Colorado Highway Safety Improvement Program

September 2016
Prepared by the Safety & Traffic Engineering Branch
Version 1.0

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Introduction

In compliance with USC Title 23, Chapter 1, section 152 ("Each State shall establish an evaluation process approved by the Secretary, to analyze and assess results achieved by safety improvement projects carried out in accordance with procedures and criteria established by this section. Such evaluation process shall develop cost-benefit data for various types of corrections and treatments which shall be used in setting priorities for safety improvement projects."), this report sets forth the Highway Safety Improvement Program (HSIP) developed by the Safety and Traffic Engineering (S&TE) Branch of the Colorado Department of Transportation (CDOT).

The purpose of the Colorado HSIP is to provide for a continuous and systematic procedure that identifies and reviews specific traffic safety issues around the state to identify locations with potential for improvement. The ultimate goal of the HSIP process is to reduce the number of crashes, injuries and fatalities by eliminating certain predominant types of crashes through the implementation of engineering, enforcement, education, and Emergency Medical Services (EMS) solutions.

This report describes the planning, implementation and evaluation of each aspect of Colorado's HSIP. The goal of the program is to achieve a significant reduction in fatalities and serious injuries on all public roads, including non-State-owned public roads and roads on tribal lands. The HSIP requires a data-driven, strategic approach to improving highway safety on all public roads that focuses on performance. This is consistent with Colorado's Strategic Highway Safety Plan (SHSP) overall Mission, Values and Goals and CDOT's Policy Directive Number 14.

All proposed projects must be consistent with Colorado's SHSP. The vision of Colorado is zero deaths so that all travelers, whether they drive, walk, ride, or bike, arrive at their destinations safely. The Plan lists nine emphasis areas which have the greatest potential for reducing fatalities and injuries. Those areas are: Aging Road Users (65+); Bicyclists and Pedestrians; Data; Impaired Driving; Infrastructure – Rural and Urban; Motorcyclists; Occupant Protection; Young Drivers (15–20); and Distracted Driving.

The process for planning and implementing the Colorado HSIP involves the cooperation of a number of departments within State government as well as the participation of local authorities through Metropolitan Planning Organizations (MPOs), Transportation Management Organizations (TMOs), Colorado Counties, Inc. (CCI), the Public Utilities Commission (PUC) and the Colorado Municipal League (CML).

Section 1 – Traffic Crash Data System

Colorado Traffic Crash Data System

All original crash data is supplied to the Department of Revenue (DOR) by the Colorado State Patrol and local law enforcement agencies. The DOR, in turn, provides information and makes crash reports available to CDOT for analysis. The Uniform Motor Vehicle Law, Colorado Revised Statutes (2015), reads in part:

42-4-1606(4), "It is the duty of all law enforcement officers who receive notification of traffic accidents within their respective jurisdictions or who investigate such accidents either at the time of or at the scene of the crash or thereafter by interviewing participants or witnesses to submit reports of all such crashes to the department [Department of Revenue] on the form provided including insurance information received from any driver, within five days of the time they receive such ..."

42-1-216, "... all records of accidents must be preserved by the department [Department of Revenue] for a period of six years."

42-1-208, "The department [Department of Revenue] shall receive accident reports required to be made by law and shall tabulate and analyze such reports and publish annually, or at more frequent intervals, statistical information based thereon as to the number, cause and location of highway accidents."

The flow chart, shown on the next page, describes the various steps of data reporting, acquisition, coding and analysis. Descriptions of the functions of each involved organization are discussed in this report.

The flow chart shows the following steps resulting in the final crash data files:

1. Crash report form (DR 2447) completed by responsible law enforcement agency. Since January of 1981, a single standard form has been used.
2. Forms are received by DOR electronically or physically.
3. Crash summary data is sent to the Safety and Traffic Engineering (S&TE) Branch of CDOT electronically where location data indexing and coding of engineering-related items are performed.
4. The S&TE Branch compiles the crash data where it can be accessed for further analysis and review.

Considerable effort is made at each step of collection, transmittal and entry in order to provide the highest quality data for use in review and analysis. Consistent cooperative effort is maintained between DOR and CDOT.

