD} = crash reduction factor for PDO crashes
CRF_{IF} = crash reduction factor for I/F crashes
$a_{PD,P}$ = crash frequency of PDO crashes in the present year
$a_{IF,P}$ = crash frequency of I/F crashes in the present year
C_{PDP} = cost of a PDO crash in present year
C_{IFP} = cost of an I/F crash in present Year
PWF_{SP} = present worth factor for single payment series
I = interest rate
$EUAC$ = equivalent uniform annual cost
PC = project cost
M =change in annual maintenance
PWF_{EPS} = present worth factor for equal payment series
S = salvage value
CF = capital recovery factor
PWB = present worth benefit
$EUAB$ = equivalent uniform annual Benefit
B/C = benefit cost ratio
NAB = net annual benefit

Updating Crash Reduction Factor

Form F7

Severity					
A_B (crashes)					
Y_A (years)			Y_B (years)		
E_A (AADT or VMT)			E_B (AADT or VMT)		
SD_1 (%)			CRF_1 (%)		
a_B refer to **FORM F1**		D refer to **FORM F1**		Z (**TABLE 7.1**)	

$a_{0A} = \dfrac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \times \left(\dfrac{E_A}{E_B}\right)^Z$		$a_A = \dfrac{A_A}{Y_A}$	
$Var(a_{0A}) = \dfrac{\frac{1}{D} + A_B}{\left(\frac{1}{D \times a_B} + Y_B\right)^2} \times \left(\dfrac{E_A}{E_B}\right)^{2Z}$		$Var(a_A) = \dfrac{A_A}{Y_A^{\,2}}$	
$CRF_2 = \left(1 - \dfrac{a_A}{a_{0A}} - \dfrac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100$			
$SD_2 = \sqrt{\dfrac{Var(a_A)}{(a_{0A})^2} + \dfrac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100$			
$CRF = \dfrac{SD_1^2 \times CRF_2 + SD_2^2 \times CRF_1}{SD_1^2 + SD_2^2}$			
$SD = \sqrt{\dfrac{SD_2^4 \times SD_1^2 + SD_1^4 \times SD_2^2}{(SD_1^2 + SD_2^2)^2}}$			

Location:

Analysis Period:

Analyst:

Date:

Notation:

A_A = number of crashes during the period after the implementation of safety project

A_B = number of crashes during the period before the implementation of safety project

Y_A =number of years for which crash data is analyzed after the implementation of safety project

Y_B =number of years for which crash data is analyzed before the implementation of safety project

E_A = average daily exposure during the period after the implementation of safety project

E_B = average daily exposure during the period before the implementation of safety project

SD_1 = standard deviation of old crash reduction factor

CRF_1 = old crash reduction factor

a_B = typical crash frequency for the location calculated using safety performance functions

Z = constant taken from Table 7.1 of the guidelines

D = over-dispersion parameter

a_{0A} =expected crash frequency in the period after the implementation safety project, had the safety project not been implemented

a_A = crash frequency during the period after the implementation of safety project

$Var(a_{0A})$ = Variance of a_{0A}

$Var(a_A)$ = Variance of a_A

CRF_2 = crash reduction factor for the implemented safety project

SD_2 = standard deviation of crash reduction of implemented isafety proejct

CRF = updated crash reduction factor

SD =standard deviation of updated crash reduction factor

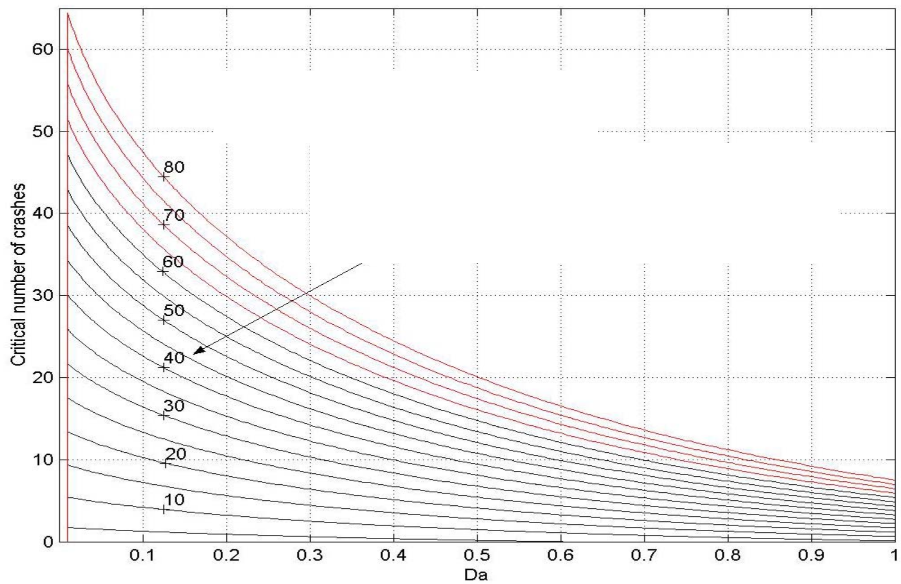
Test of Significance of Crash Reduction (10% Significance Level)

