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Evaluation of Highway Safety Improvement Projects and Countermeasures: Technical Report

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16. Abstract

The Highway Safety Improvement Program (HSIP) is a core Federal-aid, state-administered program in which each state is required to develop and establish planning, implementation, and evaluation processes. The goal of evaluation activities is to determine if highway safety improvements are achieving the desired results and the investments are worthwhile. The goal of this study is to advance HSIP evaluation processes and practices at the Texas Department of Transportation (TxDOT) and evaluate the safety and cost effectiveness of HSIP projects and countermeasures or work codes (WCs) that have been implemented in Texas over the last few years. This research involved: a) reviewing safety and cost effectiveness evaluation methods, state practices, and tools; b) gathering and compiling TxDOT data and assessing their appropriateness for supporting HSIP evaluations; c) developing safety and cost effectiveness evaluation tools for segments and intersections; and d) evaluating the effectiveness of implemented HSIP projects and countermeasures in Texas. The results show that the evaluated projects have been effective from both a safety and cost perspective in reducing target fatal, suspected serious injury, and non-incapacitating injury (KAB) crashes. The safety effectiveness index of 387 evaluated segment projects (treated as one group) was 0.84, and the corresponding index of 70 intersection projects (treated as one group) was 0.74, indicating an overall reduction in target KAB crashes after the projects were constructed. The benefit/cost ratio of all segment projects was 71.9 and that of all intersection projects (treated as one group) was 145.6.

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DISCLAIMER

This research was performed in cooperation with the Texas Department of Transportation (TxDOT) and the Federal Highway Administration (FHWA). The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official view or policies of FHWA or TxDOT. This report does not constitute a standard, specification, or regulation.

This report is not intended for construction, bidding, or permit purposes. The principal investigator of the project was Ioannis Tsapakis, and Karen Dixon served as the co-principal investigator.

The United States Government and the State of Texas do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

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TABLE OF CONTENTS

Page

LIST OF FIGURES

Page

LIST OF TABLES

Page

LIST OF ACRONYMS, ABBREVIATIONS, AND TERMS

AADT	Annual average daily traffic
AASHTO	American Association of State Highway and Transportation Officials
ALDOT	Alabama Department of Transportation
ARDOT	Arkansas Department of Transportation
B/A	Before/after
B/C	Benefit/cost
Caltrans	California Department of Transportation
CAT8	Category 8
CAVS	Crash Analysis and Visualization
CDOT	Colorado Department of Transportation
CEI	Cost-effectiveness index
CFR	Code of Federal Regulations
CMF	Crash modifications factor
CRASH	Crash Reduction Analysis System Hub
CRF	Crash reduction factor
CRIS	Crash Records Information System
CSJ	Control section job
DCIS	Design and Construction Information System
DID	Difference in differences
DDOT	District of Columbia Department of Transportation
DFO	Distance from origin
DOT	Department of transportation
EB	Empirical Bayes
FB	Full Bayesian
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
GIS	Geographic information system
GRID	Geospatial Roadway Inventory Database
HES	Hazard Elimination
HPMS	Highway performance monitoring system
HRR	High Risk Rural
HSIP	Highway Safety Improvement Program
HSM	*Highway Safety Manual*
IHSDM	Interactive Highway Safety Design Model
INDOT	Indiana Department of Transportation
MassDOT	Massachusetts Department of Transportation
MnDOT	Minnesota Department of Transportation
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NSC	National Safety Council
NYSDOT	New York State Department of Transportation
PDO	Property damage only
PennDOT	Pennsylvania Department of Transportation
PIES	Post Implementation Evaluation System

PSM	Propensity score matching
R&D	Research and development
RHiNo	Road-Highway Inventory Network
RTM	Regression to the mean
SHSP	Strategic highway safety plan
SM	SiteManager
SPF	Safety performance function
STIP	Statewide Transportation Improvement Program
TRF	Traffic Operations
TxDOT	Texas Department of Transportation
UTP	Unified Transportation Program
VZS	Vision Zero Suite
WC	Work code

CHAPTER 1:
INTRODUCTION

1.1 BACKGROUND

The Highway Safety Improvement Program (HSIP) is a core federal-aid, state-administered program designed to reduce fatalities and serious injuries on all public roads through the implementation of highway safety improvement projects (*1*). To obligate HSIP funds, a state department of transportation (DOT) must develop, implement, and update a strategic highway safety plan (SHSP), produce a program of projects or strategies to reduce identified safety problems, and evaluate its program on a regular basis. The Federal Highway Administration (FHWA) establishes the program requirements in the United States Code (USC), 23 USC 148(h), and the code of federal regulations (CFR), 23 CFR 924.15. According to these requirements, each state must develop, establish, and report processes to support HSIP planning, implementation, and evaluation activities.

State agencies are required to have a safety data system to perform problem identification and countermeasure analysis, adopt strategic and performance-based goals, advance data analysis capabilities, determine priorities for the correction of identified safety problems, and establish evaluation procedures. The general guideline is to identify actionable and measurable goals (e.g., reduce the number of fatalities and serious injuries) and perform evaluations using robust data-driven methods that account for traffic volume fluctuations, external factors, and regression-to-the-mean (RTM) effects (*2*).[1] As the national safety assessment procedures have evolved, legislation has mandated that the use of safety performance methods be elevated (*1*). These evolving methods tend to provide more reliable results than simple before/after (B/A) comparisons, which have several limitations and do not account for RTM bias (*2*).

To help agencies move toward this direction, the American Association of State Highway and Transportation Officials (AASHTO) developed the *Highway Safety Manual* (HSM), which provides guidance on how to quantify the impact of roadway design elements on highway safety (*2*). Among several elements, it introduces a roadway safety management process (Figure 1) that encompasses a series of traditional and modern safety analysis methodologies, including crash-predictive methods. Appendix A describes the most important elements of HSM predictive methods that the reader needs to be familiar with. These elements are regression to the mean effects, safety performance functions (SPFs), and crash modification factors (CMFs).

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[1] RTM is a statistical phenomenon that assumes that the longer the observation period, the closer the sample mean will be to the population mean. For example, at a given site, the average crash frequency during three years will be closer to the true mean (i.e., population mean) compared to the average crash frequency during one month only. Therefore, RTM bias or selection bias occurs when the candidate sites are selected based on short-term trends that may not be representative of actual crash trends of a given facility. More information on RTM effects is provided in Appendix A.

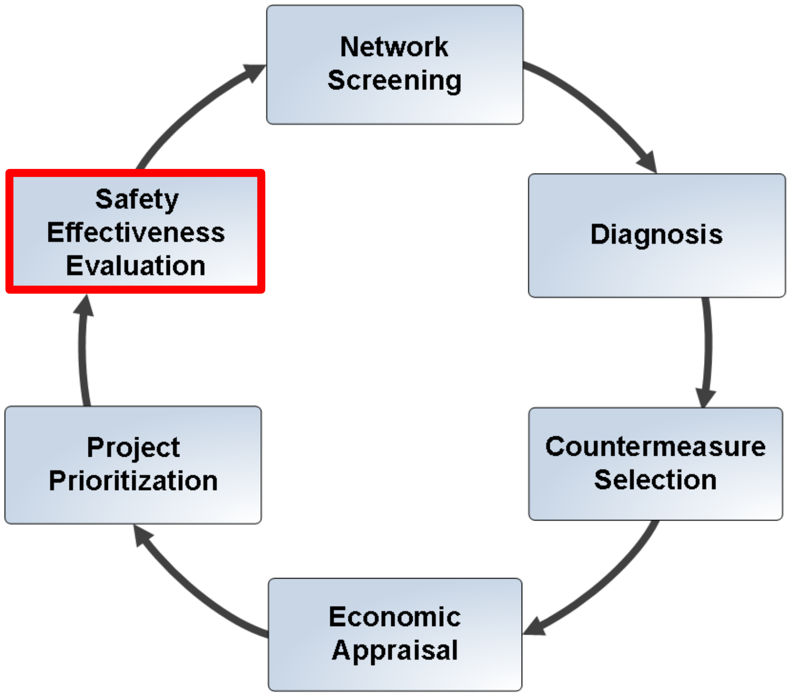


Figure 1. HSM Roadway Safety Management Process (Adapted from HSM [*2*]).

The main components of HSM's cyclical process are:

- Network Screening—Scan and calculate safety performance measures for every segment of the network and identify high-risk locations and sites.
- Diagnosis—Review past studies and roadway characteristics to determine crash patterns, understand causes of crashes, and identify safety issues and concerns.
- Countermeasure Selection—Identify risk factors contributing to causes of crashes and select appropriate countermeasures to mitigate safety issues.
- Economic Appraisal—Compare anticipated benefits and project costs of selected countermeasures.
- Project Prioritization—Rank safety improvement projects based on their potential to achieve the greatest reduction in the number and severity of crashes.
- Safety Effectiveness Evaluation—Assess the effectiveness of completed safety improvement projects, groups of similar projects (or countermeasures), or the entire program.

Several transportation agencies, including the Texas Department of Transportation (TxDOT), continuously try to find ways to improve their HSIP. Over the last few years, particular emphasis has been placed on employing HSM predictive methods and tools. For example, in 2016, TxDOT funded research project 0-6912 that tailored HSM's cyclical process to TxDOT needs, objectives, and HSIP requirements and used it as a general framework to develop crash analysis and visualization (CAVS) tools (*3*). The study focused on improving and streamlining four components of the general framework: network screening, diagnosis, countermeasure selection, and project prioritization. The main benefits gained from the use of the 0-6912 research products included an increase in the number of HSIP projects identified by TxDOT districts by up to 57 percent and a reduction in the time and effort required to select projects by 20–50 percent. Based on these results, TxDOT funded another study to further improve and refine a network screening process and implement the CAVS products to support the HSIP project selection process (*4*).

Although project 0-6912 yielded significant benefits for TxDOT, it only partially explored the last component of the general framework, *safety effectiveness evaluation*, which is highlighted in a red rectangle in Figure 1. To fill this gap, this study focused exclusively on this evaluation component. The goal and tasks of this project are described in Subsection 1.5.

1.2 WHAT IS HSIP EVALUATION?

The goal of HSIP evaluations is to determine if highway safety improvements are achieving the desired results and the investments are worthwhile (*5*). The term "HSIP evaluation" typically refers to the analysis of crash, traffic, roadway, and project construction data to quantify the safety and cost effectiveness of:

- Individual projects.
- Groups of similar projects, widely known as countermeasures, safety treatments, or work codes (WCs). Crash modification factors can be developed at this level of evaluation.
- HSIP categories or subprograms.
- Entire programs.

Evaluations can also be performed to determine the efficiency of project management activities. This type of evaluation typically involves comparing planned to actual project parameters such as project length, cost, duration, resources, and schedule (*6*). The general expectation is that the evaluation results will feed and better inform planning and implementation functions of the HSIP. This cyclical process allows agencies to identify potential deficiencies in the program and make appropriate changes.

1.3 IMPORTANCE AND BENEFITS

While identifying candidate HSIP projects, selecting countermeasures, and implementing projects are important functions to mitigate traffic safety problems, evaluating these efforts on a regular basis is critical to understanding the return on investment and improving the effectiveness of future decisions (*6*). HSIP evaluations have the potential to provide several benefits to not only TxDOT's Traffic Operations (TRF) Division, district offices, and area offices but also other divisions and local agencies that potentially build and manage non-HSIP projects. The most important benefits include the following:

- Evaluation results can help TxDOT determine if appropriate countermeasures were implemented at particular locations, whether any adverse impacts occurred, if corrective actions are necessary, and how effective those countermeasures would be for similar sites in the future.
- Safety assessment methods can be used to allocate HSIP funds in a cost-effective manner that promotes maximum return on investment, corrects existing deficiencies in a program, and leverages additional resources.
- Project evaluations can help TxDOT continuously improve its strategies for achieving SHSP targets, meeting HSIP goals, and realizing the anticipated traffic safety-related benefits.
- Evaluation results can help TxDOT assess the need for revising current policies, updating manuals, and developing strategies to address safety problems more effectively.
- Use of new tools can improve TxDOT's technical ability to systematically evaluate safety improvement projects and countermeasures while also providing a mechanism for district offices to perform independent evaluations.
- Application of modern safety assessment tools that incorporate data-driven methods can help TxDOT minimize engineering judgment, to the extent possible, reduce sources of bias in safety analysis, and therefore improve the effectiveness of proposed safety projects.
- Improved and streamlined HSIP evaluation processes will allow TxDOT to use its limited resources more efficiently by saving time and costs.
- Improved safety analysis and engineering practices will allow TxDOT to be one of the best-in-class state agencies in this arena.
- Sharing of the research products that can potentially be used to conduct similar evaluations will allow TxDOT to enhance relationships with other agencies such as local governments.
- Regular evaluations will help TxDOT meet federal requirements such as the following:
    - 23 CFR Part 924.5(a) requires states to develop, implement, and evaluate on an annual basis their HSIP.
    - 23 CFR Part 924.13(a)(1) requires states to include an evaluation process of analyzing and assessing their HSIP results in terms of contributions to improved safety outcomes and the attainment of safety performance targets established as per 23 USC 150.
    - 23 CFR Part 924.13(a)(2) requires states to evaluate their SHSP as part of the regularly recurring update process to (a) confirm the validity of the emphasis areas and strategies based on analysis of current safety data, and (b) identify issues related to the SHSP's process, implementation, and progress that should be considered during each subsequent SHSP update.
    - 23 CFR Part 924.13(b) requires states to use the HSIP evaluation results for (a) updating safety data used in the planning process, (b) setting priorities for highway

safety improvement projects, (c) assessing the overall effectiveness of the HSIP, and (d) reporting purposes.

1.4 CRASH-BASED AND SYSTEMIC PROGRAMS

Safety improvement programs typically incorporate crash-based or systemic approaches depending on how projects are selected in the planning phase. In crash-based programs, analysts identify sites based on one or multiple performance measures that account for crashes and other variables (e.g., traffic volume). For example, analysts may perform network screening using crash and other data to identify high-risk sites and then select appropriate countermeasures to address the safety concerns at each site separately. The HSM roadway safety management process (Figure 1) is an example of a crash-based approach.

On the other hand, systemic programs focus on selecting and treating sites based on roadway geometric and operational characteristics (e.g., curve radius, number of travel lanes, type or width of bicycle lanes, shoulder type and width, or intersection control type) that may be associated with high safety risk. Figure 2 shows the main elements and steps of a systemic approach.

Figure 2. Main Elements and Steps of Systemic Approach (*7*).

The first step in a systemic program is to select focus crash types, facility types, and/or contributing factors. The second step is to identify sites with the selected characteristics and then select appropriate treatments that are implemented system-wide at all sites that exhibit these characteristics. The main difference between crash-based and systemic approaches is that a site with no crash history may be selected as a systemic safety improvement project, whereas the same site is not eligible for funding under a crash-based program. The crash-based and systemic approaches are complementary and support a comprehensive safety management process (*6*).

1.5 PROJECT GOAL AND RESEARCH TASKS

The goal of this study was to find ways to advance TxDOT's HSIP evaluation processes and practices and evaluate the safety and cost effectiveness of HSIP projects and countermeasures that have been implemented in Texas over the last few years. To address this goal, the research team performed several research activities, grouped into four major tasks:

- **Reviewed safety and cost-effectiveness evaluation methods, state practices, and tools**. This task involved reviewing safety and cost-effectiveness evaluation methods available in the literature, determining general trends and state practices, and reviewing evaluation tools developed by federal and state agencies.
- **Gathered, compiled, and assessed TxDOT data**. Researchers gathered and processed roadway, traffic, crash, and construction data for HSIP projects and countermeasures that have been implemented in Texas over the last few years. After compiling the data, the research team assessed their appropriateness for supporting HSIP evaluations and identified opportunities for improvement.
- **Developed evaluation tools for segments and intersections**. The research team developed and tested two evaluation tools: one for roadway segments and the second one for intersections. The tools incorporate data-driven evaluation methods customized to TxDOT's needs, data availability, and HSIP requirements. TxDOT can use these tools in the future to evaluate the safety and cost effectiveness of completed HSIP projects and countermeasures.
- **Evaluated safety and cost effectiveness of implemented HSIP projects and countermeasures**. The research team evaluated the safety and cost effectiveness of 457 completed HSIP projects (387 segments and 70 intersections) and the corresponding countermeasures of these projects.

1.6 ORGANIZATION

The remaining chapters of this report include the following:

- **Chapter 2: Overview of Evaluation Methods**—This chapter provides an overview of traditional and evolving safety and cost-effectiveness evaluation methods.
- **Chapter 3: HSIP Evaluation Trends, State Practices, and Tools—**This chapter describes general trends, state HSIP evaluation practices, and evaluation tools developed by various agencies.
- **Chapter 4: Data Gathering and Assessment**—This chapter describes several TxDOT datasets that can be used to feed HSIP evaluations and provides data considerations and opportunities for improvement.
- **Chapter 5: Evaluation Tools—**This chapter presents two spreadsheet tools developed to evaluate the safety and cost effectiveness of individual projects and groups of similar

types of projects. The first tool is appropriate for segment evaluations and the second tool for intersection evaluations.

- **Chapter 6: Effectiveness of Completed HSIP Projects and Work Codes—**This chapter presents the results of project and countermeasure evaluations performed using the HSIP project data described in Chapter 4.
- **Chapter 7: Conclusions and Recommendations—**This chapter summarizes the most important research findings and provides a list of implementation recommendations stemming from the work performed and lessons learned throughout this project.

CHAPTER 2:
OVERVIEW OF EVALUATION METHODS

2.1 INTRODUCTION

This chapter provides a synthesis of methods that can be used to evaluate the safety and economic effectiveness of HSIP projects and countermeasures. To develop the synthesis, the research team gathered and reviewed relevant documentation such as guidebooks, research reports, HSIP manuals, annual state HSIP reports, and journal articles. The safety effectiveness evaluation methods are presented in Section 2.2, and the economic effectiveness evaluation methods are described in Section 2.3.

2.2 SAFETY EFFECTIVENESS EVALUATION METHODS

The safety effectiveness evaluation methods can be categorized by study design type into three general groups:

- Observational B/A studies.
- Observational cross-sectional studies.
- Experimental B/A studies.

The three study designs are separately described in Subsections 2.2.1 through 2.2.3, respectively.

2.2.1 Observational B/A Studies

Among the three study designs, observational B/A studies are the most frequently used in highway safety analysis. In these studies, analysts gather and analyze data for the two periods before and after the implementation of a project. There are several methods that can be used in B/A studies to evaluate individual projects and countermeasures. The remaining subsections present these methods.

Naïve B/A Studies

Naïve or simple B/A studies involve comparing the crash frequency observed in the before period to the crash frequency in the after period. Although these studies are not data demanding, they are easy to perform, and communicating their results is simple. However, they do not consider traffic volumes and cannot account for RTM bias and temporal effects or trends such as changes in driver behavior, crash reporting, and other local factors. Because of these shortcomings, they are not recommended for developing quality CMFs when they are used in countermeasure evaluations.

Naïve B/A Studies with Linear Traffic Volume Correction

A B/A study with a linear traffic volume correction is a variation of the naïve B/A study. This method accounts for temporal changes in traffic volumes. In this method, analysts compare the crash rates (instead of crash frequencies) for the two periods before and after implementing a treatment, making this method more reliable than naïve B/A studies. Crash rates are calculated as follows:

$$Crash\ Rate_i = \frac{C_{Observed,i}}{AADT_i} \quad (1)$$

Where:

- $Crash\ Rate_i$ is the crash rate at site i during a given period (e.g., three to five years).
- $C_{Observed,i}$ is the average crash frequency at site i during a given period.
- $AADT_i$ is the annual average daily traffic at site i during a given period.

This method can be used to conduct both project and countermeasure evaluations; however, it does not account for RTM effects and changes in other factors over time. The method may be appropriate for CMF development if there is limited or no potential for RTM and there are no changes in driver behavior or crash reporting in the before and after periods.

Naïve B/A Studies with Nonlinear Traffic Volume Correction

Studies have shown that the relationship between crash frequency and traffic volume is nonlinear. Crash rate is a linear function and may not account for traffic volume variations in the before and after periods. A more reliable method is to use a nonlinear function such as SPFs. This method can be used in both project and countermeasure evaluations. In the case of countermeasure evaluations, a calibrated SPF can be used to calculate the ratio of predicted number of crashes in the after period to the predicted number of crashes before implementation. However, similar to the B/A studies with a linear traffic volume correction, this method is not recommended for CMF development unless there are reasons that suggest limited RTM effects and no temporal changes in driver behavior or crash reporting.

Shifts in Crash Type Proportions

When a treatment targets specific crash types (e.g., run-off-road crashes) or crash severity (e.g., fatal and serious injury crashes), it may be useful to evaluate the shift in the proportions of crashes by type or severity level. This method calculates the proportion of target crashes to total crashes in the before period and compares it to the corresponding proportion in the after period. This method is appropriate when traffic volume data are not available, but there are reasons that indicate potential changes in traffic volume over time. The shift in proportions method can be used in both project and countermeasure evaluations. Figure 3 shows the calculation steps for evaluating countermeasures.