Evaluation of HSIP Projects

Before and after studies are periodically performed on HSIP projects once there is sufficient time passed after the project is completed (three to five years). These reports are posted at the following address on the CDOT website:

https://www.codot.gov/library/traffic/hsip/studies

Additional Colorado crash data and information can be found at the following address:

https://www.codot.gov/library/traffic/safety-crash-data

Two major sources of data are required to produce this information: Computerized traffic volume data from CDOT's Division of Transportation Development (DTD), and computerized summarized crash data collected from DOR and subsequently maintained by CDOT's S&TE Branch.

Section 2 - HSIP Project Selection

All public roadways are eligible for participation under the HSIP program. Colorado's procedure for complying with Federal requirements has evolved over the years. In years past, the procedure for identifying locations with high potential for crash mitigation was limited to considerations of crash frequency, crash severity and highway classification. The following process describes Colorado's current method for identifying locations with high potential for crash mitigation.

How Does a Safety Issue Become a Project?

While no two projects are alike, CDOT identifies a majority of safety issues to be addressed by HSIP projects through the following methods: (1) identification of a correctible crash pattern(s) through statewide crash data analyses and (2) confirmation of a locally observed safety issue(s) using engineering analyses.

CDOT is divided into five engineering regions throughout the state. Each Region is headed by a Regional Transportation Director (RTD) and has traffic engineering and planning staff that work with HSIP applications.

Region planners and engineering staff work with local partners to analyze available data and identify potentially effective safety projects within each region. Data may include existing crash patterns, geometric or roadway conditions, weather patterns, comparative evaluations, and other local qualitative and quantitative data.

Project Identification and Crash Data Analyses

CDOT uses two methods for identifying locations with potential for crash reduction: Level of Service of Safety (LOSS) and Diagnostic Analysis. LOSS is based on the concept of Safety Performance Functions (SPF), while Diagnostic Analysis is developed around the idea of statistical pattern recognition. LOSS reflects how the roadway segment is performing in regard to its expected crash frequency and severity at a specific level of annual average daily traffic. It provides a comparison of crash frequency and severity with what is expected for that type of highway facility.

While crash rates are commonly used to measure safety, they are often misleading since rates change with Annual Average Daily Traffic (AADT). Using the Crash Data System (See Section 1 – Traffic Crash Data System), CDOT has calibrated and deployed SPFs for all public roadways in Colorado, which were stratified by the number of lanes, terrain, environment, and functional classification for all roadway and intersection types.

SPFs use qualitative measures to characterize the safety of a roadway segment in reference to its expected performance. If the number of crashes predicted by the SPF represents normal or expected crash frequency at a specific level of AADT, then the degree of deviation from the norm can be stratified to represent specific levels of safety. To describe road safety from the frequency and severity standpoint, two different SPFs were calibrated: one for the total number of crashes and the other for injury and fatal crashes. When the magnitude of the safety problem is assessed, it is described from the frequency and severity standpoint. LOSS analysis is divided into four categories:

LOSS-I - Indicates low potential for crash reduction;
LOSS-II - Indicates low to moderate potential for crash reduction;
LOSS-III - Indicates moderate to high potential for crash reduction; and
LOSS-IV - Indicates high potential for crash reduction.

The LOSS calculation procedure is provided in detail in Appendix A.

LOSS only describes the magnitude of the safety problem; it does not provide any information related to the nature of the problem itself. The nature of the problem is determined through diagnostic analysis using direct diagnostic and pattern recognition techniques.

The Direct Diagnostics and Pattern Recognition methods calculate a cumulative binomial probability of the crash types and related characteristics to identify overrepresented elements in the crash data (e.g., dark conditions, overturning vehicles) that may be related to abnormal crash patterns and crash causation.

Pattern Recognition compares normative percentages of different crash parameters for highway segments and Direct Diagnostics focuses on intersections or a single point on a road and compares those particular normative averages to identify patterns. Direct Diagnostics is used for intersection analysis, and Pattern Recognition is used for roadway segments.

By using these three data sets, CDOT is able to gain a better picture of the roadway facilities and identify with better precision the locations with potential for crash reduction. CDOT ST&E Branch develops a statewide summary of locations with high potential for crash mitigation (LOSS III and IV) and locations with identified crash patterns. The summary is stratified by region. The regional summaries are distributed to the CDOT Regions for consideration in project identification.

Candidate HSIP Projects

Each engineering Region reviews the initial candidate listing of locations with higher potential for crash mitigation. The Regions use the listing along with other information such as their own operational reviews, input from citizens, staff and city/county personnel as well as other ongoing or scheduled construction activities in order to determine the most feasible and beneficial candidate safety project submittals.