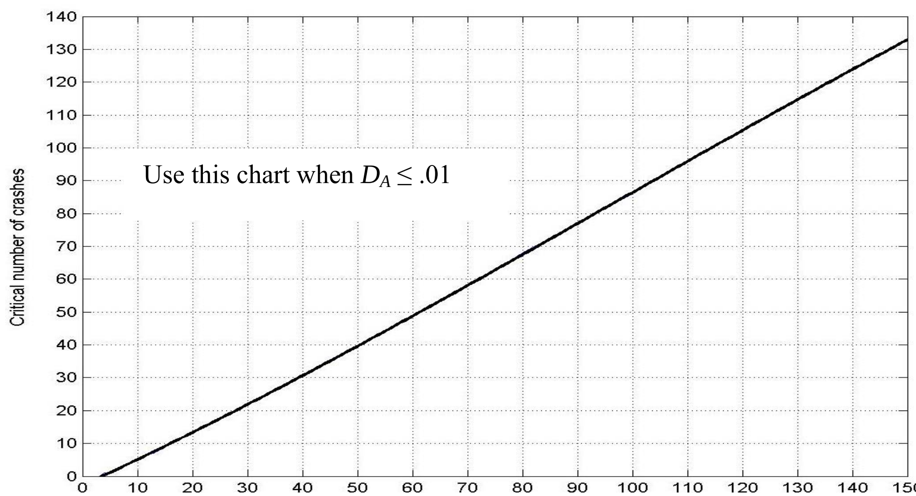
Form F8

Y_A (years)	
A_A (crashes)	
a_{0A} **FORM F7**	
$Var(a_{0A})$ **FORM F7**	
$\overline{A_{0A}} = Y_A \times a_{0A}$	
$\overline{A_{0A}}$	
$Var(\overline{A_{0A}}) = {Y_A}^2 \times Var(a_{0A})$	
$Var(\overline{A_{0A}})$	
$D_A = \frac{Var(\overline{A_{0A}})}{(\overline{A_{0A}})^2}$	
D_A	
Critical number of crashes (From chart)	

Is A_A < critical number of crashes?

- Yes, reduction is significant
- No, reduction is insignificant





Expected number of "after" crashes without safety project, $\overline{A_{0A}}$

Location:

Analysis Period:

Analyst:

Date:

Notation:

Y_A = number of years for which crash data is analyzed after the implementation of safety project

A_A =number of crashes during the period after the implementation of safety project

a_{0A} =expected crash frequency in the period after implementation of the safety project, had the safety project not been implemented

$Var(a_{0A})$ = variance of a_{0A}

$\overline{A_{0A}}$ =expected number of crashes at the location in the after period had the safety project not been implemented

$Var(\overline{A_{0A}})$ = variance of $\overline{A_{0A}}$

D_A =over-dispersion parameter for $\overline{A_{0A}}$

APPENDIX E
Forms

Index of Crash Frequency

Form F1

INPUT		Facility Type	Safety Performance Functions	*D*
Specify the facility type		Signalized intersection	$a = 0.30 \times Q^{0.953}$	0.655
A (crashes)		Two-way stop-controlled intersection	$a = 0.522 \times Q^{1.093}$	0.359
		All-way stop-controlled intersection	$a = 0.274 \times Q^{1.324}$	0.477
L (miles)		Rural two-lane road segment	$a = 0.922 \times L \times Q^{0.598}$	0.427
		Rural multilane road segment	$a = 0.737 \times L \times Q^{0.654}$	0.473
Q (thousand vehicles/ day)		Urban two-lane road segment	$a = 0.733 \times L \times Q^{0.917}$	1.459
		Urban multilane road segment	$a = 2.641 \times L \times Q^{0.458}$	2.059
Y (years)		Rural interstate	$a = 0.212 \times L \times Q^{0.939}$	1.642
		Urban interstate	$a = 0.0056 \times L \times Q^{2.016}$	2.819

a = (crashes / year)		*D*	

$I_{CF} = \dfrac{A - a \times Y}{\sqrt{(A + a^2 \times Y^2 \times D)}}$	

Comments:

Location:

Analysis Period:
Analyst:

Date:

Notation:

A = number of reported crashes during *Y* years

L = road segment length

Q = AADT entering the intersection or along the road segment, in thousands of vehicles per day

Y = number of years in analyzed period

a = typical crash frequency

D = over-dispersion parameter

I_{CE} = index of crash frequency

Index of Crash Cost

Form F2

Location:

Analysis Period:
Analyst:

Date:

INPUT	
Specify the facility type	
Q (thousand veh/day)	
L (miles)	
Y (years)	
PD (crashes)	
IF (crashes)	
C_{PD} ($)	
C_{IF} ($)	
D_{PD}	
D_{IF}	
a_{PD} (PDO crashes / year)	
a_{IF} (I/F crashes / year)	

Facility Type	Safety Performance Functions	*D*
Signalized intersection	$a_{IF} = 0.1954 \times Q^{0.723}$	0.639
	$a_{PD} = 0.1758 \times Q^{1.033}$	0.646
Two-way stop-controlled intersection	$a_{IF} = 0.234 \times Q^{1.099}$	0.649
	$a_{PD} = 0.307 \times Q^{1.034}$	0.292
Two-way stop-controlled intersection	$a_{IF} = 0.115 \times Q^{0.835}$	2.06
	$a_{PD} = 0.182 \times Q^{1.434}$	0.265
Rural two-lane segment	$a_{IF} = 0.208 \times L \times Q^{0.604}$	0.420
	$a_{PD} = 0.712 \times L \times Q^{0.592}$	0.430
Rural multi-lane segment	$a_{IF} = 0.107 \times L \times Q^{0.814}$	0.451
	$a_{PD} = 0.634 \times L \times Q^{0.615}$	0.484
Urban two-lane segment	$a_{IF} = 0.105 \times L \times Q^{1.080}$	1.253
	$a_{PD} = 0.603 \times L \times Q^{0.896}$	1.349
Urban multi-lane segment	$a_{IF} = 0.674 \times L \times Q^{0.435}$	1.588
	$a_{PD} = 2.028 \times L \times Q^{0.460}$	1.946
Rural interstate	$a_{IF} = 0.044 \times L \times Q^{0.917}$	1.053
	$a_{PD} = 0.169 \times L \times Q^{0.943}$	1.604
Urban interstate	$a_{IF} = 0.00048 \times L \times Q^{2.238}$	2.383
	$0.0057 \times L \times Q^{1.954}$	2.704

Notation:

Q = AADT entering an intersection or along a road segment, in thousands of vehicles per day