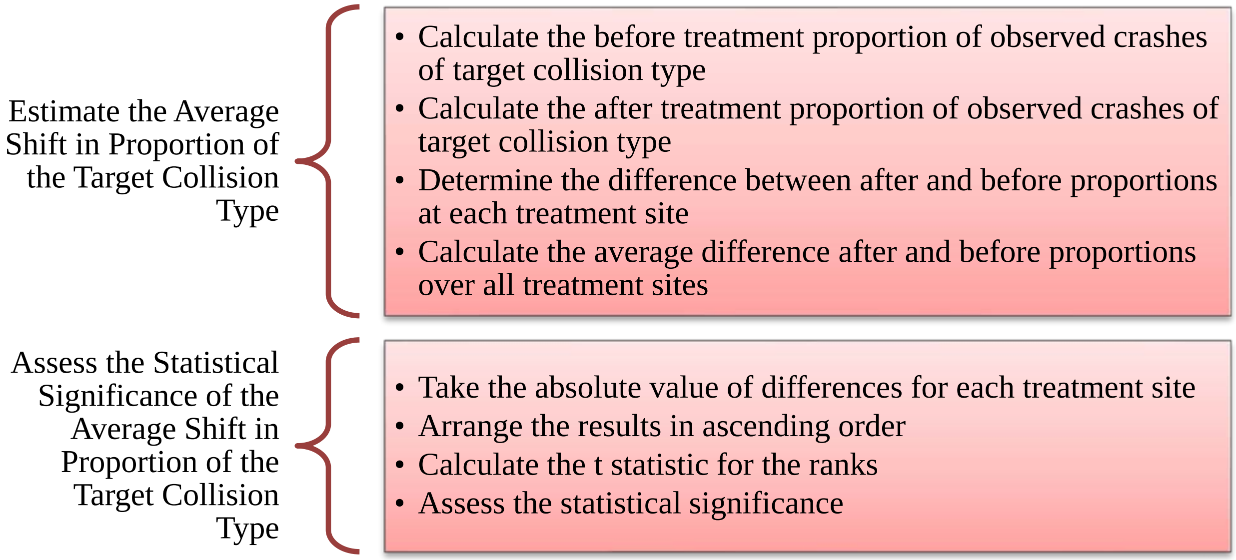


Figure 3. Overview of B/A Study Using Shifts in Crash Type Proportions—Countermeasure Evaluation (Adapted from HSM [2]).

A CMF can be developed using this method as follows:

$$CMF_{Shift\ in\ Proportions} = \frac{\left(\frac{Target\ Crashes}{Total\ Crashes}\right)_{after}}{\left(\frac{Target\ Crashes}{Total\ Crashes}\right)_{before}} \quad (2)$$

Where:

- $CMF_{Shift\ in\ Proportions}$ is the safety effectiveness of the treatment.
- $\left(\frac{Target\ Crashes}{Total\ Crashes}\right)_{after}$ is the proportion of the target crashes after the treatment.
- $\left(\frac{Target\ Crashes}{Total\ Crashes}\right)_{before}$ is the proportion of the target crashes before the treatment.

The Wilcoxon signed rank test can be used to determine statistical significance of the results. Similar to the previous methods, more reliable CMFs can be obtained from other more advanced methods, such as the empirical Bayes (EB) method, that account for RTM effects.

Comparison Group Method with Traffic Volume Correction

This method compares a group of treated sites to a comparison group of untreated sites. The comparison sites are comparable to the treated sites in traffic volume, roadway geometrics, and other characteristics. One option is to use the comparison group to calculate the ratio of observed crashes in the after period to that in the before period. The ratio is multiplied by the observed crash frequency at the treated sites in the before period to estimate the number of crashes at the treated group in the after period had the countermeasure not been implemented. The estimated crashes at the treated group in the after period (had the countermeasure not been implemented) is then compared with the crashes observed at the treated sites in the after period to determine the countermeasure effect. Figure 4 shows the calculation steps of this method.

Estimation of Mean Treatment Effectiveness

- Calculate predicted crash frequency at each treatment site, separately for before and after periods.
- Calculate predicted crash frequency at each comparison site, separately for before and after periods.
- Calculate adjustment factor at each combination of treatment and comparison site, separately for before and after periods.
- Calculate adjusted crash frequency at each combination of treatment and comparison site, separately for before and after periods.
- Calculate total comparison-group adjusted crash frequency for each treatment site in the before period.
- Calculate total comparison-group adjusted crash frequency for each treatment site in the after period.
- Calculate the comparison ratio for each treatment site.
- Calculate the expected crash frequency for each treatment site in the after period, had no treatment been implemented.
- Calculate the safety effectiveness expressed as an odds ratio at an individual treatment site.
- Calculate the log odds ratio for each treatment site.
- Calculate the weight for each treatment site.
- Calculate the weighted average log odds ratio across all treatment sites.
- Calculate the overall effectiveness of the treatment expressed as an odds ratio.
- Calculate the overall effectiveness of the treatment expressed as a percentage change in crash frequency.

Estimation of Precision of the Treatment Effectiveness

- Calculate standard error of the treatment effectiveness.
- Assess the statistical significance of the estimated safety effectiveness.

Figure 4. Overview of B/A Comparison Group Safety Evaluation Method (Adapted from HSM [*2*]).

Hauer proposed matching the comparison and treated sites based on historical crash frequencies (*8*). In this method, analysts usually select the treatment and comparison sites from the same jurisdiction to increase the likelihood of having similar trends in historical crash data.

Another option is to calibrate or develop SPFs using data from the comparison group. In this case, the ratio is estimated as the predicted number of crashes in the after period to the predicted number of crashes in the before period. The method does not use SPFs in the same manner as the EB method, yet SPFs are desirable to account for traffic volume changes and capture the nonlinear relationship between crashes and traffic volume.

This method does not account for RTM effects unless the observed crash frequency of treatment and comparison sites are matched for the before period. Matching a control site to each treated site may have a high difficulty level. Further, it is difficult to test the main assumption that the comparison group is unaffected by the treatment. Overall, the comparison group method may be a viable approach for CMF development if there are reasons that suggest limited or no potential for RTM.

Comparison Group Method without Traffic Volume Correction

This method compares a group of treated sites to a comparison group of untreated sites without accounting for traffic volumes at individual sites. This method suffers from the same limitations as other simple evaluation methods that do not use SPFs and traffic volumes. The calculation steps of this method are described in the *HSIP Evaluation Guide* (*6*) and can be performed using the companion spreadsheet tool of the guide.

The method calculates the ratio of observed crashes at the control sites in the after period to those in the before period. This ratio is multiplied by the observed crash frequency in the before period at the treated sites to estimate the number of crashes at the treated sites in the after period had the countermeasure not been implemented. The estimated crashes at the treated sites in the after period are then compared with the observed crashes at the treated sites in the after period to determine the effectiveness of the countermeasure of interest.

EB Method

The EB method estimates the expected number of crashes that would have occurred had there been no treatment and compares it to the actual number of crashes in the after period. It accounts for RTM bias, changes in traffic volumes, and temporal effects, making it one of the most reliable methods for CMF development. Figure 5 shows the calculation steps of the EB method.

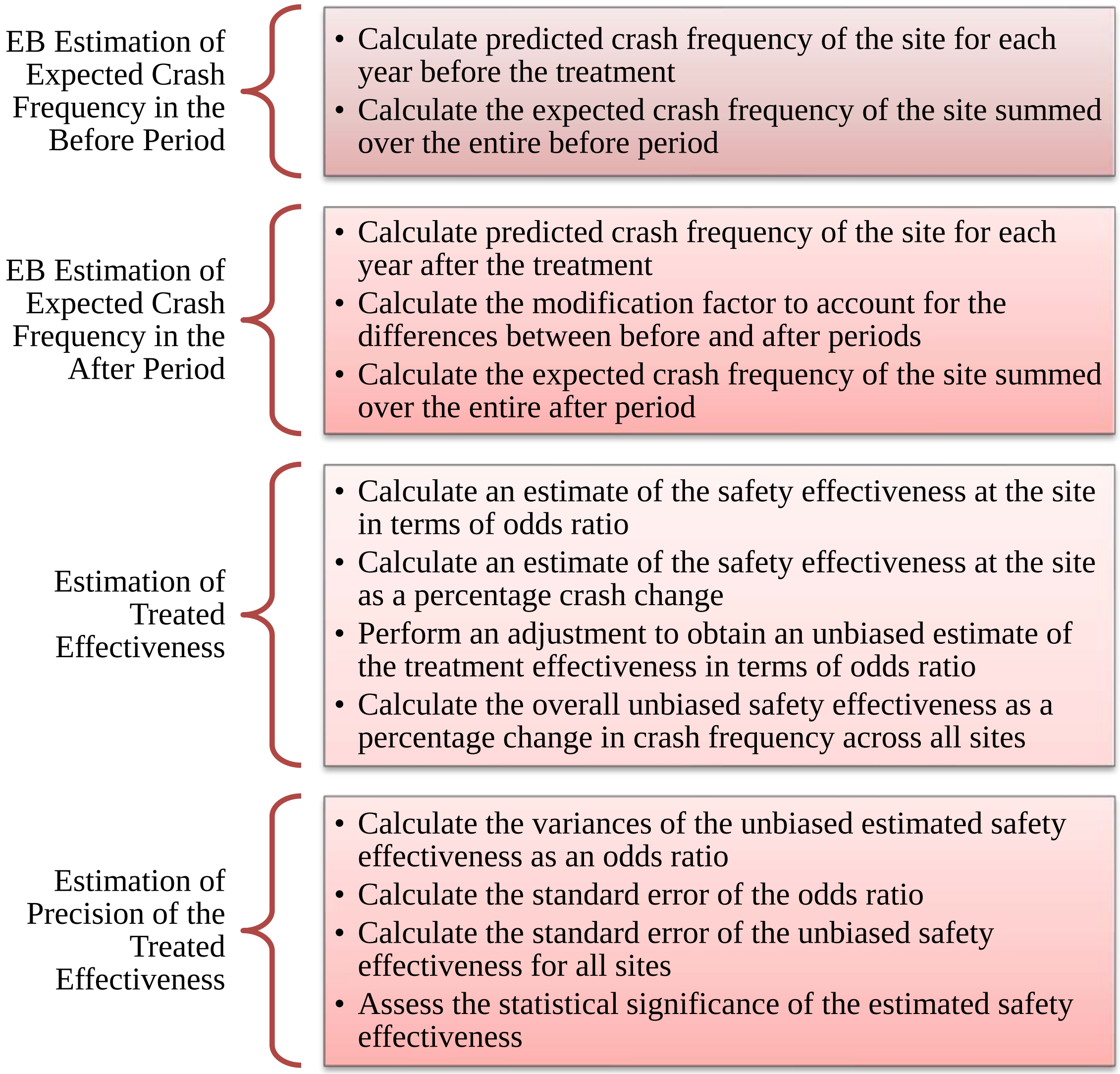


Figure 5. Overview of EB B/A Safety Evaluation (Adapted from HSM [*2*]).

The EB method is based on a weighted average principle. It uses a weight factor, w, to combine observed ($C_{Observed}$) and predicted ($C_{Predicted}$) crash frequencies to estimate the *expected crash frequency*, $C_{Expected}$:

$$C_{Expected} = w \cdot C_{Predicted} + (1 - w) \cdot C_{Observed} \tag{3}$$

Where:

- w is a weight factor, which depends on the overdispersion parameter obtained from the SPF.
- $C_{Expected}$ is the expected crash frequency.
- $C_{Predicted}$ is the predicted crash frequency, usually calculated using the SPF and CMFs.
- $C_{Observed}$ is the observed crash frequency.

Figure 6 shows a conceptual example of the EB method.

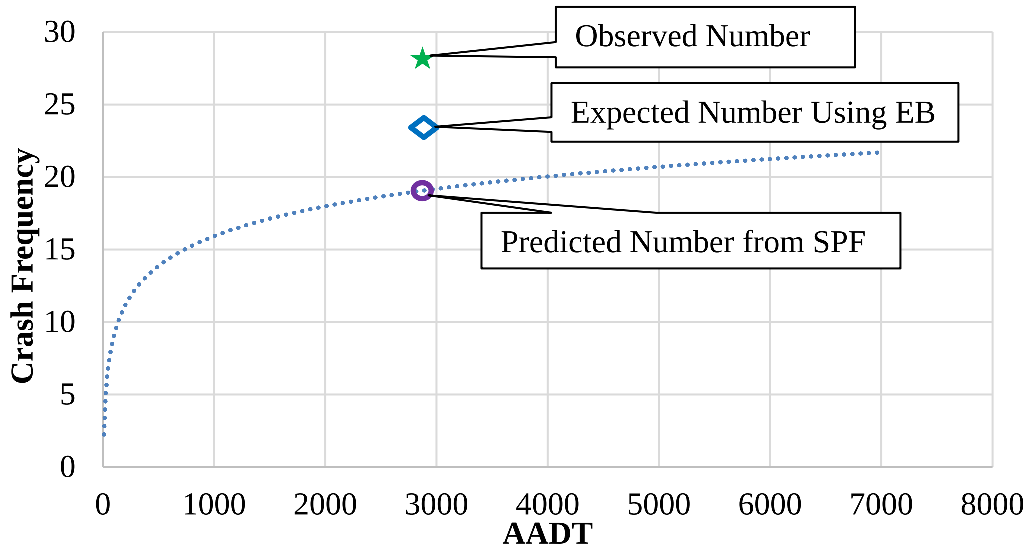


Figure 6. Conceptual Example of EB Method.

The EB method accounts for both observed and predicted crash frequencies to overcome potential bias due to RTM. However, the uncertainty in the number of predicted crashes can be high if the overdispersion parameter obtained from the SPF is high too. A weight factor is applied to mitigate this issue. As the overdispersion parameter increases, the value of the weighted adjustment factor decreases. Thus, more emphasis is placed on the observed rather than the predicted crash frequency. When the data used to develop a model are greatly dispersed, the reliability of the resulting predicted crash frequency is likely to be lower. In this case, it is reasonable to place less weight on the predicted crash frequency and more weight on the observed crash frequency. On the other hand, when the data used to develop a model have low overdispersion, the reliability of the resulting SPF is likely to be higher. In this case, it is reasonable to place more weight on the predicted crash frequency and less weight on the observed crash frequency.

Full Bayesian

Full Bayesian (FB) is a robust method that can be applied to any study design, including observational B/A and cross-sectional study designs. It is appropriate for countermeasure evaluations. Unlike the EB method, FB can be used for smaller data samples, making FB more appropriate in situations where the amount of data in the after period is small. Several research studies have examined the differences between EB and FB approaches and have found that even with large sample sizes, the FB method can perform as well as the EB method (*9, 10, 11*). Figure 7 shows the conceptual framework of the FB method.

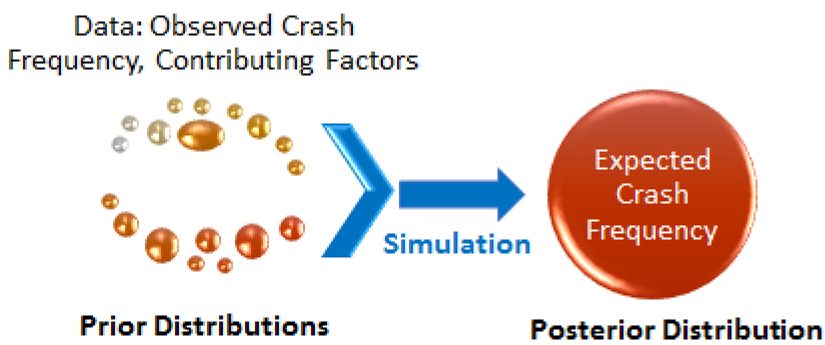


Figure 7. Conceptual Framework of FB Method.

In the FB method, the posterior distribution of the expected/predicted crashes is simulated based on both data and a prior distribution of the model. The posterior distribution of the predicted crashes for the treatment and control groups in the before and after periods can be used to estimate the CMFs to assess the safety effectiveness of the treatment. The FB approach compensates for RTM effects by estimating the expected number of crashes for the before and after periods, without directly using the observed crash count in the comparison.

Difference in Differences

The difference in differences (DID) method mimics experimental research designs using observational data to determine the differential effect of a treatment on a group of treated sites versus a control group of untreated sites. The DID method has been widely used in many fields (*12*, *13*, *14*, *15*, *16*, *17*). In conventional B/A observational studies, the same locations are analyzed in before and after periods to determine the effect of a treatment on safety. If the effects of a countermeasure take a long time to be observed, other variables may change during that time. Therefore, the difference in the crash frequency before and after implementation may not depend on the effect of the treatment only.

While other B/A evaluation methods compare performance measures at the treatment group before and after implementation, the DID is based on the difference of the two B/A differences across the treatment and control groups. This double differencing, the so-called DID method, removes potential biases (a) in the after period between the treatment and control groups that could be the result of permanent differences between these groups, and (b) over time in the treatment group that could be the result of external factors unrelated to the treatment.

2.2.2 Cross-Sectional Studies

In cross-sectional studies, data are gathered from treated sites only in the after period and from untreated sites in the before period. The two types of sites are similar in characteristics except for the treated feature. In these studies, analysts can develop CMFs using the crash frequency of the treated and the control sites. Table 1 shows the cross-sectional study design.

Table 1. Observational Cross-Sectional Study Design (Adapted from HSM [*2*]).

Group of Sites	Before Treatment	After Treatment
Treatment Sites		X
Comparison Group	X	

Cross-sectional studies are appropriate when:

- Treatment implementation dates are unknown.
- Crash and volume data for the before period are not available.
- There is a need to account for effects of roadway geometric characteristics and other features by creating a CMF function rather than using a single CMF value.

Cross-sectional studies have some disadvantages. First, they do not account for RTM effects. Second, it is difficult to assess whether the observed differences between treatment and non-treatment sites are due to the treatment or other external factors. These studies are also subject to selection bias. The treated sites usually experience a higher number of crashes compared to the control sites. This implies that, even if the number of crashes reduces after the treatment, the number of crashes could still be higher compared to the crashes at the control sites, yielding biased results. One of the methods that can be used to overcome this issue is propensity score matching (PSM), which is described below.

PSM is based on the data matching principle. Data matching methods are used to assist causal inference that quantifies the impact of a treatment variable on a given response variable. Data matching is essentially a data balancing method where each treated site is matched with at least one control site (Figure 8). The main principle behind this method is to identify control sites that are similar in their covariates to the treated locations. In doing so, analysts can obtain the counterfactual crash frequency (i.e., the crash frequency that would have been observed if the treatment had not been implemented). In this method, analysts estimate the propensity scores, which denote the probability of the site receiving the treatment. This approach is employed to mimic random selection in experimental studies. Therefore, PSM accounts for selection bias, hence the RTM bias in cross-sectional studies. PSM methodology matches sites with treatment to similar sites without treatment (i.e., control sites) based on similarities in their characteristics.

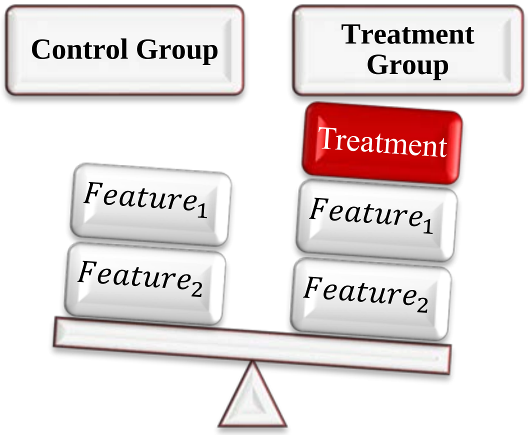


Figure 8. Data Matching Principle.

Table 2 shows an example of a matched dataset used to evaluate rumble strips. In this example, the roadway design characteristics that are assumed to be significantly associated with the rumble strip presence are number of lanes and shoulder width (*18*).

Table 2. Cross-Sectional Data Format for Safety Evaluation (Adapted from HSM [*2*]).

Site	Rumble Strip Treatment	Run-off-Road Crash Frequency	Characteristics	
			Numbers of Lanes	Shoulder Width
Segment A (Treated Site)	Yes	2	2	6 feet
Segment B (Control Site)	No	5	2	6 feet

To match the data, these elements have to be similar across the treated and control sites. After obtaining perfectly matched data, the analyst can evaluate the impact of rumble strips on traffic safety.

2.2.3 Experimental B/A Studies

In experimental studies, comparable sites of similar traffic volume and geometric features are randomly assigned to a treatment or a non-treatment group. The treatment is then implemented at the sites in the treatment group, and crash and traffic volume data are obtained before and after implementing the treatment. Although these studies minimize RTM bias, they involve random selection of sites for improvement, making transportation agencies reluctant to randomly allocate their limited safety funds for experimental purposes. Table 3 shows the basic design of experimental B/A studies.

Table 3. Experimental B/A Evaluation Study Design (Adapted from HSM [*2*]).

Type of Site	Before Treatment	After Treatment
Treatment Site Data	X	X
Comparison Group		

The research team compiled guidance and information from the literature and developed a summary table (Table 4) that shows the applicability, data needs, and relevant considerations for each observational and cross-sectional study. Experimental studies are not included in Table 4 because (a) they are not typically used to evaluate safety improvement projects, and (b) the same observational B/A methods can be used in experimental studies. This table can be used as a guide to either select appropriate evaluation methods based on existing data or to collect additional data to meet the data requirements of each method.

Table 4. Overview of Safety Effectiveness Evaluation Methods.