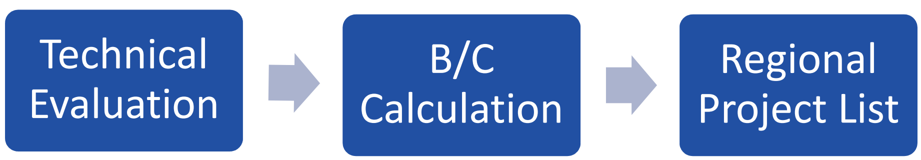
The Region may also choose to nominate other safety project locations not mentioned on the listing. Any regional nominations not on the list will still need to meet the HSIP criteria for consideration.

Applications submitted for candidate projects which are not on the state highway system are solicited from local authorities in coordination with the various MPOs, the Special Highway Committee of the Colorado Counties, Inc. and the Colorado Municipal League. These candidate proposals for safety improvement projects are submitted for locations identified using the locals' internal system for identifying locations with high potential for crash mitigation. As with the Region applications, all submittals will be required to meet the minimum HSIP criteria. Project applications from locals are submitted to the Regional traffic offices for evaluation, comments and approval. The Region traffic offices are specifically requested to verify project cost estimates, and when necessary, are also requested to make project cost adjustments with the submitting local authorities' concurrence.

Application submittals that are evaluated and approved by the Regions are then submitted to the Safety and Traffic Engineering Office. Submittals not meeting the minimum criteria will be disqualified from HSIP funding consideration. The applications are then tested to determine if all meet the necessary Pass/Fail criteria. Qualifying projects are ranked and prioritized against other qualifying local agency projects within the same Region.

Technical Evaluations

CDOT HQ performs technical evaluations of candidate projects (including safety elements of larger projects) submitted by the Regions and local agencies. CDOT HQ also calculates Benefit to Cost (B/C) ratios based on the economic analysis of crash reduction for candidate projects. A detailed description of the B/C calculation procedure for HSIP is provided in Appendix B. Candidate projects must meet the minimum B/C to be considered for implementation.



HSIP Project Evaluation Process

Following the Pass/Fail evaluation described previously, Safety and Traffic Engineering will conduct a project B/C analysis and list candidate projects in descending priority order based upon their Benefit/Cost (B/C) Ratio.
Funding approval is recommended for those projects exhibiting B/C ratios greater than or equal to 1.0. Projects exhibiting B/C ratio's less than 1.0 are not considered cost effective and consequently are not recommended for funding.

Project Prioritization

Upon completion of project technical evaluations, projects meeting the minimum criteria are prioritized for implementation by each Region. The Regions consider technical evaluation results, B/C ratio, project funding needs, time needed to develop the project, and other relevant topics.

Section 3 – HSIP Funding Allocation Process

The following describes the steps followed for the allocation of HSIP dollars to the CDOT Regions and Local Agencies:

1. The Safety and Traffic Engineering (S&TE) Branch sends the following to the Regions:
   - Statewide Pattern List stratified for Region
   - Statewide Intersection Pattern List stratified for Region

2. If the Regions choose locations other than those from the list, S&TE will complete a B/C analysis on those locations as well.

3. After selecting their candidate locations, each Region will send S&TE a list of those locations for B/C analysis. This will provide that the candidate projects selected have met the requested federal guidelines as specified in the "U.S. Code, Title 23, Chapter 1, Section 152, paragraph (f) of the Highway Safety Improvement Program" which reads as follows:

   > "Each State shall establish an evaluation process approved by the Secretary, to analyze and assess results achieved by safety improvement projects carried out in accordance with procedures and criteria established by this section. Such evaluation process shall develop cost-benefit data for various types of corrections and treatments which shall be used in setting priorities for safety improvement projects".

4. The selected allocation method formula distributes funds based on the percent of crashes occurring in each of the Regions.

5. The source of funding comes exclusively from the Federal Highway Safety Improvement Program. The Regions receive the funds and make approximately 50% of funds available to the local authorities.

6. The Regions are in charge of submitting their lists to the S&TE Branch for both the Region and local agencies. The Regions are also apportioning and distribution of total funds between CDOT projects and local agency projects. If a Region does not spend all funding allocated, then another eligible project should be submitted until all dollars have been spent. If a Region goes over the allocated funding, the Region will be responsible for covering the difference in funds. It is the objective of the S&TE Branch to maximize crash reduction, within limited budgets, by making safety improvement allocation where it does the most good and prevents the most crashes.