L = road segment length

Y = number of years in analyzed period

PD = number of PDO crashes during Y years

IF = number of I/F crashes during Y years

a_{PD} = typical PDO crash frequency

a_{IF} = typical I/F crash frequency

C_{PD} = average cost of PDO crash

C_{IF} = average cost of I/F crash

D_{PD} = over-dispersion parameter for PDO crashes

D_{PD} = over dispersion parameter for I/F crashes

I_{CC} = index of crash cost

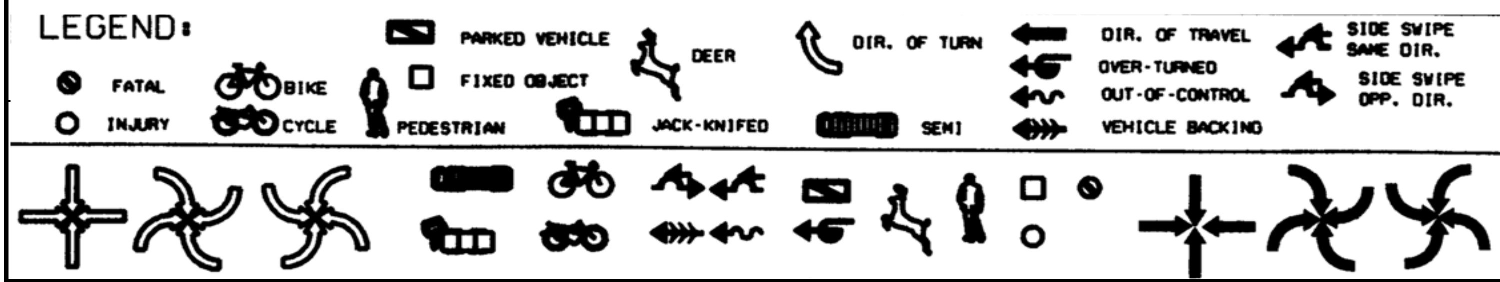
$$I_{CC} = \frac{C_{PD}(PD - Y \times a_{PD}) + C_{IF}(IF - Y \times a_{IF})}{\sqrt{(C_{PD}^2 \times PD + C_{IF}^2 \times IF + C_{PD}^2 \times Y^2 \times {a_{PD}}^2 \times D_{PD} + C_{IF}^2 \times Y^2 \times {a_{IF}}^2 \times D_{IF})}}$$

$I_{CC} =$

Comments

COLLISION DIAGRAM

N



Form F3

Location:

Analysis Period:
Analyst:

Date:

Total crashes		Fatal crashes	
PDO crashes		Total injuries	
Injury Crashes		Total fatalities	

Surface condition

Dry		Slush	
Wet		Snow/Ice	
Muddy		Other/Unknown	

Light conditions

Day		Dark (Street lights off)	
Dawn/Dusk		Dark (No street lights)	
Dark (Street lights on)			

Crash Type
Unknown

Rear end			Left turn	
Head on			Right turn	
Side swipe	Same dir		Pedestrian	
	Opp dir		Other	
Right angle			Unknown	

Comments

Safety Review Checklist	Form F4.1
Facility Type________________________**Location**__________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	Probable causes

Group A

Moving lanes

Lane widths are inadequate for vehicle classes that are common to the location	_____	_____
Number of lanes inadequate for traffic	_____	_____

Readability

Lanes end abruptly without prior warning (lanes are not aligned)	_____	_____

Auxiliary/Turning Lanes

Inadequate advance warning of lane drops	_____	_____

Driveways

Improper location of driveways(e.g. driveways are too close to the intersection)	_____	_____
Driveways are closely spaced	_____	_____
Inadequate visibility of driveways	_____	_____

Shoulders

Shoulder width inadequate for vehicle classes that are common to the intersection	_____	_____
Inappropriate shoulder surfacing	_____	_____
Rumble strips not installed where warranted	_____	_____
Shoulders are poorly maintained	_____	_____
Insufficient contrast of shoulders	_____	_____

Horizontal and vertical alignment

Horizontal or vertical alignment affect the visibility of the intersection	_____	_____
Abrupt changes in elevation	_____	_____
Inadequate visibility at sag and crest curves	_____	_____
Location at high side/low side of superelevation	_____	_____
Excessive curves that cause sliding in adverse weather condition	_____	_____
Excessive grades present, which could be unsafe in adverse weather conditions	_____	_____

Pavement markings / Delineation

Pavement markings (center lines, edge lines etc) are not clearly visible in day or night time conditions	_____	_____

Safety Review Checklist	Form F4.2
Facility Type________________________**Location**__________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	Probable causes
All necessary pavement markings not present	_____	_____
Presence of too many markings confusing the users	_____	_____
Pavement markings are inappropriate for the location	_____	_____
Old pavement markings have not been removed which may cause safety problems	_____	_____
Inadequate retroreflectivity of existing markings.	_____	_____
Road markings do not have sufficient contrast with the surfacing	_____	_____
Light conditions		
Inadequate visibility during night time conditions	_____	_____
Severe headlight glares during night time operations	_____	_____
Luminaries create glare for road users on adjacent roads	_____	_____
Adjacent road lighting affects driver perception of road	_____	_____
Lighting interferes with traffic signs	_____	_____
Inadequate lighting for signs	_____	_____
Signs		
Inadequate visibility of necessary, regulatory, warning and guide signs in normal and adverse weather conditions	_____	_____
Incorrect location of regulatory, warning and directory signs (i.e., proper height, offset, distance in advance of hazard)	_____	_____
Signs obstruct visibility	_____	_____
Signs are missing/redundant/broken	_____	_____
Signs are not maintained properly	_____	_____
Signs contradict each other	_____	_____
Any existing signs present those are no longer applicable	_____	_____
Signs are inconsistent with respect to standard fonts and phrases	_____	_____
Signs cannot be read from adequate safe distance	_____	_____
Sight distance		
Inadequate sight distance, stopping sight distance or decision sight distance	_____	_____
Sight lines are obstructed by signs, buildings, landscaping, vegetation etc.	_____	_____

Safety Review Checklist	Form F4.3
Facility Type________________________Location__________________________________	
Date:__________________Time_________________Weather_________________________	