Applicability, Data Needs, and Other Considerations		Safety Effectiveness Evaluation Method: Observational Before/After Method: Naïve	Linear Traffic Volume Correction	Nonlinear Traffic Volume Correction	Shift in Proportion	Comparison Group with Traffic Volume Correction	Comparison Group without Traffic Volume Correction	EB	FB	DID	Cross-Sectional: Trad-itional	PSM
Project evaluation		X	X	X	X			X	X			
Countermeasure evaluation		X	X	X	X	X	X	X	X	X	X	X
10–20 treatment sites	3–5 years of before crashes	X	X	X	X	X	X	X	X	X		
	3–5 years of after crashes	X	X	X	X	X	X	X	X	X	X	X
	3–5 years of before traffic data		X	X		X		X	X	X		
	3–5 years of after traffic data		X	X		X		X	X	X	X	X
	SPFs			X		X		X	X			
10–20 control sites	Minimum of 650 crashes					X						
	3–5 years of before crashes					X	X		X	X		
	3–5 years of after crashes					X	X		X	X	X	X
	3–5 years of before traffic data					X			X	X		
	3–5 years of after traffic data					X			X	X	X	X
	SPFs					X			X			
Safety measure	Crash frequency	X	X	X		X	X	X	X	X	X	X
	Target crash type				X							
Accounts for RTM								X	X			X
Accounts for traffic volume changes			X	X		X		X	X	X		X
Accounts for nonlinear relationship between crashes and traffic volume				X		X		X	X			X
Accounts for other temporal changes						X	X	X	X	X		

2.3 ECONOMIC EFFECTIVENESS EVALUATION

The economic benefits of an implemented project or countermeasure can be evaluated using two methods:

- Benefit/cost (B/C) analysis.
- Cost-effectiveness evaluation.

In B/C analysis, the expected change in crash frequency is converted to a monetary value, summed, and then compared to the countermeasure cost. In cost-effectiveness evaluation, the observed change in crash frequency is not converted into a monetary cost. It is compared directly to the actual construction cost (i.e., the cost effectiveness is expressed as the annual cost per crash reduced).

The expected reduction in crash frequency and severity can be converted into monetary values using societal comprehensive crash costs. The national comprehensive crash unit costs published by FHWA (*19*) and those used in Texas as part of the 2018 HSIP are presented in Table 5. In this table, each crash injury severity level is associated with a particular dollar amount.

Table 5. National Comprehensive Crash Unit Costs (*19*) and TxDOT's HSIP Crash Costs.

Crash Severity	FHWA Comprehensive Crash Unit Cost	TxDOT's Crash Cost (2018 HSIP)
Fatal (K)	$11,295,400	$3,500,000
Incapacitating Injury (A)	$655,000	$3,500,000
Nonincapacitating Injury (B)	$198,500	$500,000
Possible Injury (C)	$125,600	Not Applicable in HSIP
Property Damage Only (O)	$11,900	Not Applicable in HSIP

The project costs include right-of-way acquisition, construction, operation, and maintenance costs. Table 6 shows the data needs for calculating the monetary amount of benefits and costs.

Table 6. Calculation Steps and Data Needs in B/C Analysis (*2*).

Step	Data Needs
• Calculate change in number of crashes by severity	• Crash frequency by severity • Before and after traffic volumes • Implementation start and end dates • CMF for each countermeasure considered
• Convert change in crash frequency to monetary value	• Monetary value of crashes by severity
• Calculate construction and other implementation costs	• Subject to standards for the jurisdiction
• Calculate ratio of benefits (monetary value) to total project cost	

The cost-effectiveness evaluation involves calculating the ratio of the total project cost to the change in crash frequency (absolute number) before and after implementation.

CHAPTER 3: HSIP EVALUATION TRENDS, STATE PRACTICES, AND TOOLS

3.1 INTRODUCTION

This chapter presents HSIP evaluation trends, state practices, and tools developed by state and federal agencies. The goal of this review was to identify noteworthy HSIP evaluation practices and tools that could be transferable at TxDOT. To collect the information presented herein, the research team conducted a series of activities in the following order:

- Downloaded and reviewed all state HSIP reports that were submitted by state DOTs to FHWA in 2016 and 2017.
- Created a database that contains information and data from all state HSIP reports. The answers provided to the various sections of each HSIP report were extracted and organized in a tabular format.
- Created charts to determine general trends in HSIP evaluations.
- Gathered and reviewed other relevant documents such as state HSIP manuals, SHSPs, guidebooks, handbooks, and reports.
- Conducted an online search of state DOT websites to find additional information, data, and files, as needed.
- Contacted via email all states that provided project evaluation data in their 2016 or 2017 HSIP reports.
- Conducted phone interviews with state officials to request additional information, data, and files, where appropriate.

The next section presents general trends in HSIP evaluation nationwide. The third section describes state HSIP evaluation practices and tools, and the fourth section presents tools developed by AASHTO and FHWA. The last section presents European practices.

3.2 GENERAL TRENDS

Researchers reviewed 2017 state HSIP reports to identify general trends in relation to the following:

- Measures of effectiveness.
- Indicators of success.
- SHSP emphasis areas.

This review included 51 HSIP reports, one for each state and the District of Columbia (DC). The research team created a database to store pertinent information and simplify the comparison of practices among states.

3.2.1 Measures of Effectiveness

Each state measures certain aspects to determine the effectiveness of its HSIP program. Table 7 shows all measures of effectiveness documented by all states.

Table 7. Measures of Effectiveness.

• Change in fatalities and serious injuries • B/C ratio • Lives saved • Economic effectiveness (cost per crash reduced) • Other—Change in fatal and serious injury crashes • Other—Fatality rates* • Other—Naïve B/A studies for specific projects* • Other—Statewide fatal and serious injuries* • Other—Obligation of HSIP dollars* • Other—Initiative basis*	• Other—Change in all crashes at locations in the HSIP* • Other—Combination* • Other—Decrease of both fatal and serious injuries on a five-year rolling average* • Other—B/A crash analysis* • Other—Evaluation of individual HSIP projects and programs* • Other—Observational B/A studies* • Other—3 FHWA implementation plans* • Other—Reduction of severe crashes* • Other—Funding utilized for safety-related treatments*

* Measure of effectiveness selected only once by one state.

Figure 9 shows the most frequently used measures of effectiveness. The “change in fatalities and serious injuries” measure was used the most, by 37 states. The second most frequently used measure was “B/C ratio,” used by 23 states. Figure 10 shows the number of measures of effectiveness used by each state. Most states use one or two measures of effectiveness, with the exception of Delaware, New Jersey, and Pennsylvania, which used four measures.

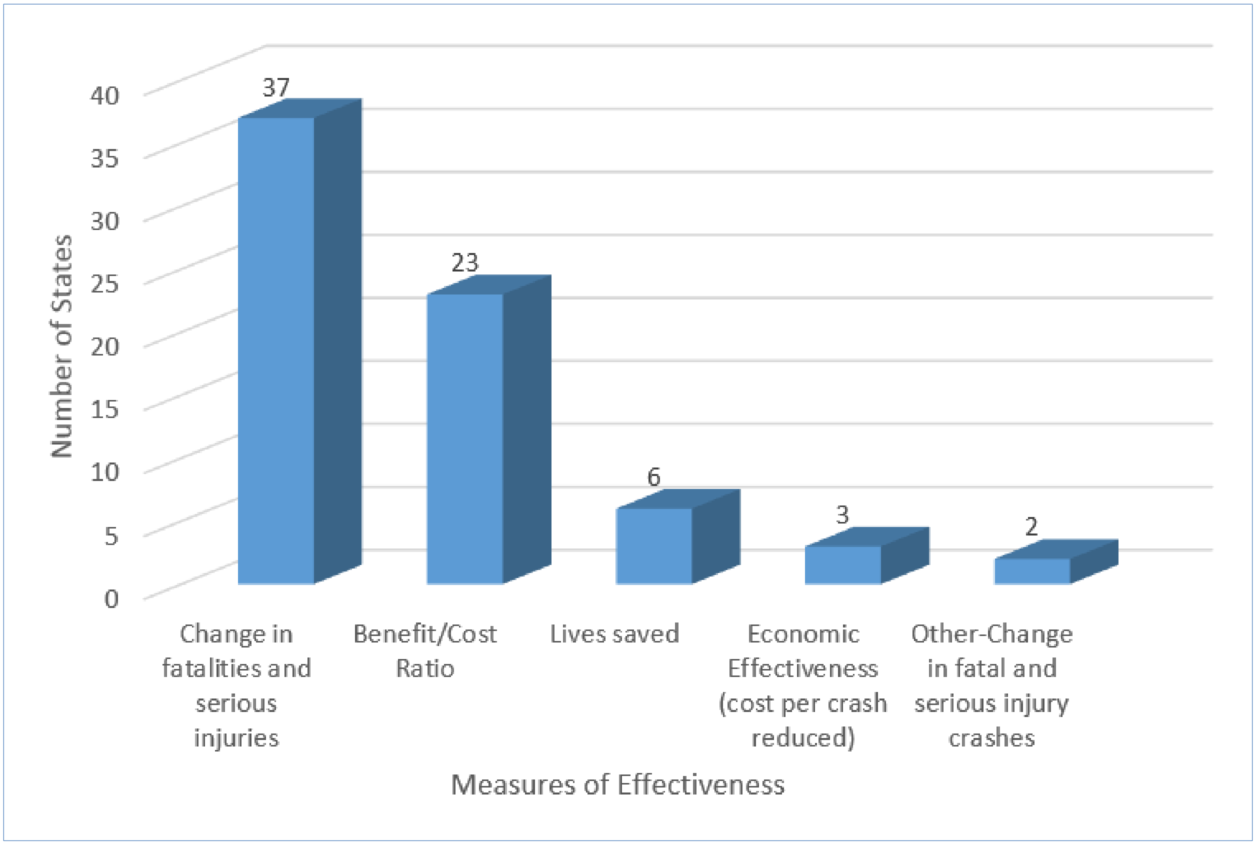


Figure 9. Most Frequently Used Measures of Effectiveness.

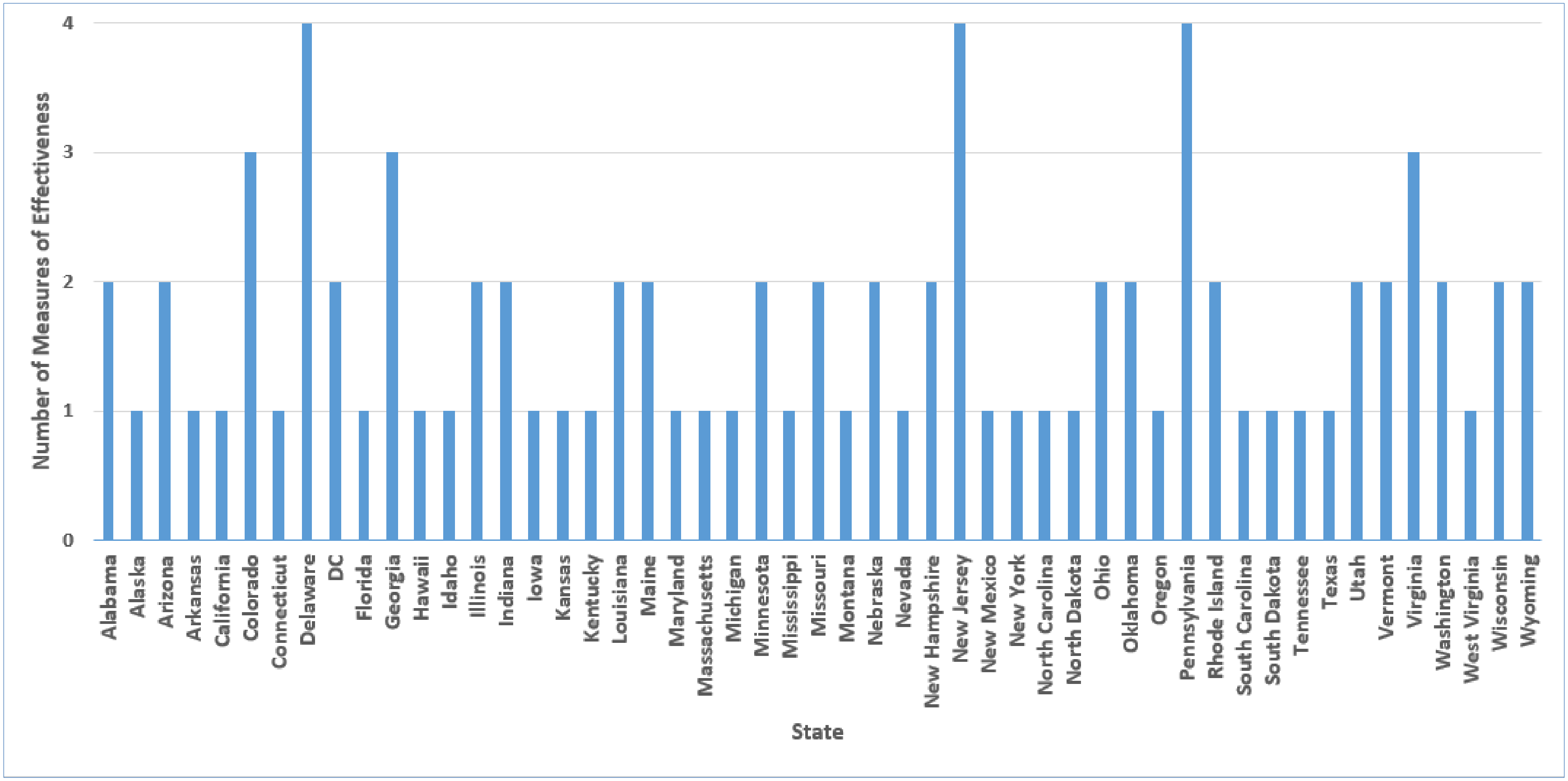


Figure 10. Number of Measures of Effectiveness Used by Each State.

3.2.2 Indicators of Success

States also use various indicators to demonstrate the effectiveness and success of their HSIP. Table 8 shows all the indicators of success documented by the states.

Table 8. Indicators of Success.

• Number of miles improved by HSIP • More systemic programs • Number of road safety assessments completed • Policy change • Organizational change • Increased focus on local road safety • Increased awareness of safety and data-driven process • HSIP obligations • Other—B/A studies • Other—Realized positive B/C ratio*	• Other—Reduction in fatalities and serious injuries* • Other—Improving and coordinating infrastructure and behavior strategies to maximize benefits* • Other—Pedestrian strategic focus outcomes* • Other—Reduction in target crashes* • Other—A more focused Local Technical Assistance Program safety program* • Other—Improved data collection, transfer, access*

* Indicator of success selected only once by one state.

Figure 11 shows the most frequently used indicators of success. The indicator with the highest usage was "increased awareness of safety and data-driven process," used by 32 states. Thirty states used the "more systemic programs" indicator.

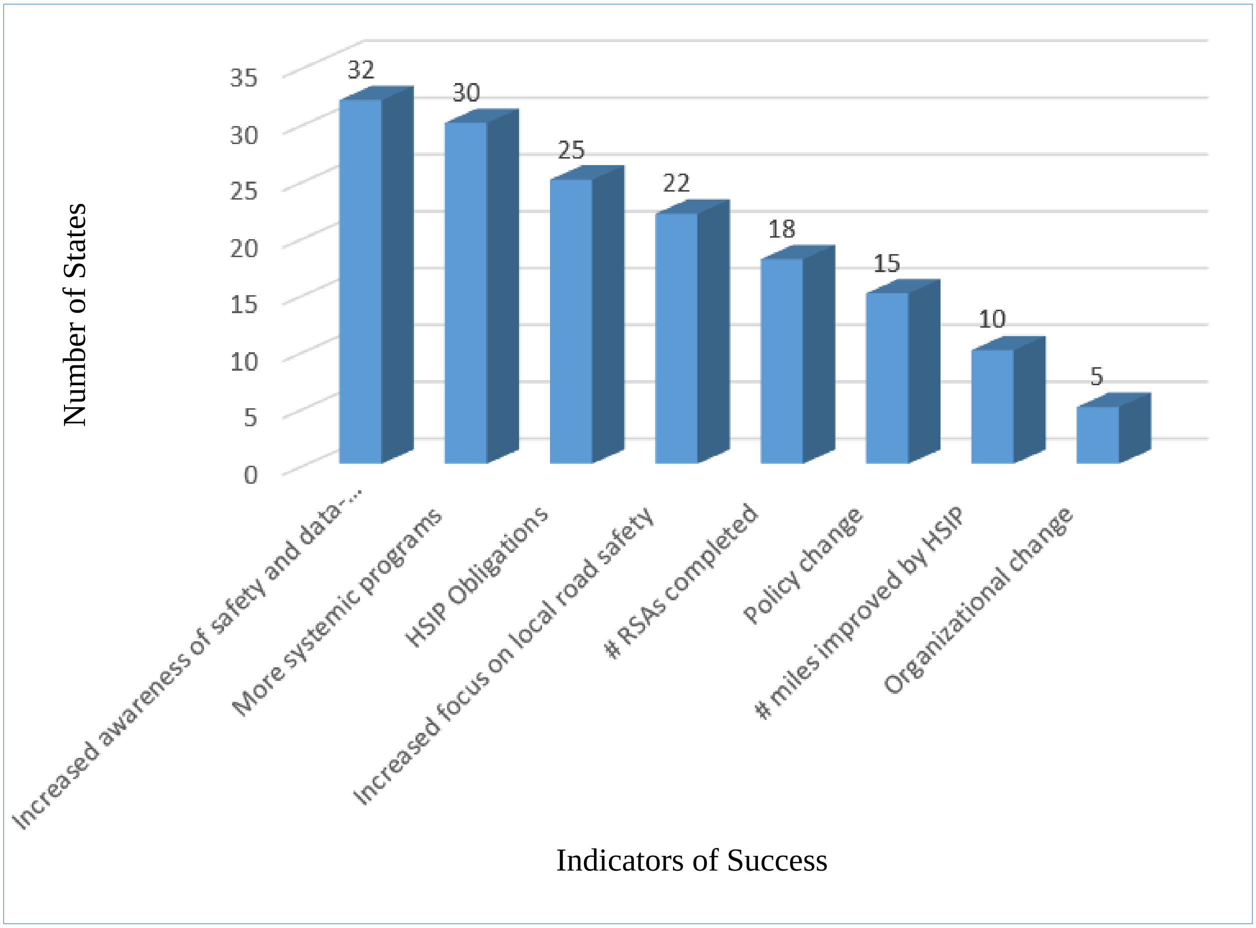


Figure 11. Most Frequently Used Indicators of Success.

Figure 12 shows the number of indicators of success used by each state. States use from zero (Alaska) to seven (Mississippi and New York) indicators of success to determine if the pursuit of highway safety awareness is increasing within an organization.

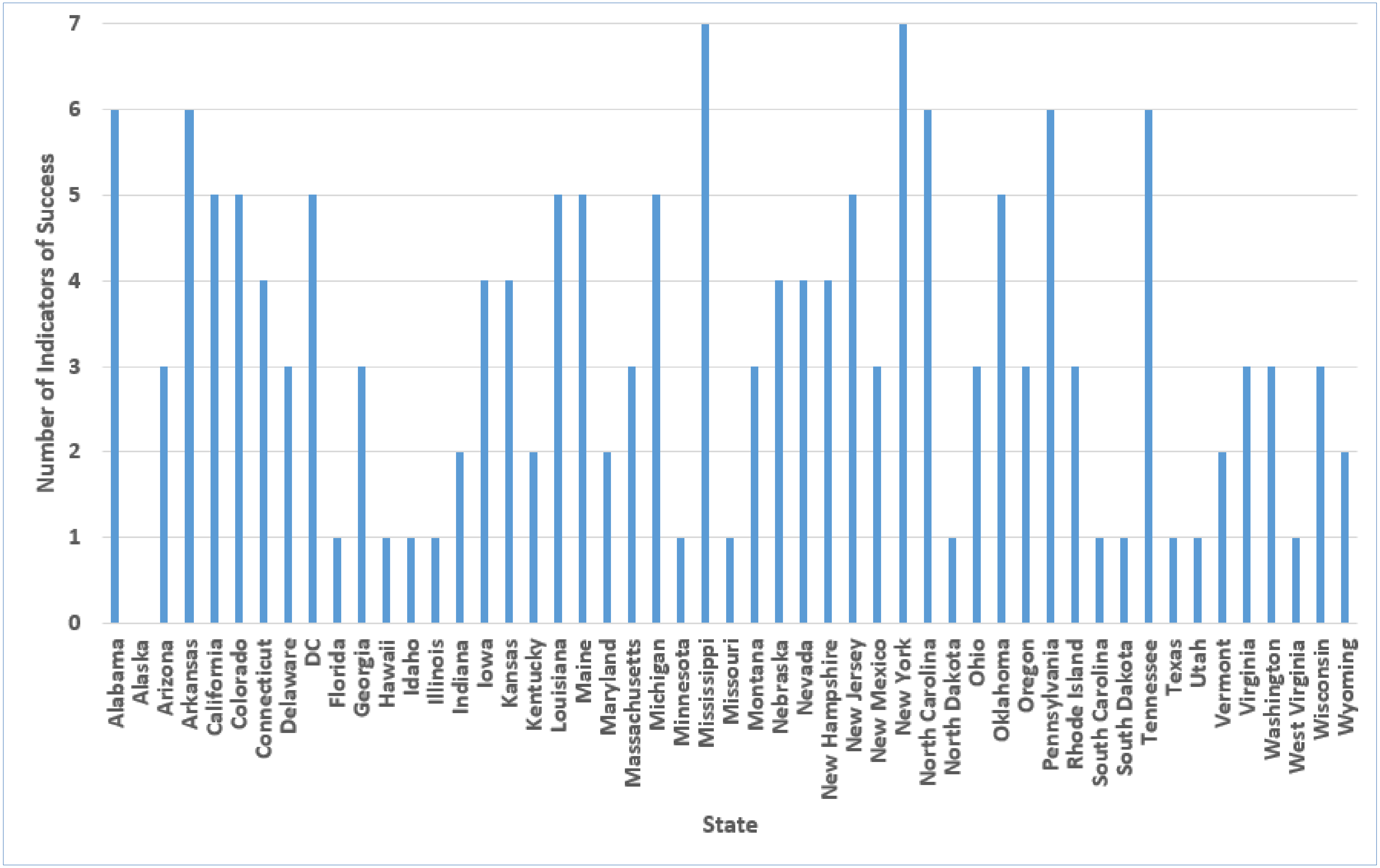


Figure 12. Number of Indicators of Success by State.