Appendix A
Level Service of Safety (LOSS) Calculation Procedure

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Calculating LOSS

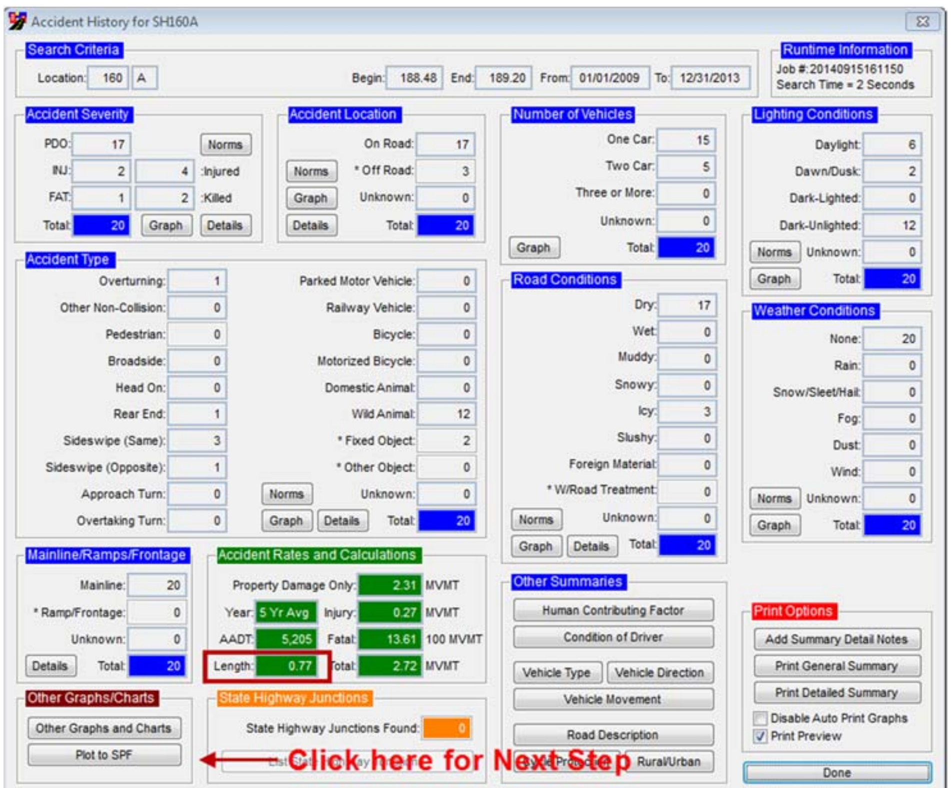
STEP 1: Determine the quantity of property damage only crashes, injury crashes, and fatal crashes; for predicted crashes, use one of the following methods:

- Federal Highway Safety Manual guidelines,
- Estimated by comparison to similar location (locations must have similar AADT and geometry); and/or
- Other FHWA approved methods.

STEP 2: Determine the number of years of crash data used for analysis. The typical number of years of crash data used are as follows:

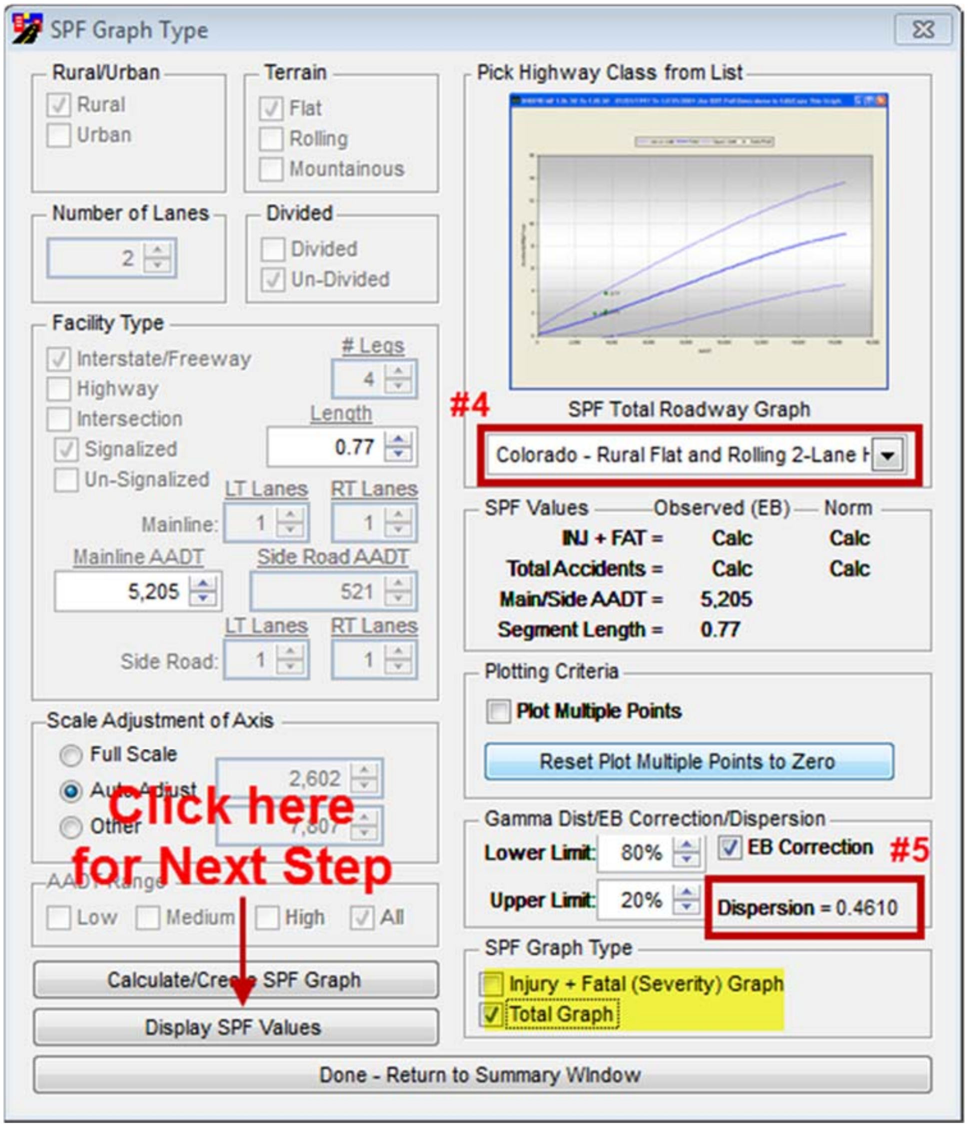
- 3 to 5 years of crash data for urban locations,
- 5 to 10 years of crash data for rural locations,

STEP 3: Determine the true length of the segment (using Vision Zero Suite traffic engineering software).

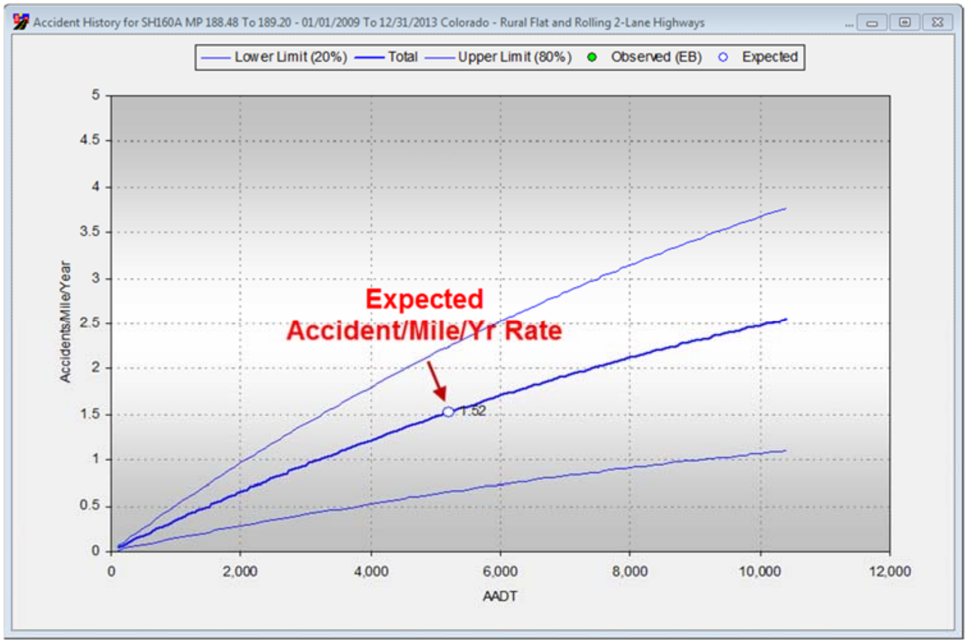


STEP 4: Determine the highway classification (i.e. Rural Flat and Rolling 2-Lane Highway, etc).