	Possible causes	Probable causes
Sight lines are obstructed temporarily by parked vehicles, snow storage, seasonal foliage, etc.	_____	_____
Opportunity for passing is insufficient	_____	_____
Pavement conditions		
Abrupt changes in pavement condition	_____	_____
Skid resistance		
Presence of locations that have inadequate skid resistance	_____	_____
Pavement defects		
Pavement has defects, which could result in safety problems(e.g. loss of steering control)	_____	_____
Pavement is not free of distresses (i.e. potholes, rutting, etc)	_____	_____
Changes in surface type (e.g. pavement ends) have drop offs / poor transitions	_____	_____
Presence of loose aggregate/gravel in pavement	_____	_____
Presence of bleeding in pavement due to excess asphalt	_____	_____
Drainage		
Presence of areas in pavement where ponding or sheet flow of water occurs resulting in safety problems	_____	_____
Drainage channel inappropriate for topography	_____	_____
Possibility of surface flooding or overflow from surrounding or intersecting drains and water courses	_____	_____
Presence of accumulated water during rainy conditions	_____	_____
Culverts are not protected	_____	_____
Embankments are too steep	_____	_____
Barriers		
Clear zone is narrow	_____	_____
Guiderails are not designed properly	_____	_____
Inappropriate transition from one barrier to another	_____	_____

Safety Review Checklist	Form F4.4
Facility Type________________________**Location**_________________________________ ____ **Date:**__________________**Time**_________________**Weather**_________________________	

	Possible causes	**Probable causes**
Inadequate retro reflectivity of barriers	_____	_____
Inappropriate treatment of barrier ends	_____	_____
Median barriers sufficiently offset from roadway	_____	_____
Medians		
Inappropriate spacing between median crossovers	_____	_____
Inadequate slopes of grass median	_____	_____
Special Road Users		
Travel paths for pedestrians and cyclists are not properly signed and / or marked	_____	_____
Bus stops are not safely located with adequate clearance and visibility from the traffic lane	_____	_____
Driver behavior indicating potential safety problems		
Overrepresentation of a particular age group as users raising safety concerns	_____	_____
Too many drivers violating the speed limit	_____	_____
Skid marks	_____	_____
Frequent off tracking	_____	_____
Illegal parking	_____	_____
Pedestrians crossing illegally (jaywalking)	_____	_____

Group B

Readability		
Confusing geometry which encourages wrong way entry	_____	_____
Layout is not consistent with adjacent interchanges	_____	_____
Auxiliary/Turning Lanes		
Queues stretch beyond the auxiliary lanes	_____	_____
Deceleration length is short	_____	_____
Tapers are not marked properly	_____	_____
Tapers are not designed properly	_____	_____

Safety Review Checklist	Form F4.5
Facility Type________________________ **Location**__________________________________ ____ **Date:**__________________ **Time**_________________ **Weather**_________________________	

	Possible causes	Probable causes
Signs		
Inconsistency of signs and markings with adjacent interchanges	_____	_____
Driver behavior indicating potential safety problems		
Presence of congestion (excessive queues and delays) leading to safety problems	_____	_____
Erratic maneuvers	_____	_____
Rapid breaking	_____	_____
Traffic conflicts	_____	_____
Wrong way entry	_____	_____
Violation of right of way	_____	_____

Group C

Readability		
Intersection layout is complex (e.g. 5 leg intersection)	_____	_____
Layout is not consistent with adjacent intersections	_____	_____
Channelization		
Presence of large unused area at the intersection	_____	_____
Island required to channel traffic at the intersection	_____	_____
Inadequate dimensions of the island	_____	_____
Inadequate visibility of the island	_____	_____
Confusing layout of islands	_____	_____
Horizontal and vertical alignment		
Location of intersection (before, inside or after) a curve	_____	_____
Presence of sharp corners	_____	_____
Curvature for turning movements		
Minimum design not provided for left and right turns(Insufficient widths and curves)	_____	_____
Markings		
Stop bar not marked properly	_____	_____

Safety Review Checklist	Form F4.6
Facility Type________________________**Location**_________________________________	
____	
Date:__________________**Time**_________________**Weather**_________________________	

	Possible causes	Probable causes
Signs		
Inconsistency of signs and markings with adjacent intersections	_____	_____
Sight distance		
Sight triangle is insufficient	_____	_____
Median		
Excessively wide median	_____	_____
Special Road Users		
Crossing points for pedestrians and cyclists not properly signed and / or marked	_____	_____
Driver behavior indicating potential safety problems		
Violation of stop signs	_____	_____
Incorrect stopping position	_____	_____
Frequent blocking of continuous lanes by queues where auxiliary lanes do not exist	_____	_____

Group D

Light conditions		
Lighting interferes with traffic signals	_____	_____
Signals		
Inadequate warning for signals not visible from an appropriate sight distance? (i.e., signs, flashing light, etc.)	_____	_____
High intensity signals/shields are not provided where sunset and sunrise glare may be a problem	_____	_____
Inadequate visibility of signals due to presence of billboards etc. (visual clutter)	_____	_____
Traffic signals adjacent to roads affect driver perception of the intersection.	_____	_____
Primary and secondary signal heads are not properly positioned	_____	_____
Confusing signals for left turning vehicles (yellow trap, conjunction of permitted-protected phasing and lagging left-turns, lead lag phasing)	_____	_____
Auxiliary heads not provided where necessary	_____	_____
Bases not installed at the proper height	_____	_____

Safety Review Checklist	Form F4.7
Facility Type________________________Location_________________________________ ____ **Date:__________________Time_________________Weather_________________________**	

	Possible causes	Probable causes
Signal Phasing		
Minimal green and clearance phases are not provided	_____	_____
Signal phasing plan inconsistent with adjacent intersections	_____	_____
A dedicated left turn signal is required	_____	_____
Light conditions		
Light interferes with traffic signals	_____	_____
Driver behavior indicating potential safety problems		
Significant number of people running on red	_____	_____