3.2.3 SHSP Emphasis Areas

States concentrate their efforts on various emphasis areas for their SHSP. Table 9 shows all the SHSP emphasis areas or issues that safety improvement projects are intended to address according to state HSIP reports. Note that some emphasis areas are redundant. For example, there are five emphasis areas related to seatbelts: safety belts and child safety seats, seat belts, increase seat belt use, unrestrained, and unrestrained vehicle occupants.

Table 9. SHSP Emphasis Areas.

• Lane Departure • Roadway Departure • Intersections • Older Drivers • Data • Work Zones • Pedestrians • Bicyclists • Motorcyclists • Reduce Occurrence & Conseq. of Leaving Roadway & Head-On Collisions • Improve Driver Decisions about Rights of Way and Turning • Safety Belts and Child Safety Seats • Improve Intersection and Interchange Safety • Make Walking and Street Crossing Safer • Improve Safety for Older Roadway Users • Reduce Speeding and Aggressive Driving • Improve Commercial Vehicle Safety • Improve Motorcycle Safety • Improve Bicycle Safety • Commercial Vehicles • Impaired Driving • Teen Drivers • Distracted Driving • Aggressive Driving • Safety Restraints • Single-Vehicle Run off Road • Head-On/Sideswipe Opposite • Occupant Protection • Large Commercial Vehicles	• Infrastructure and Operations—Intersections • Infrastructure and Operations—Roadway Departure • Highway Infrastructure • High-Risk Behaviors • At-Risk Road Users • Engineering Infrastructure • System Administration • Suspended/Revoked Licensed or Unlicensed Drivers • Seat Belts • Curb Aggressive Driving • Increase Driver Safety Awareness • Reduce Pedestrian, Bicycle, Rail, & Vehicular Conflicts • Driver Inattention • Heavy Vehicles • Inclement Weather • Speeding and Aggressive Driving • Train-Vehicle • Animal and Wildlife • Increase Seat Belt Use • Drowsy Drivers • Excessive Speed • Cable Median Barrier • Adverse Roadway Surface Condition • Adverse Weather • Collision with Fixed Object • Commercial Motor Vehicle • Domestic Animal Related • Drowsy Driving • Driving under Influence	• Interstate Highway • Night/Dark Condition • Overturn/Rollover • Railroad Crossing • Roadway Geometry Related • State Route • Single Vehicle • Speed Related • Train Involved • Transit Vehicle Involved • Urban County • Wild Animal Related • Improper Restraint • Rural Non-State • Unrestrained • Impaired Driver Involved • Speeding Involved • Distracted Driver Involved • Unrestrained Vehicle Occupants • Unlicensed Driver Involved • Opposite Direction • EMS and Trauma Care Systems • Heavy Truck Involved • Drowsy Driver Involved • Wildlife • School Bus Involved • Vehicle-Train • Reduce Cross-Median Crashes • Railcar-Vehicle • Impaired Driving (NHSTA) • Impaired Driving (Maryland) • Tribal Lands • Local Roads • Create Safer Work Zones

Figure 13 shows the SHSP emphasis areas that are most frequently used by the states. The top three SHSP emphasis areas are intersections (used by 44 states), pedestrians (used by 43 states), and bicyclists (used by 40 states).

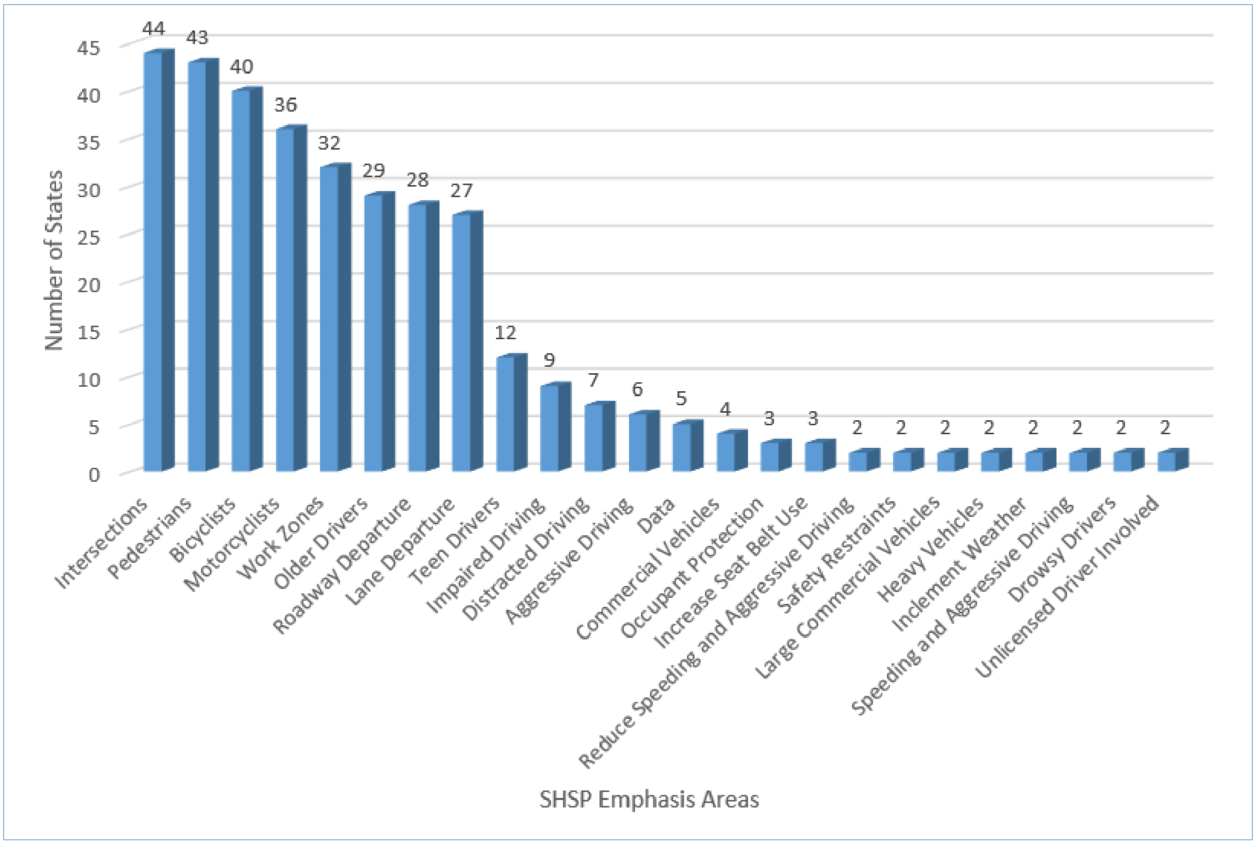


Figure 13. Most Frequently Used SHSP Emphasis Areas.

Figure 14 shows the number of SHSP emphasis areas by state. States reported from one (DC and West Virginia) to 31 (Utah) SHSP emphasis areas. Most states reported nine or fewer SHSP emphasis areas.

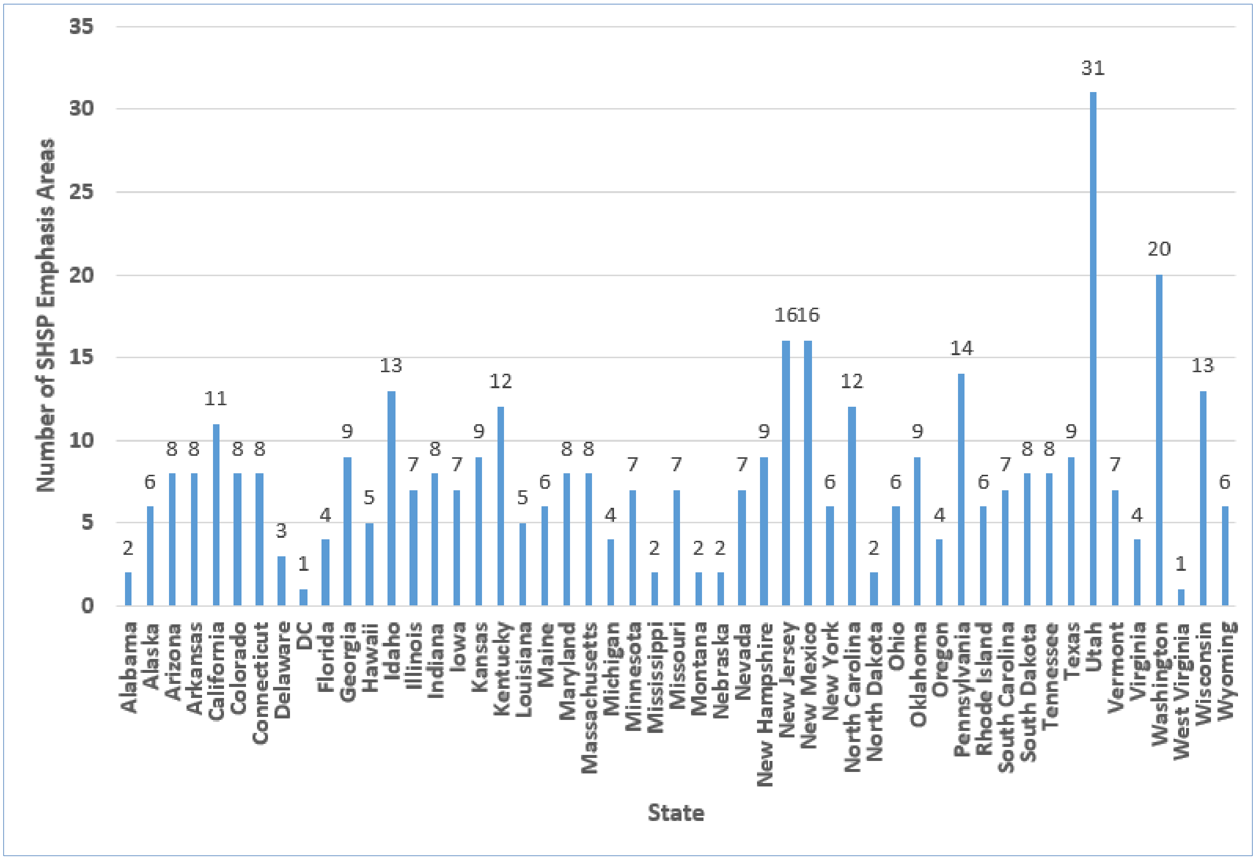


Figure 14. Number of SHSP Emphasis Areas by State.

3.3 STATE EVALUATION PRACTICES AND TOOLS

In 2016 and 2017, 25 and 27 states, respectively, provided evaluation data for completed HSIP projects in their annual HSIP reports (Table 10). In 2017, 16 states reported that they conducted countermeasure effectiveness evaluations. The research team expanded the review of state HSIP evaluation practices and tools by focusing on states that either provided evaluation data in their last two HSIP reports or those that have developed, presented, or published evaluation tools (e.g., New York). Table 10 lists these states along with the evaluation tools used, if any, by each agency.

Table 10. HSIP Evaluation Data Based on 2016 and 2017 HSIP Reports.

State	Number of Projects Evaluated [a, b]		Evaluation Tool[c]
	2016	2017	
Alabama	9	–	Spreadsheet
Alaska	19	11	Spreadsheet
Arizona	–	9	
Arkansas	3	4	
California	3	42	Spreadsheet
Colorado	1	1	Vision Zero Suite and Spreadsheet
Connecticut	1	–	
Delaware	–	23[a]	
District of Columbia	7	–	
Florida	69	1082	Crash Reduction Analysis System Hub (CRASH) system
Georgia	–	4	
Indiana	27	119	RoadHAT
Maine	26	21	Spreadsheet
Massachusetts	–	23	Spreadsheet
Minnesota	1[a]	–	
Mississippi	153	91	
Missouri	37	50	
Montana	–	12	Spreadsheet
Nebraska	5	5	
New Hampshire	16	22	
New Jersey	10	11	Spreadsheet
New York	–	–	Post Implementation Evaluation System (PIES)
North Carolina	1714[b]	1714[b]	Spreadsheet
Oregon	16	16	Spreadsheet
Pennsylvania	4	243	Spreadsheet
Rhode Island	3[a]	1[a]	
South Carolina	26	34	
South Dakota	5	2	In-house software
Tennessee	10	5	
Utah	–	11	
Virginia	93	28	
West Virginia	16	9	

[a] Some HSIP reports provide evaluation data for projects and/or countermeasures.
[b] Some HSIP reports provide historical evaluation data for projects/countermeasures that have been evaluated over a number of years, not during a single annual HSIP reporting cycle.
[c] The list of tools is not exhaustive and may not include proprietary software and tools that have not been documented, are not available online, or could not be shared with external entities.

Appendix B describes state evaluation practices and tools, if available, for the states listed in Table 10.

3.4 OTHER TOOLS

This section presents safety and cost-effectiveness evaluation tools developed by AASHTO and FHWA.

3.4.1 AASHTO—SafetyAnalyst

SafetyAnalyst is a suite of tools that implement the six steps of HSM's roadway safety management process: network screening, diagnosis, countermeasure selection, economic appraisal, priority ranking, and countermeasure evaluation (*20*). The countermeasure evaluation tool performs B/A evaluations of implemented safety improvements using the EB approach. The tool also provides users with a capability to evaluate shifts in proportions of collision types. Analyses can be performed to evaluate the effectiveness of individual countermeasures (or combinations of countermeasures) and construction projects. The user also has the option to conduct a B/C analysis to assess the economic benefits of a countermeasure or individual project. SafetyAnalyst was developed as a cooperative effort by FHWA and participating state and local agencies. The software is available for licensing as an AASHTOWare product.

3.4.2 FHWA—HSIP Evaluation Guide Supplemental Tool

In 2017, FHWA published a guide on HSIP evaluation (*6*), along with a companion spreadsheet template. The template is provided as a standalone Microsoft Office Excel file and serves as a resource to perform project- and countermeasure-level evaluations and also estimate sample size requirements for observational B/A evaluations. The template incorporates the following evaluation methods:

- Naïve B/A.
- Comparison group B/A.
- EB B/A.

Figure 15 shows data inputs and outputs of the simple B/A method. The green cells indicate the user inputs, while the yellow cells show the output. The users are assumed to input the observed B/A crashes, B/A traffic volumes, and number of B/A years.

Variable Inputs	Example Values (Table 11, pg 96)
Before Crashes (Nobserved,T,B)	18
Traffic Volume Before	7,500
Years Before	3
After Crashes (Nobserved,T,A)	10
Traffic Volume After	8,300
Years After	2
Number of count days to estimate AADT Before	365
Number of count days to estimate AADT After	365
r(d) [Years After/Years Before]	0.67
r(t) [Traffic After/Traffic Before]	1.11
Nexpected,T,A	13.28
Var(Nobserved,T,A)	10
v Before	2.12
v After	2.03
Var(r(t))	0.0011
Var(Nexpected,T,A)	9.95
CMF	0.71
Var(CMF)	0.08
SE(CMF)	0.28
User Input	
Calculated Output	

Figure 15. FHWA's HSIP Evaluation Template—Naïve B/A Evaluation (*6*).

Likewise, Figure 16 through Figure 18 show screenshots of three Excel sheets that can be used to apply the comparison group method, apply the EB method, and estimate the required sample size, respectively.

Variable Inputs	Example Values (Table 13, pg 98)
Treatment Group Before Crashes (Nobserved,T,B)	100
Treatment Group After Crashes (Nobserved,T,A)	75
Comparison Group Before Crashes (Nobserved,C,B)	84
Comparison Group After Crashes (Nobserved,C,A)	80
Nexpected,T,A	95.24
Var(Nobserved,T,A)	75
Var(Nexpected,T,A)	312.06
CMF	0.76
Var(CMF)	0.03
SE(CMF)	0.17
User Input	
Calculated Output	
Notes:	
1. Assumes before and after periods are the same for treatment and comparison group	

Figure 16. FHWA's HSIP Evaluation Template—Comparison Group B/A Evaluation (*6*).

Variable Inputs	Example Values (Table 15, pg 100)
Observed Before Crashes (Nobserved,T,B)	18
Observed After Crashes (Nobserved,T,A)	10
Predicted Before Crashes (Npredicted,T,B)	3.56
Predicted After Crashes (Npredicted,T,A)	4.40
Dispersion parameter (k)	0.24
SPF Weight (w)	0.54
Nexpected,T,B	10.22
Nexpected,T,A	12.62
Var(Nobserved,T,A)	10
Var(Nexpected,T,A)	90.63
CMF	0.51
Var(CMF)	0.13
SE(CMF)	0.36

→ Annual crashes are predicted for each year in the before period and summed

→ Annual crashes are predicted for each year in the after period and summed

$$SPF = \exp\left[-8.56 + 0.60 * \ln\left(AADT_{major\ road}\right) + 0.61 * \ln\left(AADT_{minor\ road}\right)\right]$$

Figure 17. Equation. Sample SPF for EB before-after evaluation.

SPF (before) = 1.187733

SPF (after) = 2.200035

User Input (green)

Calculated Output (yellow)

Notes:

1. Assumes SPF is developed and dispersion parameter is available for use in EB Method
2. Annual crashes are "predicted" using SPF and appropriate calibration factors

Figure 17. FHWA's HSIP Evaluation Template—EB B/A Evaluation (*6*).

Variable Inputs	Example Values (Table 16, pg 102)
Number of "before" crashes per year in treatment group	193
Number of "before" years	1
Number of "after" years	1
Number of "before" crashes per year in comparison group	193
Variance of odds ratio**	0.001
Desired level of significance (α)	0.1
Cumulative probability	1.64
Expected % reduction [100*(1-CMF)]	20
Number of "before" crashes in treatment group	193
Estimated number of "after" crashes in treatment group	154.4
Number of "before" crashes in comparison group	193
Estimated number of "after" crashes in comparison group	193
Estimated number of "after" crashes in treatment group without change	193
Estimate of the variance of crashes "after" without change	616.249
Estimated index of effectiveness [CMF]	0.8
Standard deviation of the estimated index of effectiveness [SE(CMF)]	0.121
Lower bound of confidence interval	0.6003
Upper bound of confidence interval	0.9997

User Input

Calculated Output

Instructions: Enter 4 input values. Examine standard deviation and confidence interval of index of effectiveness. Change inputs until desired level of precision is attained. If the number of before and after years is entered as "1", the OUTPUT provides the total number of crashes required in the before and after periods for both the treatment and comparison groups.

Assumptions:
1. Treatment and comparison groups have an equal number of crashes.
2. Duration of before and after periods are equal for the treatment and comparison groups.

Reference: For detailed explanation see Ezra Hauer, Observational Before-After Studies in Road Safety, Pergamon, 1997

**See section 9.3 of reference. If no information is available examine sensitivity to assuming values between 0.001 to 0.01

Figure 18. FHWA's HSIP Evaluation Template—Sample Size Estimation (*6*).

3.4.3 FHWA—Interactive Highway Safety Design Model

The Interactive Highway Safety Design Model (IHSDM) is a set of software tools that are programmed to evaluate the safety and operational implications of geometric design decisions on highways (*21*). By applying design guidelines and generalized data, IHSDM intends to predict the functionality of proposed or existing designs. IHSDM includes the following modules:

- Accident analysis.
- Design consistency.
- Intersection review.
- Driver/vehicle module.

- Traffic analysis.
- Policy review.

The facilities evaluated under these modules are the same as the facilities evaluated in HSM Part C:

- Two-lane rural highways.
- Multilane rural highways.
- Urban and suburban arterials.

IHSDM can be applied to analyze safety implications of preliminary construction plans and evaluate and prioritize safety improvements, relative safety impacts of alternative designs, and expected safety impacts of recently completed improvements.

3.5 EUROPEAN PRACTICES

European countries use the *Road Safety Manual* (RSM), the equivalent of the HSM, to identify and evaluate safety projects (*22*). The National Road Safety Council is a permanent body whose main tasks are to define the country's orientation regarding the roadway safety needs and provide coordinated actions at the national level. The components of the road safety program described in the RSM are similar to the steps of the HSM roadway safety management process (Table 11).

Table 11. Road Safety Program in Europe.