STEP 5: Determine the dispersion factor for the highway classification. The dispersion factor depends on the type of SPF graph (Total vs. Injury + Fatal) highlighted in yellow.



STEP 6: Determine the expected accidents/mile/year rate (APMPY) for the highway classification. The expected crash rate is dependent on the type of SPF graph highlighted in the above image.



STEP 7: Calculate the Accident Frequency.

$$Accident\ Frequency\ (\boldsymbol{\eta}) = \frac{\boldsymbol{Acc}}{\boldsymbol{LN}}$$

Where: $\boldsymbol{Acc} = PDO + INJ + FAT$ **for all crash SPF - LOSS**

$\boldsymbol{Acc} = INJ + FAT$ **for injury SPF – LOSS**

$\boldsymbol{L} = Length\ of\ the\ highway\ segment$

$\boldsymbol{N} = No.of\ years\ of\ data$

STEP 8: Calculate the Empirical Bayes (EB) Corrected Weight.

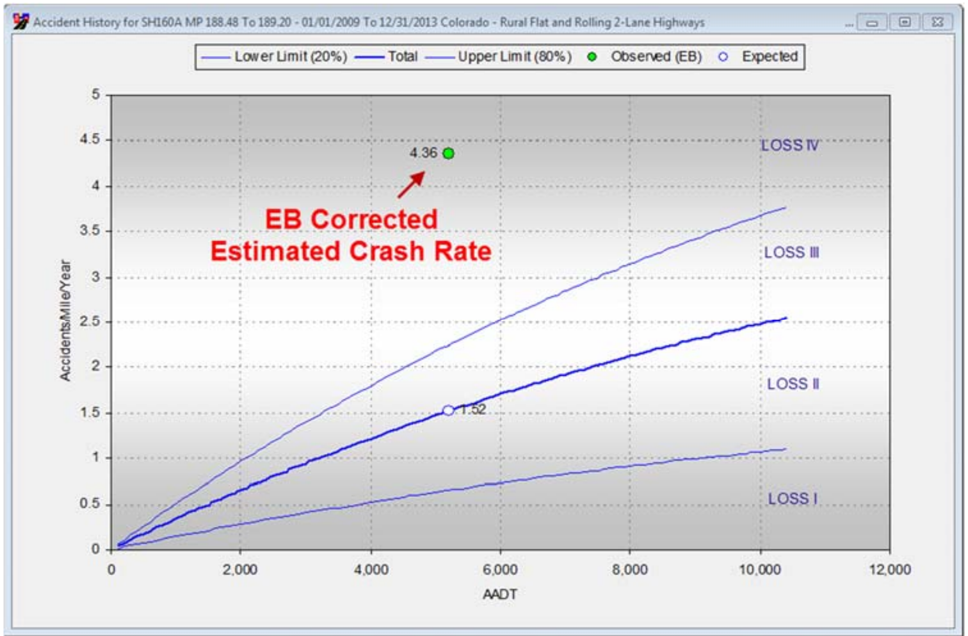
$$Weight\ (w) = \frac{1}{1 + \mu\boldsymbol{\alpha N}}$$

Where: $\mu = Expected\ Accident\ Rate$
$\boldsymbol{\alpha} = Dispersion\ Factor$
$\boldsymbol{N} = No.of\ years\ of\ data$

STEP 9: Calculate the EB Corrected Estimated Crash Rate.

$$EB\ Corrected\ Estimated\ Crash\ Rate = (\boldsymbol{w}\mu) + (1 - \boldsymbol{w})\ x\ \boldsymbol{\eta}$$

STEP 10: Plug the *EB Corrected Estimated Crash Rate* into the corresponding SPF graph to determine the LOSS of the segment.