Group E

Railroad crossings		
Absence of railroad crossing signs on each approach to railroad crossings	_____	_____
Absence of advance warning signs at railroad crossing approaches	_____	_____
Presence of obstructions at rail road crossings which restrict sight distance	_____	_____
Grades of roadway approach to railroad crossings are not flat enough and encourage prevent vehicle snagging	_____	_____

Condition Diagram

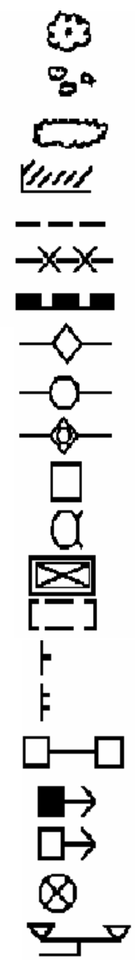
Form F5

Location:

Analysis Period:
Analyst:

Date:

Legend



TREES
SHRUBS
HEDGE
BUILDING
RIGHT OF WAY LINE
FENCE
GUARDRAIL
POWER POLE
TELEPHONE POLE
COMBINATION POLE
TRAFFIC SIGNAL POLE
HYDRANT
CONTROLLER CABINET
VEHICLE DETECTOR LOOP
SIGN (1 POST)
SIGN (2 POSTS)
OVERHEAD SIGN
TRAFFIC SIGNAL HEAD
PED. SIGNAL HEAD
PED. PUSHBUTTON
RR SIGNAL (W/GATE)

Benefit Cost Analysis

Form F6.1

Location:

Analysis Period:

Analyst:

Date:

PD (crashes)		*IF* (crashes)	
PC ($)		*M* ($)	
S ($)		*R* (%)	
C_{PD01} ($)		C_{IF01} ($)	
F (%)		*I* (%)	
Y (years)		*T*	
CRF_{PD} (%)		CRF_{IF} (%)	
For a_{PD} and D_{PD} refer to **Form F2**		For a_{IF} and D_{IF} refer to **Form F2**	
For Z_{PD} refer to **Table 6.2**		For Z_{IF} refer to **Table 6.2**	

$PWF_{EPS} = \frac{((1+I)^T - 1)}{I(1+I)^T}$		$PWF_{SP} = \frac{1}{(1+I)^T}$		$CF = \frac{I}{1-(1+I)^{-T}}$	

Y_2 (years)		Y_3 (years)	

$a_{PD,P} = \frac{1/D_{PD} + PD}{1/(D_{PD} \times a_{PD}) + Y} \times \left(1 + \frac{R}{100}\right)^{Z_{PD} \times Y_2}$ (PDO crashes/year)	
$a_{IF,P} = \frac{1/D_{IF} + IF}{1/(D_{IF} \times a_{IF}) + Y} \times \left(1 + \frac{R}{100}\right)^{Z_{IF} \times Y_1}$ (I/F crashes/year)	

$C_{PDP} = \left(1 + \frac{F}{100}\right)^{Y_3} \times C_{PD01}$		$C_{IFP} = \left(1 + \frac{F}{100}\right)^{Y_3} \times C_{IF01}$	

Notation:

PD = number of PDO crashes
IF = number of I/F crashes
PC = project cost
M change in annual maintenance cost
S = = salvage value
R exposure change rate
C_{PD01} = cost of a PDO crash in 2001 dollars
C_{IF01} = cost of an I/F crash in 2001 dollars
F = inflation rate
I interest rate
Y = number of years for which crash data is available
T = service life of the safety improvement
CRF_{PD} =crash reduction factor for a PDO crash
CRF_{IF} =crash reduction factor for a I/F crash
a_{PD} typical PDO crash frequency
D_{PD}= =over-dispersion parameter for PDO crashes
a_{IF} = typical I/F crash frequency
D_{IF} =over-dispersion parameter for I/F crashes
Z_{PD} constant taken from Table 6.2 of the guidelines
Z_{IF} = constant taken from Table 6.2 of the guidelines
PWF_{EPS} =present worth factor for equal payment series
PWF_{SP} =present worth factor for a single payment
CF = capital recovery factor
Y_2 = number of years between the before period and the present year
Y_3 = number of years between the before period and the year in which crash cost values are given
$a_{PD,P}$ = crash frequency of PDO crashes in the present year
$a_{IF,P}$ = crash frequency of I/F crashes in the present year
C_{PDP} = cost of a PDO crash in present year
C_{IFP} = cost of an I/F crash in present year

Inputs to this form are in Form F6.1	Benefit Cost Analysis	Form 6.2

Location:

Analysis Period:
Analyst:

Date:

Y_1 = service year - present year (1)	EAF_{PD} = $(1+R/100)^{Z_{PD} \times Y_1}$ (2)	EAF_{IF} = $(1+R/100)^{Z_{PD} \times Y_1}$ (3)	PDO saved = $a_{PD,P} \times EAF_{PD} \times CRF_{PD}$ (4)	I/F saved = $a_{IF,P} \times EAF_{IF} \times CRF_{IF}$ (5)	Annual Benefits ($): PDO benefits = PDO saved × C_{PDP} (6)	I/F benefits = I/F saved × C_{IFP} (7)	Total benefits = PDO benefits + I/F benefits (8)	PWF_{SP} = $1/(1+I)^{Y_1}$ (9)	Annual present worth benefits= Total benefits × PWF_{SP} (10)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									

$EUAC = (PC + M \times PWF_{EPS} - S \times PWF_{SP}) \times CF$		$EUAB = PWB \times CF$	
B/C = EUAB / $EUAC$ =		$NAB = EUAB - EUAC$ =	