Road Safety Program Step	Description	Equivalent Step in Roadway Safety Management
Identification	Accident-based identification (i.e., performance measures); accident patterns; blackspot and other target identification	Network Screening
Diagnosis	Site history; site categorization; accident analysis; and site observations	Diagnosis
Priority Ranking	Determination of range of countermeasures; economic assessment; and preparation of priority listing	Countermeasure Selection Economic Appraisal Prioritization
Evaluation	Monitoring national targets by means of observations and behavioral studies; accident-based evaluation analysis (including with the graphical and statistical analysis); economic evaluation	Safety Effectiveness Evaluation

The evaluation methods included in RSM are divided into two categories: (a) observational and behavioral, and (b) crash-based. Behavioral studies examine changes in non-crash elements after the implementation of a countermeasure or program. In these studies, analysts monitor factors that are likely to affect road user safety. These elements include:

- Spot speed.
- Speed variance.
- Traffic conflicts.
- Traffic volumes.
- Travel time delay.
- Compliance with traffic control devices.
- Skid resistance.
- Sight distance.
- Pedestrian safety (gaps, delays, crossing times).

The crash-based studies in the RSM are similar to the HSM's predictive methods. The crash-based evaluation is conducted using cross-sectional (control sites) and B/A studies. In the cross-sectional analysis, the control sites are selected either by matched pairs or area controls. A matched pair control site involves finding a site that is geographically close to the treated site and has similar general characteristics. Although this is the preferred method, finding matching sites with similar safety problems might be difficult in practice. The control sites are assumed to have the following characteristics:

- Be as similar as possible to the treated site.
- Not affected by the safety treatment.
- Be more than the treated sites. The RSM proposes 10 matched sites; however, according to the PSM method, matching one treated site with four control sites usually produces reliable estimations.

The RSM proposes to account for several factors when using B/A analysis:

- The before and after periods should be identical when using control sites.
- The before period should be long enough to provide a good statistical estimate of actual safety trends.
- The after period should be (ideally) more than three years.

Similar to the HSM, the RSM recommends using the EB regression for safety effectiveness evaluation. Another evaluation method described in the RSM is B/A studies with a comparison (control) group. These two methods are similar to the HSM methods.

In addition to these methods, the RSM recommends using standard statistical tests for effectiveness evaluation:

- *Student t-test*—used to determine whether the mean of one set of measurements is significantly different than the other.
- *Kolmogorov-Smirnov test*—a two-tailed test used to determine whether two independent samples have been drawn from the same population.

- *K-test*—used to calculate the changes in the number of crashes at a particular site relative to a set of crash data from a control group of sites.
- *Chi-square*—used to determine whether changes in crash frequency in the before and after periods were due to a treatment or occurred by chance.

In the RSM, the economic effectiveness of a safety treatment or project accounts for the following factors:

- Initial engineering costs.
- Annual maintenance and operating costs.
- Terminal salvage value.
- Service life.
- Resulting changes in crash data and monetary values of different crash types. Since some countries might not have a reliable record of property-damage-only (PDO) crashes, the economic effectiveness accounts for changes in the number of fatal and injury crashes.
- Cost of side effects (e.g., increased fuel consumption).
- Discount rate.

The RSM uses various methods for conducting B/C analysis. Some of these methods are described below:

- *First year rate of return*—the net monetary value of savings and drawbacks incurred in the first year of the project. This evaluation criterion is not very rigorous since it does not account for maintenance costs after the first year; however, it is very simple to calculate.
- *Net present value*—the difference between discounted costs and benefits of the construction, which may extend over a number of years.
- *Internal rate of return* (of a treatment)—the discount rate that makes the net present value equal to zero. This type of evaluation is preferred by multilateral agencies because it avoids the use of local discount rates.

CHAPTER 4: DATA GATHERING AND ASSESSMENT

4.1 INTRODUCTION

This chapter provides a review and assessment of existing TxDOT datasets for use in HSIP evaluations. The chapter discusses data limitations and relevant considerations and provides strategies for improving existing TxDOT data. For the task described in this chapter, the research team performed the following activities:

- Determined data types needed to evaluate projects and countermeasures and identified existing TxDOT data sources that can potentially feed HSIP evaluations.
- Gathered and processed TxDOT data.
- Assessed TxDOT data and identified potential data limitations and opportunities for improvement.
- Assessed the applicability of evaluation methods and tools (those presented in the previous chapters) in Texas by taking into consideration the availability and potential limitations of TxDOT data.

4.2 TXDOT DATA SOURCES

The research team identified data types required to apply the evaluation methods presented in the second chapter. These data types are listed in the first column of Table 12. For each data type, the research team reviewed various TxDOT databases and, in consultation with project panel members, identified the databases (second column in Table 12) that contain relevant attributes that can feed HSIP evaluations.

Table 12. Data Needs and TxDOT Data Sources.

Required Data Type		TxDOT Data Source
HSIP project construction data	Highway name	• Category 8 (CAT8) project database • Design and Construction Information System (DCIS) • SiteManager
	Geographic coordinates and distance from origin (DFO)	• CAT8 project database • DCIS • Other district data
	Construction (start and end) dates	• SiteManager • Other district data
	Implemented work code(s)	• CAT8 project database • DCIS • Other district databases
	Construction cost	• SiteManager • Other district databases
Linear reference system (LRS) network and roadway data		• Road-Highway Inventory Network (RHiNo)
Traffic data		• RHiNo
Crash data		• Crash Record Information System (CRIS)
SPFs		• *TxDOT Roadway Safety Design Workbook*

The main TxDOT data sources include the CAT8 project database, DCIS, SiteManager, RHiNo, CRIS, and *Roadway Safety Design Workbook*. Further, additional data can be found in individual project files and local databases that some district offices maintain. The subsections that follow describe each TxDOT data source and the attributes extracted to perform the HSIP evaluations presented in Chapter 6.

4.2.1 CAT8 Project Database

Initially, TxDOT provided the research team with data for completed HSIP projects that were funded by the Hazard Elimination (HES) Program and the High Risk Rural (HRR) roads program (*23*).[2] TxDOT extracted the data from a local database maintained by the TRF Division. The database contains data for Category 8 projects. The initial dataset included attributes such as program year, project number, contract control section job (CCSJ), control section job (CSJ), district, county, priority highway/roadway, intersecting road, from, to, beginning DFO, ending DFO, length of project, type of work, program category, programmed construction amount, letting cost to program, total letting cost, estimated letting date, fiscal year, and safety improvement index (SII).

The initial dataset contained HSIP projects that were let between 2010 and 2016. Out of 2,053 records that were included in this dataset, 1,888 records had a single CSJ number and unique data for each HSIP project. Each of the remaining 165 records included aggregated data for two

[2] Both programs were part of TxDOT's HSIP and aimed to reduce the number and severity of crashes. The main difference between the HES and HRR programs is that the latter focused on paved roadways functionally classified as rural major, minor collectors, and rural local roads.

or more HSIP projects that had been grouped together. In other words, each of the 165 records had multiple CSJ numbers, but one CCSJ number, one project length, one letting cost, etc. The main reason for having aggregated project data in a single record is because some HSIP projects (e.g., rumble strip projects) may occasionally be grouped together in a single contract so that TxDOT receives a smaller number of bids that are easier to manage than receiving separate bids for each individual HSIP project.

The total number of grouped and not grouped HSIP projects that had a unique CSJ number was 2,281. Though most data attributes were complete, some important attributes required for HSIP evaluations (e.g., beginning DFO and ending DFO) had missing data. To find the missing data, the Texas A&M Transportation Institute (TTI) was given access to DCIS.

4.2.2 DCIS

DCIS is TxDOT's automated information system used for planning, programming, and developing projects (*24*). DCIS is an essential component in the preparation of construction projects for contract letting. Project information in DCIS includes work descriptions, funding requirements, dates for proposed activities, and so forth. TTI extracted all data attributes included in DCIS separately for each CSJ (2,281 CSJs in total).

The data extraction process included the following steps:

1. Log into the system's main menu, shown in Figure 19, and enter the CSJ number of each project.

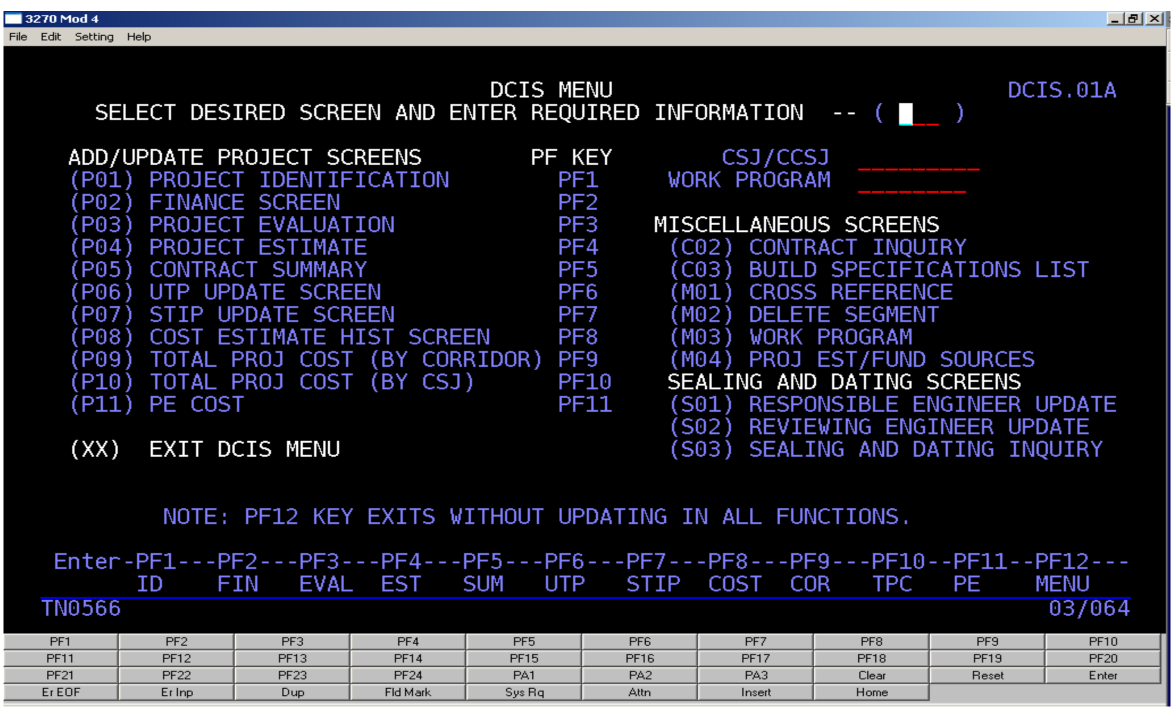


Figure 19. DCIS Main Menu.

The main menu provides links to 11 screens. Each screen contains different types of information and data, as briefly explained below:

- P01 Project identification screen: required to set up a project record (i.e., CSJ) in DCIS.
- P02 Project finance screen: contains financial information about the project.
- P03 Project evaluation screen: contains information that can be used for reporting and project evaluation purposes (e.g., proposed design speed; terrain; plans, specifications, and estimates percent complete; right-of-way percent complete; environmental process percent complete).
- P04 Project estimate screen: provides the itemized list of work-related construction line items (with unit bid price and quantities).
- P05 Contract summary screen: reflects whether a CSJ is to be let alone or with other CSJs in a contract.
- P06 Unified Transportation Program (UTP) update screen: allows for ad hoc reporting by the Design Division (DES) and the Transportation Planning and Programming Division (TPP) through the use of various report codes for both TxDOT divisions.
- P07 Statewide Transportation Improvement Program (STIP) update screen: allows users to update TIP information (i.e., project identifications data; TIP year; STIP revision date; funding broken down by local, state, federal, and contributions; etc.).
- P08 Cost estimate history screen: tracks project construction and right-of-way cost history. The construction and right-of-way cost estimates from the project identification (P1) screen, the scheduled UTP year, and current UTP date of approval will be captured. This information is also utilized for ad hoc reporting by both TPP and DES.
- P09 Total project cost (by corridor) screen: shows project costs separated by corridor if applicable. If this is not done, the DCIS home screen appears when the P09 screen is selected.
- P10 Total project cost (by CSJ) screen: shows an estimate of total project costs reflecting construction, preliminary engineering (survey and utilities), environmental documentation, potential construction change orders, and so forth.
- P11 Project engineer cost screen: shows the approximate professional engineering cost and references if designed in-house or by an engineering consultant.

2. Copy all data from each screen (separately for each CSJ) and paste them to a Microsoft Office Excel database. The database includes up to 1,128 lines of information and data for each CSJ.

3. Identify and further process the following data attributes needed for HSIP project evaluations:
    - CSJ number.
    - Project length.
    - Beginning DFO.
    - Ending DFO.
    - Limits from (description) to (description).
    - Beginning latitude.
    - Beginning longitude.
    - Ending latitude.
    - Ending longitude.

The CAT8 database and DCIS include data from the planning and letting phases of the project development process. SiteManager was used to extract project construction data.

4.2.3 SiteManager

SiteManager (SM) is TxDOT's official project construction database (*25*). TxDOT extracted and provided TTI with 88 SM data attributes for 1,228 HSIP projects (1,172 on-system and 56 off-system projects) funded through the HES and HRR programs. The attributes contained information about contract dates, project location, bid price adjustments, approved change orders, contract discrepancy options, contractor payments, performance dates, and project construction status. The SM attributes needed for HSIP evaluations were the following:

- [Date Work Began]: Indicates the project construction start date.
- [Date Work Accepted]: Reflects the project construction end date. Note that TTI also considered using attribute [Physical Work Complete Date] as the end date of project construction; however, of 1,228 projects, only 395 projects had a valid non-missing [Physical Work Complete Date]. On the other hand, attribute [Date Work Accepted] had a valid date for 1,010 projects. The average difference ([Physical Work Complete Date] − [Date Work Accepted]) was 164 days. It is worth noting that in line with guidelines (*2*, *6*), TTI considered the first 90 days following the end of project construction as the period that drivers need to adjust to new roadway conditions, after a treatment has been implemented. This 90-day period was excluded from the HSIP project evaluations that are presented in Chapter 6.
- [Total Amount Paid to Contractor]: Captures the construction cost of a project.

4.2.4 RHiNo

RHiNo is TxDOT's roadway inventory that is exported from the Geospatial Roadway Inventory Database (GRID) (*26*). RHiNo includes the Texas LRS network and roadway data that are necessary to geolocate HSIP projects and crashes and identify roadway design characteristics that are used as inputs in certain evaluation methods (e.g., EB method). RHiNo contains a series of attributes that are categorized as follows:

- Roadway identification/referencing attributes (e.g., record type, roadbed identifier, highway name, DFOs, control sections, milepoints, etc.).
- Geographic attributes (e.g., district, county, city, rural urban code).
- Administrative attributes (e.g., administrative system, functional classification, etc.).
- Operational attributes (e.g., highway status, speed limit, etc.).
- Physical and cross-section attributes (e.g., number of lanes, acceleration-deceleration lane, climbing passing center-turning lane, surface width, inside and outside shoulder width, inside and outside shoulder type, etc.).
- Traffic attributes (e.g., current and historical annual average daily traffic [AADT] values, truck AADT, etc.).
- Highway performance monitoring system (HPMS) attributes (e.g., physical roadbed, HPMS volume group, left turn lane, traffic signal type, lane width, etc.).

TTI used ArcGIS to geolocate HSIP projects in RHiNo. First, researchers mapped the start and end point of each segment using the geographic coordinates (beginning latitude/longitude and ending latitude/longitude) extracted from DCIS. The points were mapped using the ArcGIS tool *Display XY Data*. Then, for each start and end point, a DFO was extracted from RHiNo using the ArcGIS tool *Locate Features Along Routes*. TTI created a line feature containing HSIP projects using the tool *Display Route Events*. The inputs to this tool were the highway name, the beginning DFO, and the ending DFO of each project. TTI then visually inspected whether each project was correctly mapped on the network using aerial images and online street maps.

For each HSIP project, TTI extracted the RHiNo attributes shown in Table 13. These attributes were used to evaluate HSIP projects and countermeasures (see Chapter 6).

Table 13. RHiNo Attributes Needed for HSIP Evaluations.

Attribute Name	Attribute Description	Attribute Needed to Evaluate Segments and/or Intersections
[ADT_YEAR]*	Year of most current annual average daily traffic value	Segment/Intersection
[ADT_CUR]*	Most current annual average daily traffic value	Segment/Intersection
[ADT_HIST_YR]*	[ADT_YEAR] minus one	Segment/Intersection
[HY_1]* through [HY_9]*	Historical ADT values ([HY_1] corresponds to year [ADT_HIST_YR])	Segment/Intersection
[RU_F_SYSTEM]+	Rural/urban designation and functional class of a road	Segment/Intersection
[NUM_LANES]+	Number of through lanes	Segment/Intersection
[MED_TYPE]+	Type of median	Segment
[NBR_SGNL]+	Count of signalized at-grade intersections	Intersection
[NBR_STOP_SIGN]+	Count of at-grade intersections with stop signs	Intersection
[MED_WID]	Median width (feet)	Segment/Intersection
[LANE_WIDTH]	Lane width (feet)	Segment/Intersection
[S_WID_I]	Inside shoulder width (feet)	Segment/Intersection
[S_WID_O]	Outside shoulder width (feet)	Segment/Intersection
[LT_TURN_LANE]	Left turn lane	Intersection

* Required attribute.
\+ Attribute is required to determine an SPF, which is used only in the EB method.

4.2.5 CRIS

CRIS is TxDOT's official crash database that contains over 150 attributes. The attributes are divided into three major groups:

- Crash event and roadway characteristics.
- Primary person characteristics.
- Vehicle (unit) characteristics.

The attributes extracted from CRIS included the following: crash ID, severity, TxDOT district, county, highway, DFO, date, time, year, latitude, longitude, functional system, on-system flag, bridge detail, surface condition, weather condition, light condition, road part, manner of collision, first harmful event, object struck, roadway related, intersection related, crash contributing factors, vehicle unit number, and vehicle direction of travel.

TTI used the highway name, the geographic coordinates, and the road part of each crash for geolocation purposes. Most of the remaining attributes were used to determine whether each crash could theoretically be prevented by implementing various WCs. For this determination, TTI used information and data found in the TxDOT *HSIP Work Codes Table* (*27*), which includes 98 WCs that are grouped into five general categories:

- 100 Signing and Signals.
- 200 Roadside Obstacles and Barriers.
- 300 Resurfacing and Roadway Lighting.
- 400 Pavement Markings.
- 500 Roadway Work.

For each WC, the document provides a WC description, reduction factor, service life (years), maintenance cost (if available), and preventable crash criteria. These criteria are based on the crash attributes stated above. For example, the preventable crash criteria for WC 105 *Install Intersection Flashing Beacon* are [Intersection Related] = (intersection or intersection related). The preventable crash criteria for WC 304 *Safety Lighting* are [Light Condition] = (dark not lighted or dark lighted or dark unknown lighting).

If the preventable crash criteria of a WC were met for a specific crash, then TTI considered the crash to be a "target" crash for that particular WC. The HSIP evaluations conducted in this study (see Chapter 6) were performed for all crashes and target crashes separately.

4.2.6 TxDOT Roadway Safety Design Workbook

Some evaluation methods such as the EB method require SPFs and CMFs. Though many organizations (e.g., AASHTO) and research projects (e.g., NCHRP projects) have developed SPFs and CMFs using data from various states, the general guideline is to develop or calibrate SPFs and CMFs using local data (*2*). The TxDOT *Roadway Safety Design Workbook* provides several SPFs and CMFs developed specifically for Texas (*28*). The SPFs included in the workbook can be used to predict the number of KABC crashes for different facility types such as interstates, freeways and expressways, rural highways, urban and suburban arterials, interchange ramps, rural intersections, and urban intersections.

The research team reviewed the SPFs included in *Roadway Safety Design Workbook* and determined those that could be calculated using existing TxDOT data and those that could not be calculated because certain data inputs are not currently available at TxDOT. Further, researchers identified the roadway functional class that best matched the roadway type and the characteristics associated with each SPF. Table 14 summarizes the results of this assessment. Appendix C provides in detail all data inputs and SPFs that could and could not be calculated using existing TxDOT data.

Table 14. Applicability and Characteristics of SPFs Provided in *Roadway Safety Design Workbook* (*28*).

Functional Class	Roadway Characteristics of Available SPFs	Applicability
U1—Urban Interstates U2—Urban Other Freeways and Expressways	4 lanes 6 lanes 8 lanes 10 lanes	Limited (crash frequency for ramps is needed)
U3—Urban Other Principal Arterials U4—Urban Minor Arterials U5—Urban Major Collectors	2 lanes, undivided median 2 lanes, nonrestrictive median 4 lanes, undivided median 4 lanes, nonrestrictive median 4 lanes, restrictive median 6 lanes, nonrestrictive median 6 lanes, restrictive median	Limited (land use data, number of driveways, and curb miles are needed)
U6—Urban Minor Collectors U7—Urban Local Roads	No SPF provided	No
R1—Rural Interstates R2—Rural Other Freeways and Expressways	4 lanes 6 lanes	Limited (ramp crash frequency is needed)
R3—Rural Other Principal Arterials	2 lanes 4 lanes, undivided median 4 lanes, nonrestrictive median 4 lanes, restrictive median	Limited (land use data and number of driveways are needed)
R4—Rural Minor Arterials R5—Rural Major Collectors	2 lanes, undivided median 2 lanes, nonrestrictive median 4 lanes, undivided median 4 lanes, nonrestrictive median 4 lanes, restrictive median 6 lanes, nonrestrictive median 6 lanes, restrictive median	Limited (land use data, number of driveways, and curb miles are needed)
R6—Rural Minor Collectors R7—Rural Local Roads	No SPF provided	No

Note that the *Roadway Safety Design Workbook* SPFs have been developed and are appropriate for predicting the number of KABC crashes only; however, the goal of the HSIP is to reduce KAB crashes. The *Roadway Safety Design Workbook* does not provide SPFs for the lower functional classes of 6 (minor roads) and 7 (local roads). Certain data inputs (e.g., number of driveways) required for some SPFs are not currently available in existing TxDOT databases (RHiNo) but can be collected in the field or by using aerial and street view images. In addition, the SPFs were developed several years ago and need to be calibrated for current conditions.