Appendix B – Calculating Benefit to Cost (B/C) Ratio

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Calculating B/C

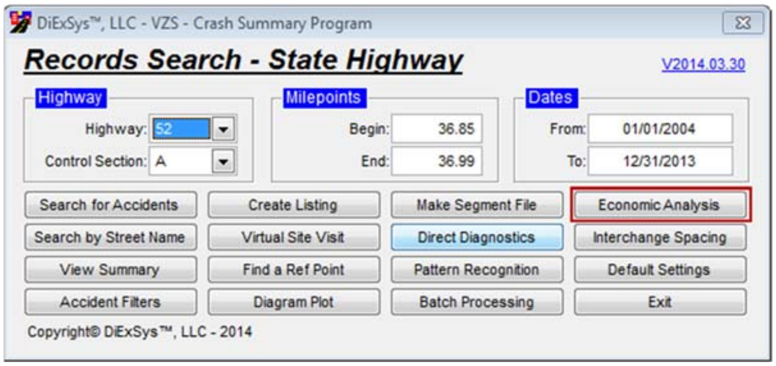
STEP 1: Determine the quantity of property damage only crashes, injury crashes, number of persons injured (if possible), fatal crashes, and number of persons killed (if possible) related specifically to the countermeasure implemented within the scope of the project; for predicted crashes, use one of the following methods:

- Federal Highway Safety Manual guidelines,
- Estimated by comparison to similar location (locations must have similar AADT and geometry); and/or
- Other FHWA approved methods.

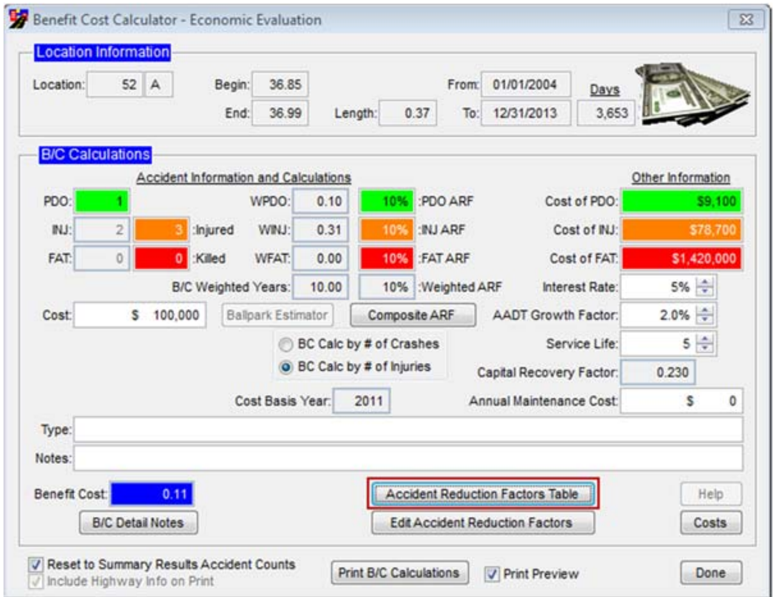
STEP 2: Determine the cost of the countermeasure implemented within the scope of the project.

STEP 3: Determine the Percentage Accident Reduction Factor for property damage, injury, and fatal crashes. Determine the Service Life. Values provided in Vision Zero Suite may be used for the crash reduction factor and service life.

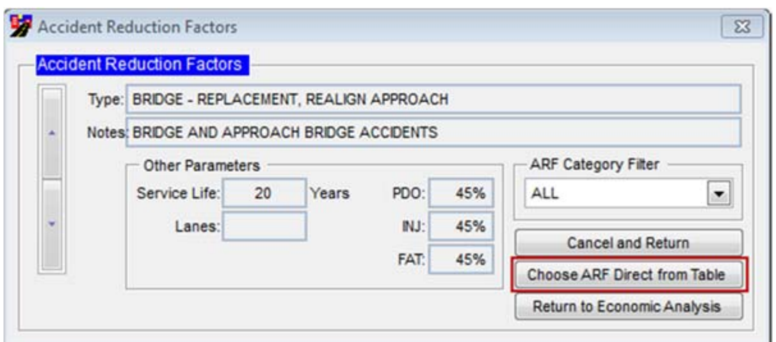
- Click on 'Economic Analysis'



- Click on ‘Accident Reduction Factors Table’



- Click on ‘Choose ARF Direct from Table’



NOTE: Crash modification factors (CMF) may also be found at www.cmfclearinghouse.org

STEP 4: Calculate the capital recovery factor.