Notation

Y_1 = number of years between present analysis year and service year
EAF_{PD} = exposure adjustment factor for PDO crashes
EAF_{IF} = exposure adjustment factor for I/F crashes
CRF_{PD} = crash reduction factor for PDO crashes
CRF_{IF} = crash reduction factor for I/F crashes
$a_{PD,P}$ = crash frequency of PDO crashes i n the present year
$a_{IF,P}$ = crash frequency of I/F crashes in the present year
C_{PDP} = cost of a PDO crash in present year
C_{IFP} = cost of an I/F crash in present Year
PWF_{SP} = present worth factor for single payment series
I = interest rate
$EUAC$ = equivalent uniform annual cost
PC = project cost
M =change in annual maintenance
PWF_{EPS} = present worth factor for equal payment series
S = salvage value
CF = capital recovery factor
PWB = present worth benefit
$EUAB$ = equivalent uniform annual Benefit
B/C = benefit cost ratio
NAB = net annual benefit

Updating Crash Reduction Factor					
Severity					
A_B (crashes)					
Y_A (years)		Y_B (years)			
E_A (AADT or VMT)		E_B (AADT or VMT)			
SD_1 (%)		CRF_1 (%)			
a_B refer to **FORM F1**		D refer to **FORM F1**		Z (**TABLE 7.1**)	
$a_{0A} = \dfrac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \times \left(\dfrac{E_A}{E_B}\right)^Z$		$a_A = \dfrac{A_A}{Y_A}$			
$Var(a_{0A}) = \dfrac{\frac{1}{D} + A_B}{\left(\frac{1}{D \times a_B} + Y_B\right)^2} \times \left(\dfrac{E_A}{E_B}\right)^{2Z}$		$Var(a_A) = \dfrac{A_A}{Y_A^2}$			
$CRF_2 = \left(1 - \dfrac{a_A}{a_{0A}} - \dfrac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100$					
$SD_2 = \sqrt{\dfrac{Var(a_A)}{(a_{0A})^2} + \dfrac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100$					
$CRF = \dfrac{SD_1^2 \times CRF_2 + SD_2^2 \times CRF_1}{SD_1^2 + SD_2^2}$					
$SD = \sqrt{\dfrac{SD_2^4 \times SD_1^2 + SD_1^4 \times SD_2^2}{(SD_1^2 + SD_2^2)^2}}$					

Form F7

Location:

Analysis Period:

Analyst:

Date:

Notation:

A_A = number of crashes during the period after the implementation of safety project

A_B = number of crashes during the period before the implementation of safety project

Y_A =number of years for which crash data is analyzed after the implementation of safety project

Y_B =number of years for which crash data is analyzed before the implementation of safety project

E_A = average daily exposure during the period after the implementation of safety project

E_B = average daily exposure during the period before the implementation of safety project

SD_1 = standard deviation of old crash reduction factor

CRF_1 = old crash reduction factor

a_B = typical crash frequency for the location calculated using safety performance functions

Z = constant taken from Table 7.1 of the guidelines

D = over-dispersion parameter

a_{0A} =expected crash frequency in the period after the implementation safety project, had the safety project not been implemented

a_A = crash frequency during the period after the implementation of safety project

$Var(a_{0A})$ = Variance of a_{0A}

$Var(a_A)$ = Variance of a_A

CRF_2 = crash reduction factor for the implemented safety project

SD_2 = standard deviation of crash reduction of implemented isafety proejct

CRF = updated crash reduction factor

SD =standard deviation of updated crash reduction factor

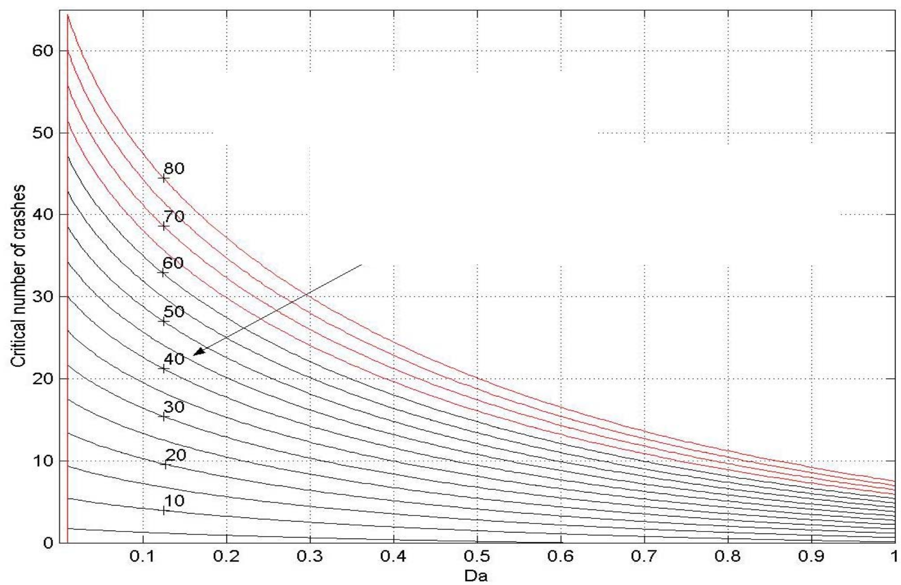
Test of Significance of Crash Reduction (10% Significance Level)