4.2.7 Other District Data

Additional construction data may be entered and stored in local databases and files that district offices maintain. The management and administration of construction data vary from one district to another. For example, the Dallas District's construction office tracks all construction projects, including HSIP projects, through the DALNET Construction Database (Figure 20). Some of the information in this database is manually entered from various information management systems such as DCIS and SiteManager. The district updates each project's information by the 10th of each month for project managers and area office/district engineers to review; thus, it is termed the "10th Report." This database can be used to generate a district project sheet for each HSIP project based on its CSJ number. Figure 21 shows a sample district project sheet that was extracted from SiteManager (*25*). The sheet contains several data attributes such as CSJ number, start-end construction dates, final project limits, and construction cost.

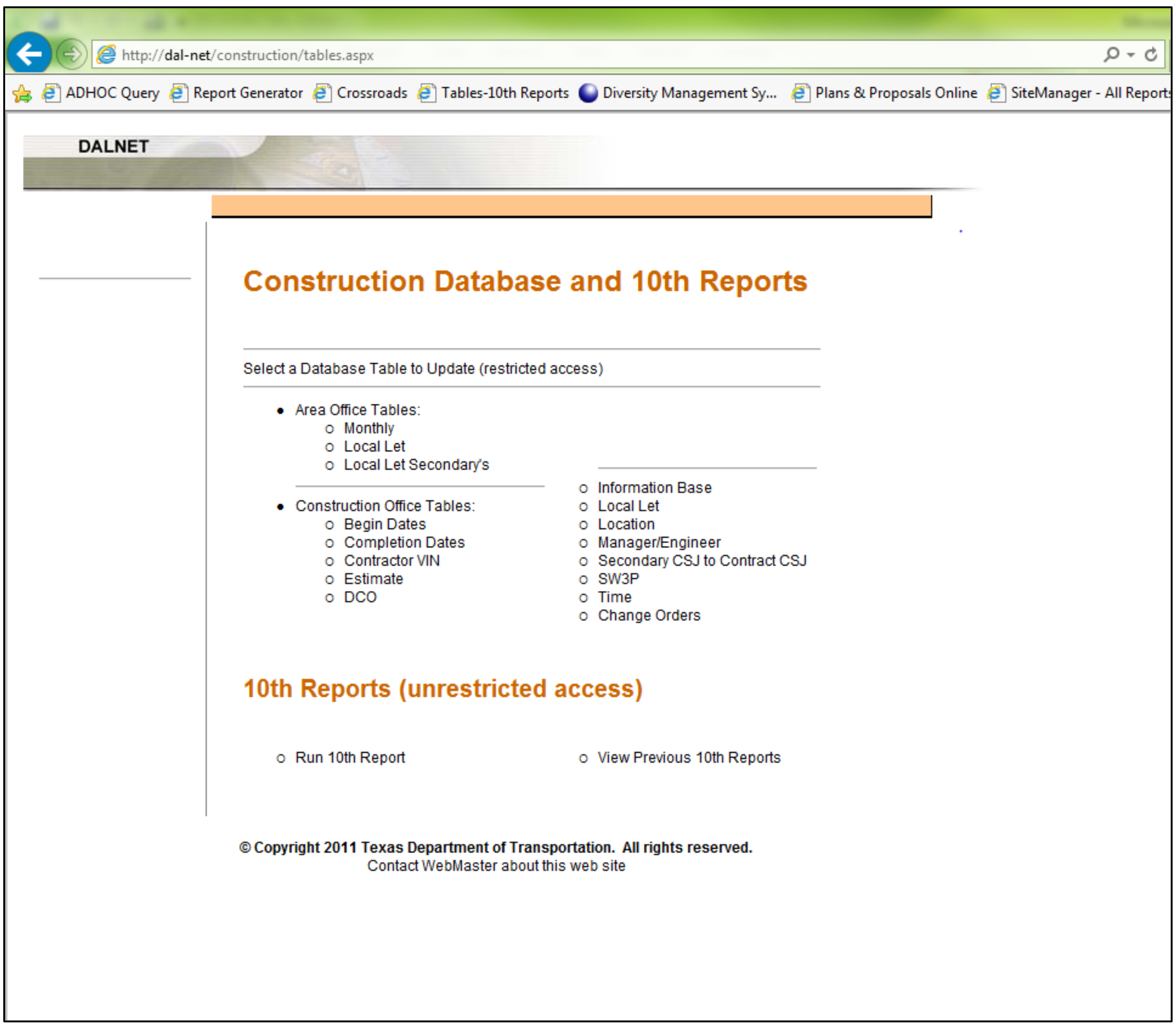
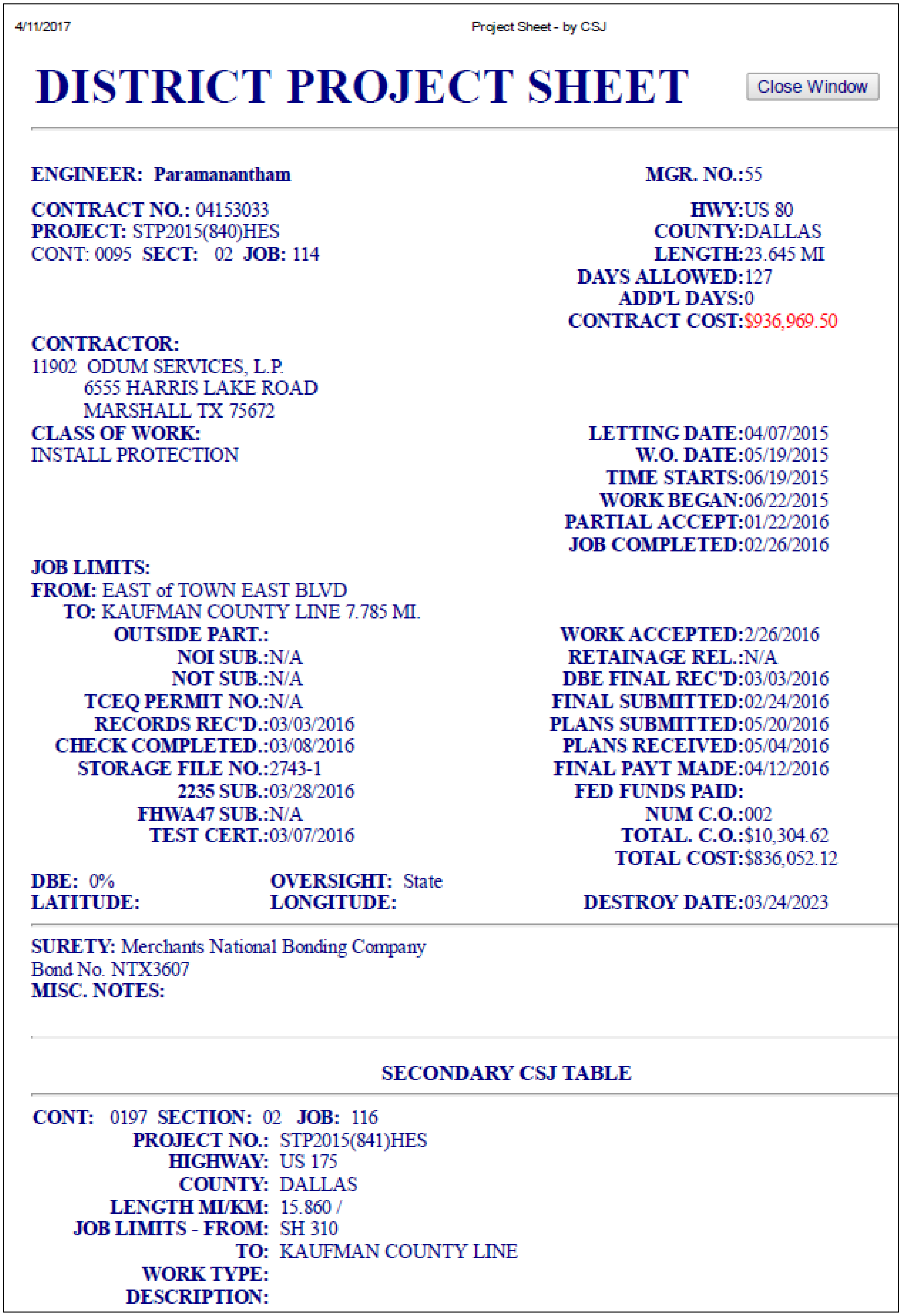


Figure 20. Dallas DALNET Construction Database.



4/11/2017 Project Sheet - by CSJ

DISTRICT PROJECT SHEET

Close Window

ENGINEER: Paramanantham

MGR. NO.:55

CONTRACT NO.: 04153033
PROJECT: STP2015(840)HES
CONT: 0095 **SECT:** 02 **JOB:** 114

HWY:US 80
COUNTY:DALLAS
LENGTH:23.645 MI
DAYS ALLOWED:127
ADD'L DAYS:0
CONTRACT COST:$936,969.50

CONTRACTOR:
11902 ODUM SERVICES, L.P.
6555 HARRIS LAKE ROAD
MARSHALL TX 75672

CLASS OF WORK:
INSTALL PROTECTION

LETTING DATE:04/07/2015
W.O. DATE:05/19/2015
TIME STARTS:06/19/2015
WORK BEGAN:06/22/2015
PARTIAL ACCEPT:01/22/2016
JOB COMPLETED:02/26/2016

JOB LIMITS:
FROM: EAST of TOWN EAST BLVD
TO: KAUFMAN COUNTY LINE 7.785 MI.
OUTSIDE PART.:
NOI SUB.:N/A
NOT SUB.:N/A
TCEQ PERMIT NO.:N/A
RECORDS REC'D.:03/03/2016
CHECK COMPLETED.:03/08/2016
STORAGE FILE NO.:2743-1
2235 SUB.:03/28/2016
FHWA47 SUB.:N/A
TEST CERT.:03/07/2016

WORK ACCEPTED:2/26/2016
RETAINAGE REL.:N/A
DBE FINAL REC'D:03/03/2016
FINAL SUBMITTED:02/24/2016
PLANS SUBMITTED:05/20/2016
PLANS RECEIVED:05/04/2016
FINAL PAYT MADE:04/12/2016
FED FUNDS PAID:
NUM C.O.:002
TOTAL. C.O.:$10,304.62
TOTAL COST:$836,052.12

DBE: 0% **OVERSIGHT:** State
LATITUDE: **LONGITUDE:** **DESTROY DATE:**03/24/2023

SURETY: Merchants National Bonding Company
Bond No. NTX3607
MISC. NOTES:

SECONDARY CSJ TABLE

CONT: 0197 **SECTION:** 02 **JOB:** 116
PROJECT NO.: STP2015(841)HES
HIGHWAY: US 175
COUNTY: DALLAS
LENGTH MI/KM: 15.860 /
JOB LIMITS - FROM: SH 310
TO: KAUFMAN COUNTY LINE
WORK TYPE:
DESCRIPTION:

Figure 21. Example of District Project Sheet Extracted from TxDOT (*25*).

The Waco District enters basic project information into SiteManager at contract initiation. The information is entered by an auditor in the district construction office and verified by the lead auditor. The lead auditor uses monthly reports to monitor project progress and close out projects. The district has developed performance and issue tracking dashboards that are updated by the area offices monthly to track project progress (scope creep, schedule creep, etc.) and monitor potential issues in ongoing projects, as shown in Figure 22 and Figure 23, respectively.

CSJ	Hwy	Current Paid to Date	Original Contract Days	Current Days Charged to Date	Days Added	% Work Complete Cost Basis	% Complete Time	% Scope Growth	%Schedule Growth	Work Complete vs Time
0014-08-084	IH-35 (MISC PVMT REP)	$778,637.91	60	42	0	96.08%	70.00%	0.12%	0.00%	26.08%
0015-01-229	IH-35 (4A)	$29,022,079.03	459	1,044	459	94.73%	227.45%	13.64%	100.00%	-132.72%
0015-01-243	IH-35 (4B)	$23,520,328.46	1,150	22	0	6.68%	1.91%	3.13%	0.00%	4.77%
0055-08-099	US 84 SPEEGLEVILLE	$14,003,214.27	595	293	4	66.07%	49.24%	2.95%	0.67%	16.82%
0055-08-119	US 84	$2,723,961.08	90	75	10	54.53%	83.33%	5.80%	11.11%	-28.80%
0120-05-025	FM 218	$512,475.96	90	60	0	89.17%	66.67%	0.50%	0.00%	22.50%
0209-01-063	SL 2 (18th St)	$0.00	30	0	0	0.00%	0.00%	1.61%	0.00%	0.00%
0209-07-045	FM 933	$1,005,029.58	120	135	19	94.92%	112.50%	2.44%	15.83%	-17.58%
0258-09-111	LP 340 OLD ROBINSON	$22,903,563.50	701	706	10	98.66%	100.71%	3.69%	1.43%	-2.05%
0258-09-124	LP 340 SH6 BRAZOS	$15,771,259.80	617	582	1	102.64%	94.33%	4.29%	0.16%	8.31%
0833-03-035	FM 1637	$29,110,907.55	574	644	53	101.64%	112.20%	2.89%	9.23%	-10.55%
0833-03-036	FM 1637	$6,567,674.74	425	250	5	55.10%	58.82%	3.76%	1.18%	-3.72%
0834-04-024	FM 308	$1,040,881.17	192	216	0	81.78%	112.50%	1.11%	0.00%	-30.72%
0909-00-049	ADA RAMPS	$1,376,445.05	198	206	0	82.54%	104.04%	1.21%	0.00%	-21.50%
0909-22-176	CR 790 (Crunk Rd)	$0.00	150	0	0	0.00%	0.00%	0.79%	0.00%	0.00%
1192-01-024	FM 939	$540,873.31	240	30	0	8.30%	12.50%	1.29%	0.00%	-4.20%
2362-01-036	LP 340	$2,195,497.27	60	64	7	99.34%	106.67%	5.16%	11.67%	-7.33%

Figure 22. Waco Performance Tracking Dashboard.

Current Date	6/18/2019						
Project	**Roadway**	**Contractor**	**Notification Date**	**Response Critical Date**	**Days to Reponse Need**	**Brief Description**	**Issue Type**
0015-01-229	IH-35	James Const	8/25/17	10/1/17	-625	Revised Drainage Sheets	Change Order
0015-01-229	IH-35	James Const	12/20/17	2/1/18	-502	Peach St Storm Drain ATT Conflict	Change Order
0015-01-229	IH-35	James Const	2/26/18	4/1/18	-443	Adjustment Inlet NA 35	Change Order
0015-01-229	IH-35	James Const	1/4/19	2/1/19	-137	Addition of Chain Link Gate	Change Order
0015-01-229	IH-35	James Const	2/6/19	4/1/19	-78	IH-35 4A Scope Deletion CO	Change Order
0015-01-229	IH-35	James Const	2/6/19	4/1/19	-78	TRACC and Power Pole Dmg Rep	Change Order
0258-09-124	LP 340	J.D. Abrams	10/5/18	4/1/19	-78	Flexible Pvmt Str Rep	Change Order
0833-03-036	FM 1637	Big Creek	4/5/19	6/1/19	-17	Add cross drainage @ Pigeon Forge	
0055-08-099	US 84	Big Creek	2/1/19	6/25/19	7	TCP Revisions	Change Order
0014-08-084	Various	Texas Materials	4/8/19	6/25/19	7	Replace Intersection Detectors	Change Order
2362-01-036	LP 340	Knife River	4/8/19	6/25/19	7	Move Traffic Sign	Change Order
1192-01-024	FM 939	Knife River	5/10/19	6/25/19	7	Addl Work Culvert #16	Change Order
0055-08-099	US 84	Big Creek	5/30/19	6/25/19	7	Add DAT Item for Detour	Change Order
0833-03-036	FM 1637	Big Creek	5/28/19	6/25/19	7	Overweight Permits	RFI
2362-01-036	LP 340	Knife River	5/28/19	6/25/19	7	Relocate small sign assm price	Misc Submittal
2362-01-036	LP 340	Knife River	6/7/19	6/25/19	7	Possible intersection config changes at	
1192-01-024	FM 939	Knife River	5/1/19	6/25/19	7	Revise Base Item (RDWY CY to TON)	Change Order
0258-09-111	LP 340	Big Creek	5/6/19	6/30/19	12	Add Boring: Replace Electrical	Change Order
0014-08-084	Various	Texas Materials	3/1/19	8/1/19	44	Milled out Loop Detectors	Change Order

Figure 23. Waco Issue Tracking Dashboard.

The San Antonio District uses SiteManager to report payments, keep diaries, and store project information. Each area office enters payments and daily project information into SM, as needed. The San Antonio District construction office uses various reports from SiteManager (Figure 24) to build custom monthly diagnostic reports with information useful to the district for managing its construction jobs, such as the ones shown in Figure 25.

SiteManager Reports

Category	Title	Description	Database	Parameters	Modified
Items	Change Order Item Report	Displays all change orders and change order items for a given CSJ.	SMGRPRD	CSJ	February 9, 2018
Approval	Pending Change Order Approver	Displays all pending change orders and the queued approver.	DSS	Auto-Refresh	February 9, 2018
Items	Change Order-Daily Work Report (DWR) & Estimate Auditing Tool	Displays all contract items and associated change orders. Used to check if a change order item has a corresponding Daily Work Report (DWR).	DSS	CSJ	February 9, 2018
Summary	Statewide Change Order: Reason, Frequency, and Cost Report	The Statewide Change Order: Reason, Frequency, and Cost Report displays change orders grouped by reason code. It also displays the percent of occurrence for each reason code.	Production	Date Range	February 9, 2018
Items	Change Order Report	The Change Order Report displays change order details. This report is used for approval signatures.	Production	CSJ and Change Order Number	February 9, 2018
Summary	Change Order Summary by District	The Change Order Summary by District displays the number of change orders and total dollar amount per district for by requested date	Production	Date Range	February 9, 2018

Figure 24. SiteManager Reports.

SAT Construction Monthly Report
April 2019

Type of Work	Location Description 1	Location Description 2	Area Engineer	Date Let	Bid Days	Days Charged	PCT Comp (Time)
SEAL COAT	GUADALUPE COUNTY LINE	1.2 MILES SOUTH OF LP 337	Christen Longoria, P.E.	10/03/2017	100	36	36.00
SEAL COAT	0.4 MILES SW OF KRUEGER CANYON	IH 35	Christen Longoria, P.E.	10/02/2018	135	0	0.00
	ATASCOSA/BEXAR COUNTY LINE	ATASCOSA/MEDINA COUNTY LINE	Christen Longoria, P.E.	03/06/2019	345	0	0.00
REHABILITATION OF EXISTING ROAD	FM 3352	FM 462	Christen Longoria, P.E.	05/01/2018	358	126	35.20
	FM 140	US 57	Christen Longoria, P.E.	05/08/2019	303	0	0.00
SEAL COAT	ATASCOSA C/L	FM 463	Christen Longoria, P.E.	10/05/2016	65	65	100.00
REHABILITATION OF EXISTING ROAD	IH 35	BI 35D	Christen Longoria, P.E.	01/09/2019	105	0	0.00
RESTORATION	US 281	IH 37	Christen Longoria, P.E.	08/09/2017	308	286	92.86
REHABILITATION OF EXISTING ROAD	0.8 MI S OF FM 476	US 281	Christen Longoria, P.E.	06/05/2018	278	100	35.97
REHABILITATION OF EXISTING ROAD	0.6 MILES EAST OF BURNETT AVE	SH 16	Christen Longoria, P.E.	05/05/2015	339	742	206.69
REHABILITATION OF EXISTING ROAD	FM 140	0.6 MILES EAST OF BURNETT AVE	Christen Longoria, P.E.	08/05/2015	417	784	184.47
REHABILITATION OF EXISTING ROAD	2.6 MILES NORTH OF MCMULLEN C/L	9.0 MI NORTH OF MCMULLEN C/L	Christen Longoria, P.E.	09/02/2015	451	722	160.09
WIDEN NON-FREEWAY	MCMULLEN/ATASCOSA C/L	2.6 MI N. OF MCMULLEN/ATASCOSA C/L	Christen Longoria, P.E.	08/08/2017	185	198	90.83
WIDEN NON-FREEWAY	LASALLE COUNTY LINE	ATASCOSA COUNTY LINE	Christen Longoria, P.E.	06/07/2017	312	273	86.94
REHABILITATION OF EXISTING ROAD	0.1 MILES NORTH OF CR 5710	SH 132	Christen Longoria, P.E.	07/11/2018	109	90	82.57
REHABILITATION OF EXISTING ROAD	SH 97	SH 16	Christen Longoria, P.E.	09/06/2018	354	98	28.49
REHABILITATION OF EXISTING ROAD	FM 1332	MCMULLEN/ATASCOSA COUNTY LINE	Christen Longoria, P.E.	08/08/2018	356	120	33.71
REHABILITATION OF EXISTING ROAD	ATASCOSA/MCMULLEN COUNTY LINE	SH 72 E	Christen Longoria, P.E.	12/06/2018	359	0	0.00
REHABILITATION OF EXISTING ROAD	SH 72 EAST	DUVAL COUNTY LINE	Christen Longoria, P.E.	07/10/2018	524	114	21.76
BRIDGE REPLACEMENT	AT ATASCOSA RIVER	.	Christen Longoria, P.E.	05/02/2018	252	98	38.89
REHABILITATION OF EXISTING ROAD	SH 16	LA PARITA CREEK	Christen Longoria, P.E.	10/02/2018	358	65	18.16
REHABILITATION OF EXISTING ROAD	CR 433	CASTRO AVENUE	Christen Longoria, P.E.	03/06/2018	257	173	67.32
MISCELLANEOUS CONSTRUCTION	VARIOUS LOCATIONS IN ATASCOSA,	FRIO & MEDINA COUNTIES	Christen Longoria, P.E.	05/01/2018	193	100	51.81
BRIDGE REPLACEMENT	ON CR 324 0.5 MI W OF SH 16	AT GOOSE CREEK	Christen Longoria, P.E.	03/05/2019	153	0	0.00
	CR 422 @ LA PARITA CREEK	.	Christen Longoria, P.E.	05/07/2019	102	0	0.00
BRIDGE REPLACEMENT	ON DERBY RD AT BUCK CREEK	.	Christen Longoria, P.E.	02/05/2019	72	0	0.00
BRIDGE REPLACEMENT	CR 511 @ DRAW	.	Christen Longoria, P.E.	09/06/2018	78	60	76.92
BRIDGE REPLACEMENT	4.1 MI SW OF FM 471	.	Christen Longoria, P.E.	07/12/2017	64	108	125.58

Figure 25. San Antonio Monthly Diagnostic Report.