$$Capital\ Recovery\ Factor\ (\boldsymbol{CRF}) = \frac{\boldsymbol{i}(1+\boldsymbol{i})^{\boldsymbol{L}}}{(1+\boldsymbol{i})^{\boldsymbol{L}}-1}$$

Where: $\boldsymbol{i} = Interest\ Rate\ (Typically\ 5\%)$
$\boldsymbol{L} = Service\ Life$

STEP 5: Determine the Year Factor.

$$Year\ Factor\ (\boldsymbol{N}) = \frac{\boldsymbol{n}}{\boldsymbol{m}}$$

Where: $\boldsymbol{n} = Number\ of\ days\ in\ Crash\ History\ search$

$\boldsymbol{m} = Average\ number\ of\ days\ per\ year\ in\ Crash\ History\ search$

- *Year Factor could be calculated in Excel using the equation:*
  = Yearfrac(Start Date, End Date, 1)

  NOTE: The number of years of crash history could be used as a close approximation of the Year Factor. However, the Benefit to Cost Ratio may be slightly off.

STEP 6: Calculate the accident rate per year accounting for growth factor for each crash type.

$$PDO\ Accident\ Rate\ per\ Year\ (\boldsymbol{\alpha}) = \frac{(\boldsymbol{PDO})(1+\boldsymbol{a})^{\boldsymbol{L}/2}}{\boldsymbol{N}}$$

Where: $\boldsymbol{PDO} = No.of\ PDO\ Crashes$

$\boldsymbol{L} = Service\ Life$

$\boldsymbol{N} = Year\ Factor$

$\boldsymbol{a} = ADT\ Growth\ Rate\ (Typically\ 2\%)$

$$Injury\ Accident\ Rate\ per\ Year\ (\boldsymbol{\beta}) = \frac{(\boldsymbol{INJ})(1+\boldsymbol{a})^{\boldsymbol{L}/2}}{\boldsymbol{N}}$$

Where: $\boldsymbol{INJ} = No.of\ Injury\ Crashes\ or\ No.of\ Persons\ Injured$

$\boldsymbol{L} = Service\ Life$

$\boldsymbol{N} = Year\ Factor$

$\boldsymbol{a} = ADT\ Growth\ Rate$

NOTE: For a more accurate Benefit to Cost Ratio assessment, use the number of persons injured.

$$Fatal\ Accident\ Rate\ per\ Year\ (\boldsymbol{\tau}) = \frac{(\boldsymbol{FAT})(1+\boldsymbol{a})^{\boldsymbol{L}/2}}{\boldsymbol{N}}$$

Where: $\boldsymbol{FAT} = No.of\ Fatl\ Crashes\ or\ No.of\ Persons\ Killed$

$\boldsymbol{L} = Service\ Life$

$\boldsymbol{N} = Year\ Factor$

$\boldsymbol{a} = ADT\ Growth\ Rate$

NOTE: For a more accurate Benefit to Cost Ratio assessment, use the number of persons killed.

STEP 7: Calculate the benefit to cost ratio.

- Per the National Safety Council's (NSC) *Estimating the Costs of Unintentional Injuries, 2013*, "the calculable costs of motor-vehicles are wage and productivity losses, medical expenses, administrative expenses, more vehicle damage, and employers' uninsured costs. The cost of all these items for each death, injury, and property damage were: Death $1,500,000; Nonfatal Disabling Injury $80,700; Property Damage Crash $9,300."

$$Benefit\ to\ Cost\ Ratio = \frac{(\$9{,}300)(\boldsymbol{\alpha})(\boldsymbol{x}) + (\$80{,}700)(\boldsymbol{\beta})(\boldsymbol{y}) + (\$1{,}500{,}000)(\boldsymbol{\tau})(\boldsymbol{z})}{(\boldsymbol{C})(\boldsymbol{CRF})}$$

Where:

$\boldsymbol{\alpha} = PDO\ Crashes\ per\ Year$
$\boldsymbol{\beta} = Injuries\ per\ Year$
$\boldsymbol{\tau} = Fatalities\ per\ Year$
$\boldsymbol{x} = PDO\ Accident\ Reduction\ Factor$
$\boldsymbol{y} = Injury\ Accident\ Reduction\ Factor$
$\boldsymbol{z} = Fatal\ Accident\ Reduction\ Factor$
$\boldsymbol{C} = Cost\ of\ Countermeasure\ Implemented$
$\boldsymbol{CRF} = Capital\ Recovery\ Factor$