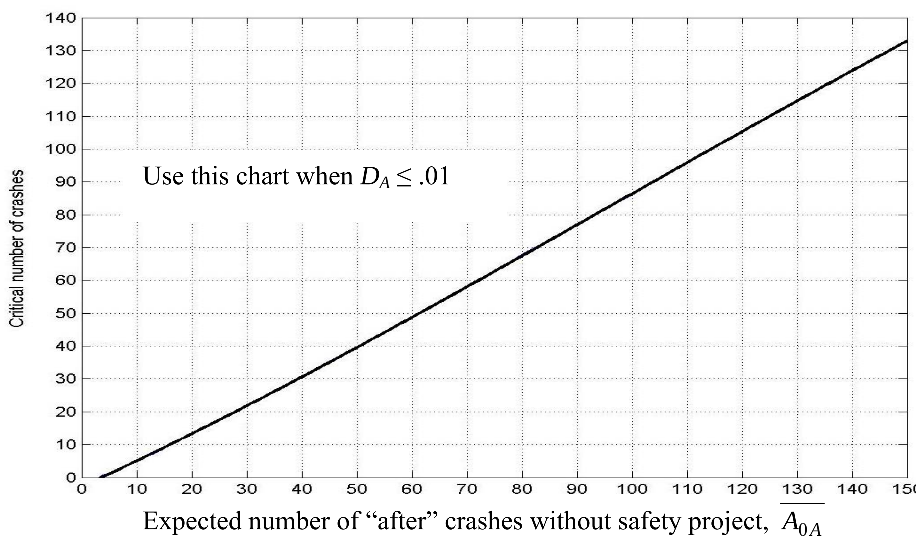
Form F8

Y_A (years)	
A_A (crashes)	
a_{0A} **FORM F7**	
$Var(a_{0A})$ **FORM F7**	
$\overline{A_{0A}} = Y_A \times a_{0A}$	
$\overline{A_{0A}}$	
$Var(\overline{A_{0A}}) = Y_A{}^2 \times Var(a_{0A})$	
$Var(\overline{A_{0A}})$	
$D_A = \frac{Var(\overline{A_{0A}})}{(\overline{A_{0A}})^2}$	
D_A	
Critical number of crashes (From chart)	

Is A_A < critical number of crashes?

- Yes, reduction is significant
- No, reduction is insignificant





Location:

Analysis Period:

Analyst:

Date:

Notation:

Y_A = number of years for which crash data is analyzed after the implementation of safety project

A_A =number of crashes during the period after the implementation of safety project

a_{0A} =expected crash frequency in the period after implementation of the safety project, had the safety project not been implemented

$Var(a_{0A})$ = variance of a_{0A}

$\overline{A_{0A}}$ =expected number of crashes at the location in the after period had the safety project not been implemented

$Var(\overline{A_{0A}})$ = variance of $\overline{A_{0A}}$

D_A =over-dispersion parameter for $\overline{A_{0A}}$

Updating Crash Reduction Factor

Form F7

Severity			
A_B (crashes)			
Y_A (years)		Y_B (years)	
E_A (AADT or VMT)		E_B (AADT or VMT)	
SD_1 (%)		CRF_1 (%)	
a_B refer to **FORM F1**		D refer to **FORM F1**		Z (**TABLE 7.1**)	

$a_{0A} = \dfrac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \times \left(\dfrac{E_A}{E_B}\right)^Z$		$a_A = \dfrac{A_A}{Y_A}$	
$Var(a_{0A}) = \dfrac{\frac{1}{D} + A_B}{\left(\frac{1}{D \times a_B} + Y_B\right)^2} \times \left(\dfrac{E_A}{E_B}\right)^{2Z}$		$Var(a_A) = \dfrac{A_A}{Y_A^2}$	
$CRF_2 = \left(1 - \dfrac{a_A}{a_{0A}} - \dfrac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100$			
$SD_2 = \sqrt{\dfrac{Var(a_A)}{(a_{0A})^2} + \dfrac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100$			
$CRF = \dfrac{SD_1^2 \times CRF_2 + SD_2^2 \times CRF_1}{SD_1^2 + SD_2^2}$			
$SD = \sqrt{\dfrac{SD_2^4 \times SD_1^2 + SD_1^4 \times SD_2^2}{(SD_1^2 + SD_2^2)^2}}$			

Location:

Analysis Period:

Analyst:

Date:

Notation:

A_A = number of crashes during the period after the implementation of safety project

A_B = number of crashes during the period before the implementation of safety project

Y_A =number of years for which crash data is analyzed after the implementation of safety project

Y_B =number of years for which crash data is analyzed before the implementation of safety project

E_A = average daily exposure during the period after the implementation of safety project

E_B = average daily exposure during the period before the implementation of safety project

SD_1 = standard deviation of old crash reduction factor

CRF_1 = old crash reduction factor

a_B = typical crash frequency for the location calculated using safety performance functions

Z = constant taken from Table 7.1 of the guidelines

D = over-dispersion parameter

a_{0A} =expected crash frequency in the period after the implementation safety project, had the safety project not been implemented

a_A = crash frequency during the period after the implementation of safety project

$Var(a_{0A})$ = Variance of a_{0A}

$Var(a_A)$ = Variance of a_A

CRF_2 = crash reduct ion factor for the implemented safety project

SD_2 = standard deviation of crash reduction of implemented isafety proejct

CRF = updated crash reduction factor

SD =standard deviation of updated crash reduction factor

APPENDIX F

Supplement on Post Implementation Study

Supplement on Post Implementation Study

Crash reduction factors

The crash reduction factor is used to calculate the benefits provided by the safety project. The crash reduction factor for the project is calculated using crash data before and after implementing the safety project, for which the equations are presented below. Expected crash frequency in the period after implementation of the safety project, had the safety project not been implemented, is calculated using Equation 1, accounting for the "regression to mean effect" and changes in exposure at the location. CRF_2, the new crash reduction factor and its standard deviation, is calculated using Equation 7 and Equation 8.

$$a_{0A} = \left(\frac{\frac{1}{D} + A_B}{\frac{1}{D \times a_B} + Y_B} \right) \times \left(\frac{E_A}{E_B} \right)^Z , \qquad 1$$

$$a_A = \frac{A_A}{Y_A} , \qquad 2$$

$$\theta = \frac{a_A}{a_{0A}} + \frac{2a_A}{(a_{0A})^3} \times Var(a_{0A}) , \qquad 3$$

$$Var(\theta) = \left(\frac{1}{a_{0A}} \right)^2 \times Var(a_A) + \left(\frac{a_A}{a_{0A}^{\ 2}} \right) \times Var(a_{0A}) , \qquad 4$$

$$Var(a_{0A}) = \left(\frac{E_A}{E_B} \right)^{2Z} \times \frac{1/D + A_{Bi}}{(1/(D \times a_i) + Y_{Bi})^2} , \qquad 5$$

$$Var(a_A) = \frac{A_A}{Y_A^{\ 2}} , \qquad 6$$

$$CRF_2 = \left(1 - \frac{a_A}{a_{0A}} - \frac{2a_A}{(a_{0A})^3} \times Var(a_{0A})\right) \times 100, \quad 7$$

$$SD_2 = \sqrt{\frac{Var(a_A)}{(a_{0A})^2} + \frac{a_A^2 \times Var(a_{0A})}{(a_{0A})^4}} \times 100. \quad 8$$

where:

a_{0A} = expected number of crashes per year in the period after implementation of the safety project had the safety project not been implemented,

a = typical crash frequency (crashes / year) calculated using safety performance functions,