The Fort Worth District uses Microsoft Access to enter and update construction information, as shown in Figure 26 and Figure 27. The database is maintained by the district's administrative assistant and is updated as events happen (e.g., letting, work initiation, etc.). This information is available to everyone within the district. Pertinent information required by SiteManager is entered by the area office record keeper or the district's construction office auditor, as needed.

Figure 26. FTW Construction Database.

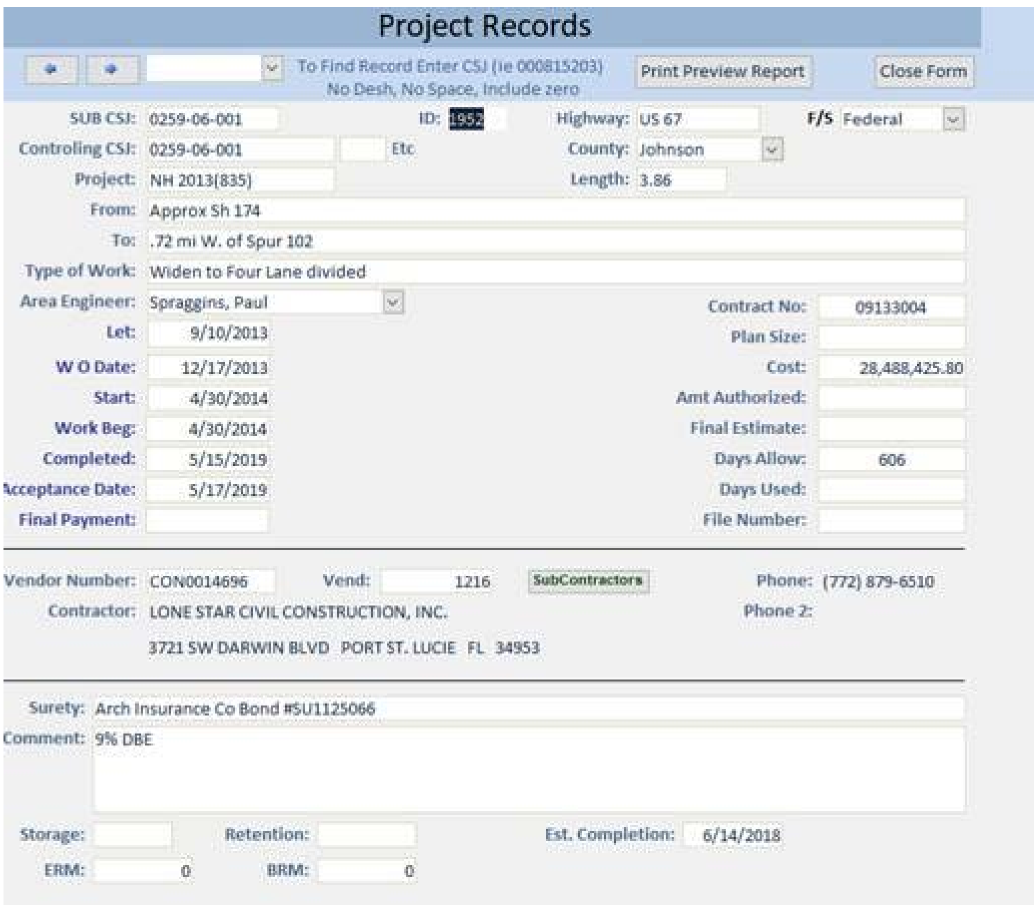


Figure 27. FTW Construction Project Records.

4.3 DATA ASSESSMENT AND CONSIDERATIONS

The purpose of the data assessment was to determine the completeness and potential limitations of existing TxDOT data, identify opportunities for improvement, and determine which evaluation methods and tools can be applied in Texas.

The first step of the assessment was to compile all TxDOT HSIP project data into a master Excel spreadsheet. TTI used CSJ number as the primary data attribute to join the various data tables. After developing the master spreadsheet, the research team determined the number and percent of missing data in each data attribute (Table 15). Other attributes not shown in Table 15 (e.g., highway name, implemented work codes, etc.) did not have missing data.

Table 15. Missing Data and Other Data Considerations.

Data Consideration	Number of Projects	Percent of All (2,281) Projects
Missing start date (field [Date_Work_Began] from SiteManager)	1,577	69%
Missing end date (field [Date_Work_Accepted] from SiteManager)	1,593	70%
Missing start date or end date (from SiteManager)	1,594	70%
Missing construction cost (field [Total_Amount_Paid_to_Contractor] from SiteManager)	1,576	69%
Missing beginning coordinates (from DCIS)	361	16%
Missing ending coordinates (from DCIS)	367	16%
Multiple projects (CJSs) merged into a single contract (from CAT8 database)	393	17%
Project construction start date prior to 1/1/2011	99	4%

The main observations from Table 15 are discussed below:

- *Significant amount of missing SiteManager data*. Missing construction dates and costs in SiteManager are the main reasons for not being able to evaluate the effectiveness of around 70 percent of all (2,281) HSIP projects that TxDOT initially retrieved from the CAT8 database. To evaluate more HSIP projects in the future, TxDOT needs to search for missing data in local files and databases that some districts maintain. Moving forward, one strategy to address this data limitation is to require all districts to upload to

SiteManager, at a minimum, the construction (start and end) dates and cost of each individual project.

- *Missing coordinates in DCIS*. Around 16 percent of all projects did not have geographic coordinates in DCIS. One strategy to address this data limitation is to require all districts to upload the coordinates of each project to a central database (e.g., DCIS, SiteManager).
- *Lack of disaggregated project-specific data for 393 HSIP projects*. The second to last row in Table 15 shows that 17 percent of all projects had been grouped with other projects, and the CAT8 database provided aggregated data for each group rather than for each individual project. Due to the absence of disaggregated data, these projects were not evaluated in this study. Similar to the strategy above, project-specific data need to be stored for evaluation purposes.
- *Short before periods, particularly for HSIP projects constructed prior to 2011*. Crash data from 2003–2009 are stored in historical Microsoft Access databases that have a significant amount of missing data, such as geographic coordinates. Further, there are several differences between the historical crash databases and CRIS in regard to data attributes, data definitions, data format, and database structure. These differences can create several challenges when data from both databases need to be combined and analyzed. The general strategy is to minimize, to the extent possible, the use and analysis of data from both databases by ideally focusing only on CRIS data (2010–present), which are generally more complete and accurate than historical crash records. For example, the last row in Table 15 shows that the construction of 99 HSIP projects (4 percent) started prior to January 1, 2011, which means that the before period for which CRIS data are available is short and generally not recommended to be used in safety effectiveness evaluations (*2*). These projects were excluded from further analysis. Although some methods can be used to overcome this challenge, it is generally recommended to use safety data (crash and traffic data) for three to five years in the before period and three to five years after construction to increase the sample size, and hence the reliability of the results. It is preferred to use the same duration for both periods. If different durations are used, the analyst needs to normalize the performance measures by comparing crashes per year, rather than the total number of crashes before and after.

In addition, TTI identified other relevant challenges and data considerations that can potentially affect the quality and reliability of HSIP evaluations. For each challenge/consideration, TTI developed appropriate strategies for improvement.

- *Difficulty in geolocating frontage road crashes*. CRIS typically maps frontage road crashes to the centerline of freeway and expressway mainlanes. The CRIS attribute [Road Part] can be used to separate frontage road crashes from mainlane crashes. However, frontage roads often exist on both sides of mainlanes (left and right), so it is difficult to determine whether a crash happened on the left or the right frontage road. To overcome this challenge, analysts need to examine the following: (a) direction of vehicles involved in each crash; (b) direction of adjacent roadway segments; (c) crash narrative; (d) crash diagram; (e) crash DFO; (f) traffic control devices, if any, on frontage roads; and (g) aerial and street images (e.g., Google maps and street view). A long-term strategy moving forward is to determine accurate crash coordinates based on which crashes are snapped onto the centerline of the correct (right or left) frontage road, not the centerline of mainlanes.

- *Crash DFOs generated from an unknown version of RHiNo resulting in inaccurate crash geolocation*. RHiNo is the underlying LRS in CRIS based on which crash DFOs are extracted. CRIS does not store the version of RHiNo that was used to extract the DFO of each crash. While CRIS is typically updated with the latest version of RHiNo toward the end of the summer of each year, the schedule of updating CRIS has not been fixed over time. Since DFOs may change along a route from one RHiNo version to the next, mapping crashes on an incorrect version of RHiNo may result in inaccurate crash locations (assuming that crashes are geolocated using the highway name and the DFO of each crash), which can affect the reliability and accuracy of the evaluation results. One way to overcome this challenge it to geolocate crashes using their geographical coordinates, if available, which are fixed in space over time. Moving forward, a potential strategy to address this challenge is to store in CRIS the version or year of RHiNo that is used to determine the DFO of each crash. The year of RHiNo can be saved in a new data attribute called [DFO_RHiNo_Year].
- *Limited roadway and traffic data for certain types of roads*. RHiNo contains several attributes that can be used for HSIP evaluations; however, it has limited roadway inventory and AADT data for certain road parts such as ramps, U-turns/turnarounds, connectors, and off-system roads. Therefore, the evaluation of these road parts may require additional data collection activities in the field or using aerial and street view images.
- *Limited inventory data to calculate the SPFs and CMFs included in the TxDOT Roadway Safety Design Workbook*. RHiNo does contain some data attributes (e.g., number of driveways, land use, curb miles, etc.) that are required to calculate the workbook SPFs and CMFs.
- *Lack of comprehensive intersection database*. The 2017 RHiNo includes new data attributes for intersections. However, currently, there is not any comprehensive database for intersections in Texas. This creates difficulties in performing data-demanding safety analyses such as network screening and safety effectiveness evaluations. For example, in the case of HSIP evaluations, TTI collected some intersection data using aerial and street view images. The general strategy is to geolocate all intersections in the state and collect detailed roadway, geographic, geometric, traffic, operational, HPMS, and other types of data for each intersection approach.
- *SPF limitations*. As explained in Section 4.2.6, the *Roadway Safety Design Workbook* does not include SPFs for certain types of roads, such as freeways with 12 lanes or more,

highways with managed lanes, and local roads. In addition, the SPFs were developed several years ago and need to be calibrated for current conditions. Further, the SPFs are appropriate for predicting only KABC crashes; however, the goal of the HSIP is to reduce KAB crashes. There is a need to calibrate existing SPFs and develop new SPFs.

After comparing the data requirements of each evaluation method presented in Chapter 2 against existing TxDOT attributes, the researchers concluded that all evaluation methods can be applied in Texas; however, the applicability and reliability of each method may be limited by the factors described above.

Further, TTI assessed the applicability of seven evaluation tools at TxDOT by taking into consideration existing TxDOT data. Of all the tools presented in Chapter 3, the assessment focused on those that are publicly accessible online and those that were provided to the research team by other state agencies. Proprietary software and applications that could not be shared with the research team were not included in this assessment. Each of the seven tools assessed in this activity incorporate one or more of the following four methods:

- Naïve B/A.
- Naïve B/A with linear traffic volume correction.
- B/A with comparison group.
- EB B/A that uses SPFs.

Table 16 shows the safety effectiveness evaluation methods that each of the seven tools supports and indicates their applicability at TxDOT.

Table 16. Applicability of Various Evaluation Tools in Texas.

Organization/ State	Project (P) or Counter-measure (C) Evaluation	Safety Effectiveness Evaluation Method				Applicable at TxDOT?
		Naïve B/A	Naïve B/A with Linear Traffic Volume Correction	B/A with Comparison Group	EB B/A	
FHWA HSIP Evaluation Guide Companion	C		X	X	X	Yes, but TxDOT-specific SPFs and dispersion parameters are needed for EB method
Alaska	P	X	X			Yes
Maine	P	X				Yes
Massachusetts	P	X	X	X	X	Yes (the tool provides 248 SPFs), but Texas-specific SPFs and dispersion parameters are needed for EB method
North Carolina	C	X	X		X	Yes, but Texas-specific SPFs and dispersion parameters are needed for EB method
Pennsylvania	P	X				Yes
South Carolina	P	X	X			Yes

Most of the tools support naïve B/A analysis with and without accounting for traffic volumes. The spreadsheets developed by FHWA and Massachusetts incorporate the B/A method with the comparison group and the EB method. North Carolina's spreadsheet also supports the EB method. Note that Massachusetts' tool lists 248 SPFs—12 SPFs were developed by the Massachusetts Department of Transportation (MassDOT) and the rest were gathered from different sources including the HSM, SafetyAnalyst, and NCHRP 17-58. Of the seven tools listed in Table 16, FHWA's companion tool and North Carolina's spreadsheet can be used to perform countermeasure evaluations. The other five spreadsheets are appropriate for project-level evaluations.

Of the examined states, four of them incorporated economic effectiveness evaluation methodologies into their safety evaluation spreadsheets or developed separate B/C calculators. Although their B/C formulas vary, they are all based on the main principle of comparing the monetary value associated with the number of crashes reduced to the project cost. Table 17 shows the main elements considered for the calculation of project benefits and costs.

Table 17. B/C Spreadsheet Tools.

State	Benefits	Costs	Applicable at TxDOT?
Alaska	• Annual reduction in accident cost • Decrease in maintenance cost	• Annualized construction cost • Increase in annual maintenance cost	Yes
Maine	• Total annualized benefit in crashes reduced multiplied by a traffic growth factor	• Total annualized initial project cost • Total annual maintenance cost	Limited, used for project selection
Massachusetts	• Benefits due to crash reduction multiplied by a growth factor	• Actual construction cost • Maintenance cost adjusted by a growth factor	Yes
North Carolina	• Annual reduction in crash cost by crash severity	• Construction cost • Utilities/maintenance cost • Right-of-way cost	Limited, used for project selection
Pennsylvania	• Annual reduction in crash cost by crash severity	• Total project cost	Yes
South Carolina	• Crash rate reduction per crash severity	• Total cost • Interest rate • Service life	Yes

The benefits typically account for the reduced number of crashes by severity. Project costs are comprised of construction, maintenance, utility, and right-of-way acquisition costs. Note that many states have developed and use B/C calculators to select and prioritize projects during the planning phases of their HSIP, not to conduct B/A project evaluations. Overall, the B/C tools reviewed could potentially be used in Texas, if modified accordingly and tailored to TxDOT datasets. It is worth noting that none of these tools can support both project and countermeasure evaluations by applying each of the four methods listed above and calculating B/C ratios for each method.

To address these limitations, TTI developed two evaluations tools, one for segments and another for intersections. Both tools perform evaluations at the project and countermeasure levels. Chapter 5 presents the two tools and explains how analysts can use them and interpret the results.

CHAPTER 5:
EVALUATION TOOLS

5.1 INTRODUCTION

This chapter presents two spreadsheet tools that TTI developed for TxDOT to perform safety and cost-effectiveness evaluations of individual projects and groups of similar types of projects. The evaluation of groups of projects refers to the evaluation of WCs and development of CMFs. The first tool is appropriate for roadway segment evaluations, and the second tool is for intersection evaluations. The tools have similar format, structure, data inputs, and outputs. Both tools incorporate the following four B/A observational methods:

- **Naïve**. The naïve or simple B/A method involves comparing the number of crashes expected in the after period to the number of crashes observed in the after period. The expected number of crashes is calculated by multiplying the number of crashes observed in the before period to the ratio [Duration of after period] / [Duration of before period]. Based on HSIP report data, many state DOTs still use this method. Although this method is easy to apply, it does not consider traffic volumes and cannot account for RTM bias and temporal effects or trends such as changes in driver behavior, crash reporting, and other local factors. Because of these shortcomings, naïve B/A studies are not recommended for developing quality CMFs. However, this method is included in the tool in case traffic volume and other types of data required by other (more advanced) methods are not available and cannot be easily collected.
- **Naïve with traffic volume correction**. A simple B/A study with a traffic volume correction is a variation of the naïve B/A study. This method accounts for temporal changes in traffic volumes, but not for RTM effects. This method involves calculating crash rates rather than crash frequencies, making the method more reliable than naïve B/A studies.
- **Comparison group**. The comparison group method compares a group of treated sites to a comparison group of untreated sites. The comparison sites must be comparable to the treated sites in traffic volume, roadway geometrics, and other characteristics. The method calculates the ratio of observed crashes at the control sites in the after period to those in the before period. This ratio is multiplied by the observed crash frequency in the before period at the treated sites to estimate the expected number of crashes at the treated sites in the after period had the countermeasure not been implemented. The estimated crashes at the treated sites in the after period are then compared with the observed crashes at the treated sites in the after period to determine the effectiveness of the countermeasure of interest. For completeness, the comparison group method is included in the tool, but it requires a significant amount of data processing time to identify control sites that are comparable to treated sites. Further, the results may change from one analyst to another because each analyst may select different control sites.

- **Empirical Bayes that uses SPFs**. The EB method estimates the expected number of crashes that would have occurred had there been no treatment and compares it to the actual number of crashes in the after period. The calculation steps are shown in Figure 5 (Chapter 2). The method accounts for RTM bias, traffic volume changes, and temporal effects, making it one of the most reliable methods for CMF development (*2*). However, the SPFs included in TxDOT's *Roadway Safety Design Workbook* can be used to predict only KABC crashes.

The HSM (*2*) and Ezra Hauer's textbook *Observational Before-After Studies in Road Safety* (*29*) were the main references that TTI used to incorporate these methods into the tools. The tools also conduct an economic analysis that produces four B/C ratios for each evaluated project and group of projects—one B/C ratio is calculated for each evaluation method.

TTI developed the tools in Microsoft Office Excel format so that users would not have to install and learn potentially new software or applications, as well as to minimize the need for future maintenance of the tools by TxDOT. Microsoft Excel is widely available and commonly used at TxDOT for data storage, management, analysis, and other purposes. Both tools are macro-enabled Excel files (.xlsm format). The main framework of the tools is based on that of MassDOT's tool presented in Chapter 3. TTI tailored the tools to TxDOT datasets, needs, and HSIP requirements. Each tool includes the following worksheets, which are shown at the bottom of Figure 28:

- **Intro**: Provides a general description of the tool, explains how to use it, presents the remaining worksheets, and includes relevant references that were used to develop the tool. Figure 28 shows a screenshot of the "Intro" sheet.
- **Input**: Contains optional and required data fields that the user needs to enter. The data in the required fields are used in other worksheets of the tool to perform calculations and apply the evaluation methods.
- **Results for Single Projects**: Provides a summary of the evaluation results produced for each project individually in separate rows (one row per project).
- **Results for Groups of Projects**: Provides a summary of the evaluation results produced for groups of similar projects.
- **Naïve**: Uses naïve or simple B/A method.
- **Naïve with Volume Correction**: Uses naïve or simple B/A method with linear traffic volume correction.
- **Comparison Group**: Uses B/A comparison group method.
- **Empirical Bayes**: Uses empirical Bayes B/A method that employs SPFs.
- **Economic Analysis**: Calculates four B/C ratios—one ratio for each of the methods listed above. For each ratio, the expected change in crash frequency is converted to a monetary value, summed, and then compared to the total construction and maintenance cost of each project.

- **SPFs_CMFs**: Uses safety performance functions and crash modification factors. The sheet contains a list of SPFs and CMFs published in TxDOT's *Roadway Safety Design Workbook*. The SPFs and CMFs are used only in the EB method.
- **Menu Lists**: Provides drop-down menu list items and other information and data that are used in other worksheets of the tool.

To use the tools, analysts simply need to enter data for individual projects in the "Input" sheet. After entering the data, the tools automatically perform all calculations and summarize the results in sheets "Results for Single Projects" and "Results for Groups of Projects."

The sheets are color coded based on the data/information that they contain (see bottom part of Figure 28). For example, the input sheet is in blue; the two sheets that provide the results are in green; the five sheets that include formulas and perform calculations for the different methods are in orange; and the sheets that contain Texas-specific information and data (e.g., SPFs, CMFs, drop-down menu items, etc.) that are used in the remaining sheets are in gray.