D = over-dispersion parameter,

A_B = number of crashes during the period before implementation of the safety project,

Y_B = number of years for which crash data is analyzed before implementation of the safety project,

E_B = average daily exposure during the period before the safety project is implemented (exposure for intersections is average AADT at the intersection whereas for segments it is the product of AADT and the length of the segment),

E_A = average daily exposure during the period after the safety project is implemented,

Z = constant taken from Table 7.1 of the guidelines,

a_A = number of crashes per year during the period after the implementation of safety project,

A_A = number of crashes during the period after the implementation of safety project for which crash data is collected,

Y_A = number of years for which crash data is analyzed after the implementation of safety project,

θ = crash reduction,

$Var(\theta)$ = variance of θ,

CRF_2 = crash reduction factor calculated using the crash data obtained after implementing the safety project, in percent,

$Var(a_{0A})$ = variance of a_{0A},

$Var(a_A)$ = variance of a_A, and

SD_2 = Standard deviation of the crash reduction factor for the implemented safety project, in percent.

Crash reduction factor using control group

In order to account for unknown factors that may cause a change in the number of crashes after implementation of the safety project, crash reduction factors are calculated using a control group, which consists of locations that have characteristics similar to locations where the safety project is implemented, but at these locations the safety project is not implemented. The expected number of crashes per year in the period after implementation of the safety project, a_{0A}, the number of crashes per year during the period after the implementation of the safety project, a_A, the crash reduction, θ, and the variance of crash reduction, $Var(\theta)$, are calculated using Equations 1, 2, 3, and 4 respectively for locations in the control group. Using these values, the crash reduction factor and its standard deviation is calculated using Equations 9 and 10 respectively.

$$CRF_2 = \left(1 - \frac{\theta}{\theta'}\right) \times 100, \qquad 9$$

$$SD_2 = 100 \times \sqrt{\left(\frac{1}{\theta'}\right)^2 \times Var(\theta) + \left(\frac{\theta}{\theta'^2}\right)^2 \times Var(\theta')} \qquad 10$$

where:

θ' = crash reduction at the location with control group,

$Var(\theta')$ = variance of θ',

CRF_2' = crash reduction factor after implementing the safety project with control group, in percent, and

SD_2' = standard deviation of the crash reduction factor for the implemented safety project with the control location, in percent.

Crash reduction factor for multiple sites

The crash reduction factor for multiple sites with a control group is calculated using the following equations. The expected number of crashes per year in the period after the implementation of safety project and its variance, a_A; $Var(a_A)$, and the number of crashes per year during the period after implementation of the safety project and its variance , a_{0A}; $Var(a_{0A})$, are calculated for each treated location and untreated (control) location. The total values for the treated sites and control group locations are calculated using Equations 11, 12, 13, and 14. Crash reduction and its variance, θ, $Var(\theta)$, and crash reduction and its variance for control group, θ' and $Var(\theta')$ are calculated using Equations

3 and 4, as for a single location but using the total values for a_A, $Var(a_A)$, a_{0A}, and $Var(a_{0A})$. The crash reduction factor and its standard deviation using a control group are calculated using Equations 9 and 10 respectively, while crash reduction factors and its standard deviation without using a control group are calculated using Equations 5 and 8.

$$a_A = \sum_i a_{Ai} \qquad 11$$

$$Var(a_A) = \sum_i Var(a_{Ai}) \qquad 12$$

$$a_{0A} = \sum_i a_{0Ai} \qquad 13$$

$$Var(a_{0A}) = \sum_i Var(a_{0Ai}) \qquad 14$$

Glossary

Glossary

A number of crashes during Y years

AB annual benefits

$\overline{A_{0A}}$ expected number of crashes in the period after implementation of safety project, had the safety project not been implemented

A_B crash count during Y_B years before improvement

A_A number of crashes during the period after the implementation of safety project

a typical crash frequency at similar locations

a_P crash frequency in the present year

a_{0A} expected crash frequency in the period after the implementation of safety project had the safety project not been implemented

a_A crash frequency during the period after the implementation of safety project

a_{IF} typical I/F crash frequency at similar locations

a_{PDO} typical PDO crash frequency at similar locations

C_{01} crash cost in 2001 dollars

C_P crash cost in dollar value of present year

C_{PD} cost of a PDO crash

C_{IF} cost of a I/F crash

C_{PDP} cost of a PDO crash in dollar value of present year

C_{IFP} cost of a I/F crash in dollar value of present year

CRF updated crash reduction factor

CRF_1 old crash reduction factor

CRF_2 crash reduction factor for the implemented safety project

CR annual crash reduction

D over-dispersion factor

D_A over-dispersion for $\overline{A_{0A}}$

EAF exposure adjustment factor

E_A average annual exposure during the period after the safety improvement project is implemented (AADT, VMT, etc)

E_B average annual exposure during the period before the safety improvement project is implemented (AADT, VMT, etc)

F inflation rate

I interest rate

I_{CC} index of crash cost

I_{CF} index of crash frequency

IF number of I/F crashes during Y years

L road section length

M change in annual maintenance cost

N number of legs without lanes exiting the intersection

PC project cost

PD number of PDO crashes during Y years

PWB present worth benefits

PWC present worth costs

PWF_{EPS} present worth factor (equal payment series)