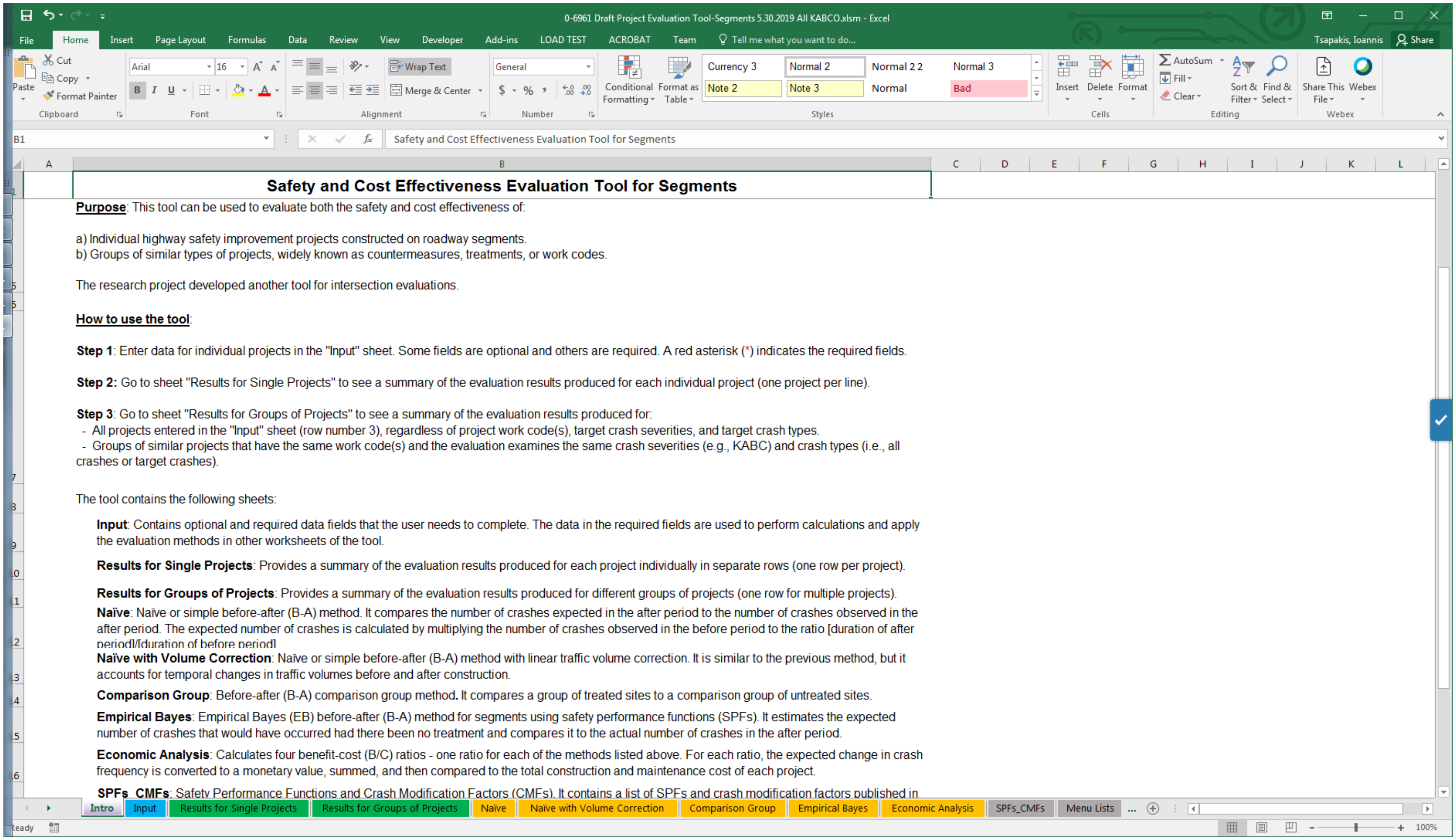
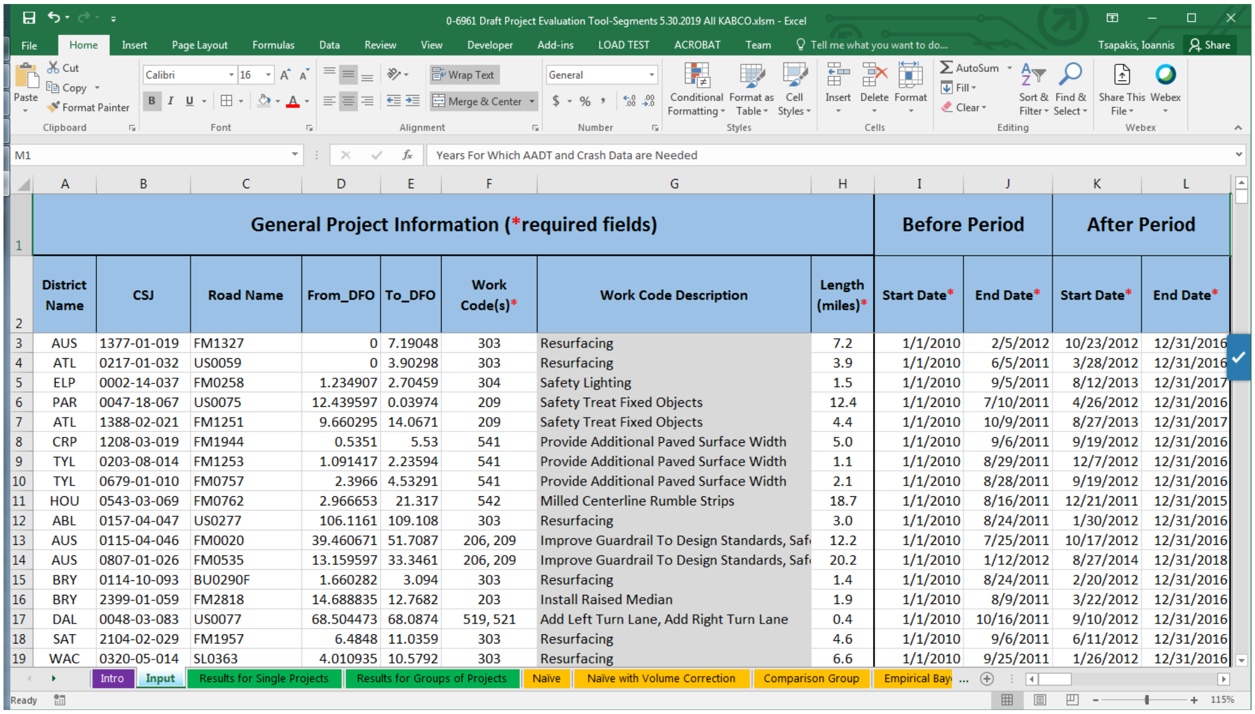


Figure 28. "Intro" Sheet of Roadway Segment Project Evaluation Tool.

Sections 5.2 through 5.4 present the "Input," "Results for Single Projects," and "Results for Groups of Projects" worksheets, respectively. These are the most important worksheets that analysts need to use to evaluate projects and groups of projects and to review evaluation results. Section 5.5 describes the five calculation sheets, and Section 5.6 presents the other two sheets. Because the tools have similar structure, format, data inputs, and outputs, screenshots and examples are provided only for the segment tool.

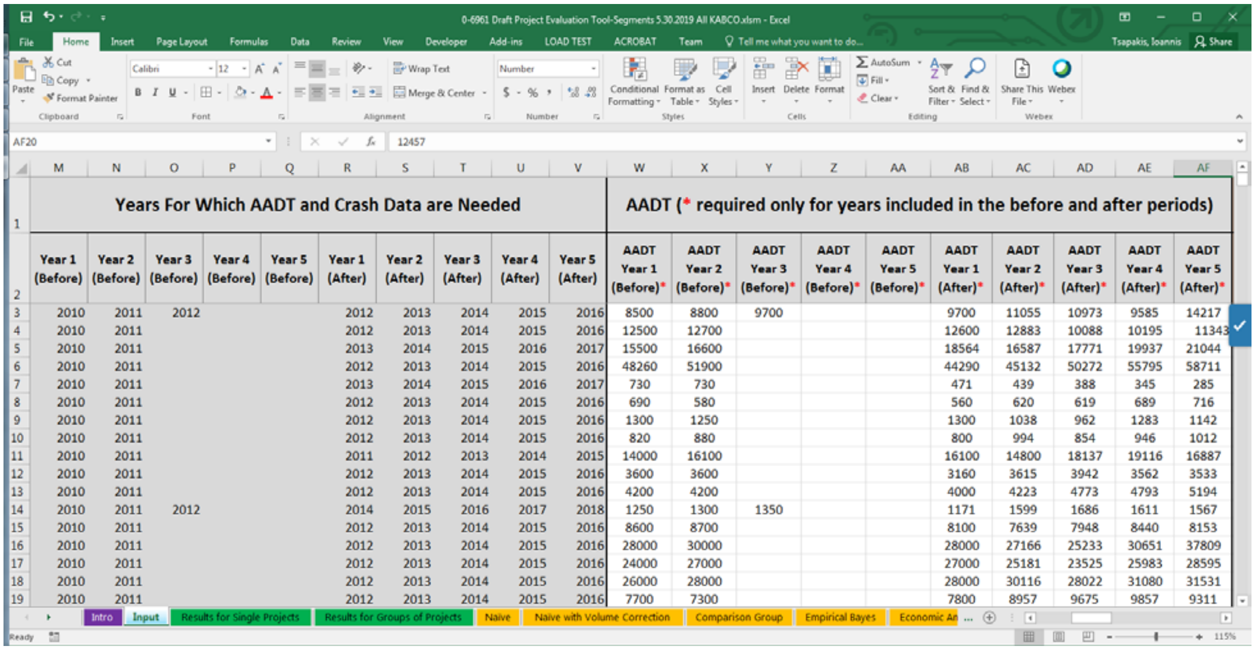
5.2 INPUT

The first step to use either tool is to enter data for individual projects in the "Input" sheet. Figure 29 through Figure 32 show 62 data fields included in this sheet. In these figures, data for various HSIP projects have been entered for illustration purposes. Appendix D provides a detailed description and examples for each field. As shown in Figure 29 through Figure 32, the first row provides a general description of various data types, and the second row includes the data field names within each data type. The first two rows are color coded by data type. For example, as shown in Figure 31, the target crashes for evaluation (columns AG and AH) have a different color than the crash frequencies that the user has to enter in columns AI through AR. Likewise, the actual construction cost (column AS) and annual maintenance cost (column AT) required for the economic analysis are highlighted in a different color so that users can easily distinguish them from their adjacent fields.



General Project Information (*required fields)								Before Period		After Period	
District Name	CSJ	Road Name	From_DFO	To_DFO	Work Code(s)*	Work Code Description	Length (miles)*	Start Date*	End Date*	Start Date*	End Date*
AUS	1377-01-019	FM1327	0	7.19048	303	Resurfacing	7.2	1/1/2010	2/5/2012	10/23/2012	12/31/2016
ATL	0217-01-032	US0059	0	3.90298	303	Resurfacing	3.9	1/1/2010	6/5/2011	3/28/2012	12/31/2016
ELP	0002-14-037	FM0258	1.234907	2.70459	304	Safety Lighting	1.5	1/1/2010	9/5/2011	8/12/2013	12/31/2017
PAR	0047-18-067	US0075	12.439597	0.03974	209	Safety Treat Fixed Objects	12.4	1/1/2010	7/10/2011	4/26/2012	12/31/2016
ATL	1388-02-021	FM1251	9.660295	14.0671	209	Safety Treat Fixed Objects	4.4	1/1/2010	10/9/2011	8/27/2013	12/31/2017
CRP	1208-03-019	FM1944	0.5351	5.53	541	Provide Additional Paved Surface Width	5.0	1/1/2010	9/6/2011	9/19/2012	12/31/2016
TYL	0203-08-014	FM1253	1.091417	2.23594	541	Provide Additional Paved Surface Width	1.1	1/1/2010	8/29/2011	12/7/2012	12/31/2016
TYL	0679-01-010	FM0757	2.3966	4.53291	541	Provide Additional Paved Surface Width	2.1	1/1/2010	8/28/2011	9/19/2012	12/31/2016
HOU	0543-03-069	FM0762	2.966653	21.317	542	Milled Centerline Rumble Strips	18.7	1/1/2010	8/16/2011	12/21/2011	12/31/2015
ABL	0157-04-047	US0277	106.1161	109.108	303	Resurfacing	3.0	1/1/2010	8/24/2011	1/30/2012	12/31/2016
AUS	0115-04-046	FM0020	39.460671	51.7087	206, 209	Improve Guardrail To Design Standards, Saf	12.2	1/1/2010	7/25/2011	10/17/2012	12/31/2016
AUS	0807-01-026	FM0535	13.159597	33.3461	206, 209	Improve Guardrail To Design Standards, Saf	20.2	1/1/2010	1/12/2012	8/27/2014	12/31/2018
BRY	0114-10-093	BU0290F	1.660282	3.094	303	Resurfacing	1.4	1/1/2010	8/24/2011	2/20/2012	12/31/2016
BRY	2399-01-059	FM2818	14.688835	12.7682	203	Install Raised Median	1.9	1/1/2010	8/9/2011	3/22/2012	12/31/2016
DAL	0048-03-083	US0077	68.504473	68.0874	519, 521	Add Left Turn Lane, Add Right Turn Lane	0.4	1/1/2010	10/16/2011	9/10/2012	12/31/2016
SAT	2104-02-029	FM1957	6.4848	11.0359	303	Resurfacing	4.6	1/1/2010	9/6/2011	6/11/2012	12/31/2016
WAC	0320-05-014	SL0363	4.010935	10.5792	303	Resurfacing	6.6	1/1/2010	9/25/2011	1/26/2012	12/31/2016

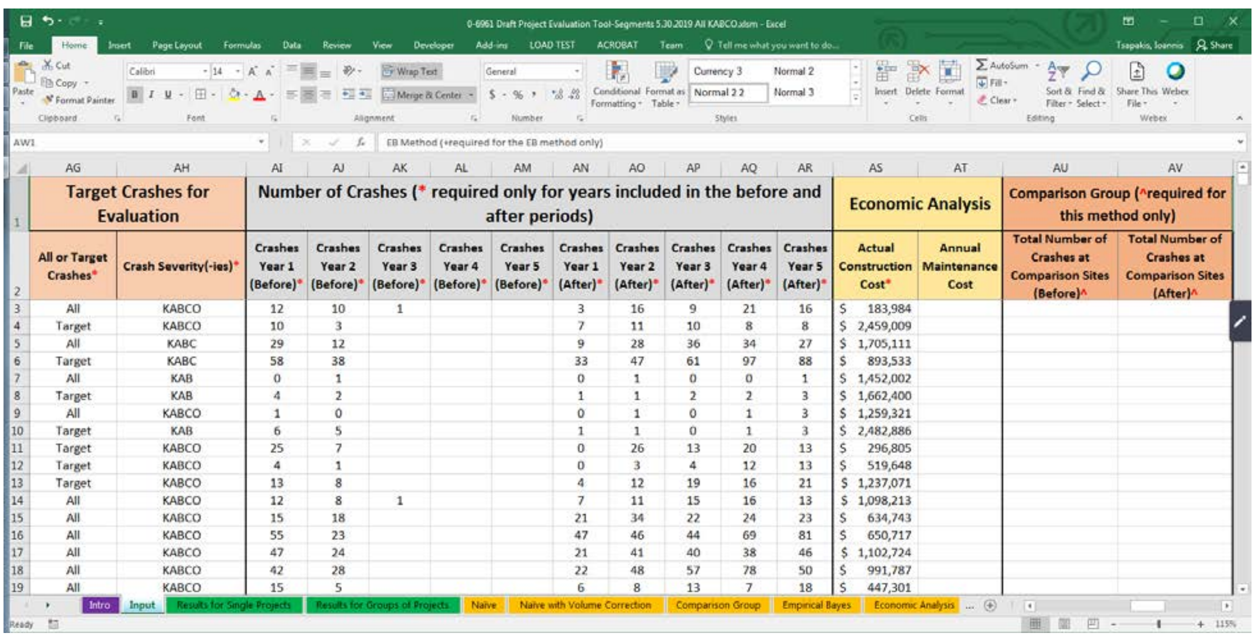
Figure 29. Input Sheet (Columns A–L).



Row	Year 1 (Before)	Year 2 (Before)	Year 3 (Before)	Year 4 (Before)	Year 5 (Before)	Year 1 (After)	Year 2 (After)	Year 3 (After)	Year 4 (After)	Year 5 (After)
3	2010	2011	2012			2012	2013	2014	2015	2016
4	2010	2011				2012	2013	2014	2015	2016
5	2010	2011				2013	2014	2015	2016	2017
6	2010	2011				2012	2013	2014	2015	2016
7	2010	2011				2013	2014	2015	2016	2017
8	2010	2011				2012	2013	2014	2015	2016
9	2010	2011				2012	2013	2014	2015	2016
10	2010	2011				2012	2013	2014	2015	2016
11	2010	2011				2011	2012	2013	2014	2015
12	2010	2011				2012	2013	2014	2015	2016
13	2010	2011				2012	2013	2014	2015	2016
14	2010	2011	2012			2014	2015	2016	2017	2018
15	2010	2011				2012	2013	2014	2015	2016
16	2010	2011				2012	2013	2014	2015	2016
17	2010	2011				2012	2013	2014	2015	2016
18	2010	2011				2012	2013	2014	2015	2016
19	2010	2011				2012	2013	2014	2015	2016

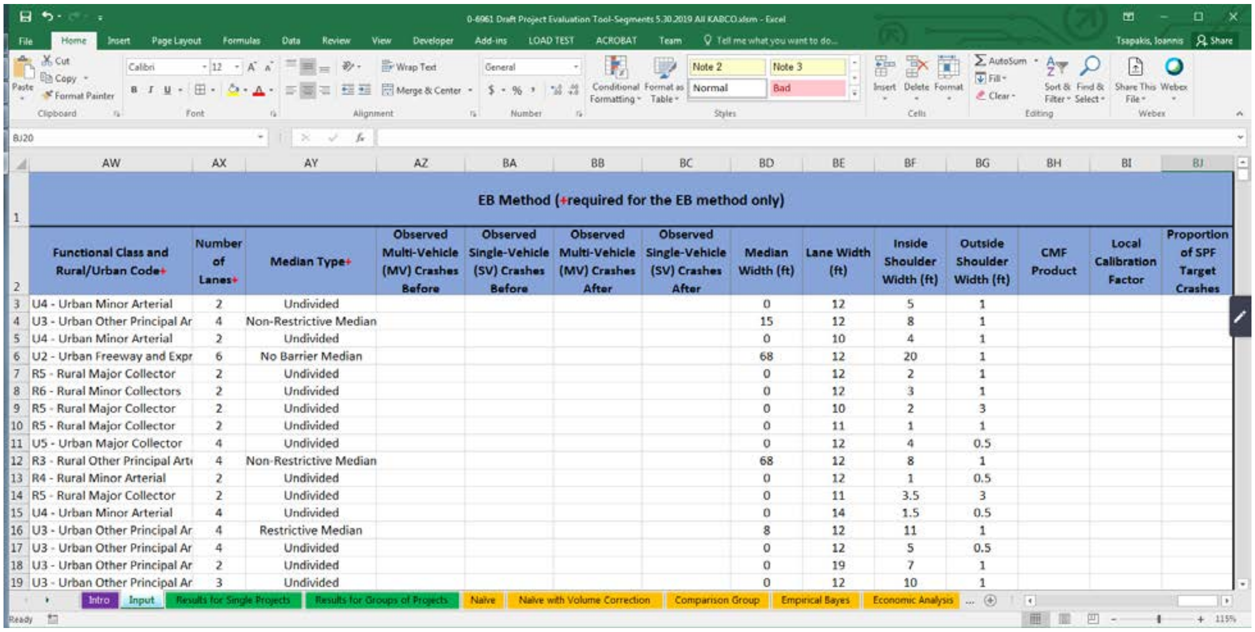
Row	AADT Year 1 (Before)*	AADT Year 2 (Before)*	AADT Year 3 (Before)*	AADT Year 4 (Before)*	AADT Year 5 (Before)*	AADT Year 1 (After)*	AADT Year 2 (After)*	AADT Year 3 (After)*	AADT Year 4 (After)*	AADT Year 5 (After)*
3	8500	8800	9700			9700	11055	10973	9585	14217
4	12500	12700				12600	12883	10088	10195	11343
5	15500	16600				18564	16587	17771	19937	21044
6	48260	51900				44290	45132	50272	55795	58711
7	730	730				471	439	388	345	285
8	690	580				560	620	619	689	716
9	1300	1250				1300	1038	962	1283	1142
10	820	880				800	994	854	946	1012
11	14000	16100				16100	14800	18137	19116	16887
12	3600	3600				3160	3615	3942	3562	3533
13	4200	4200				4000	4223	4773	4793	5194
14	1250	1300	1350			1171	1599	1686	1611	1567
15	8600	8700				8100	7639	7948	8440	8153
16	28000	30000				28000	27166	25233	30651	37809
17	24000	27000				27000	25181	23525	25983	28595
18	26000	28000				28000	30116	28022	31080	31531
19	7700	7300				7800	8957	9675	9857	9311

Figure 30. Input Sheet (Columns M–AF).



Row	All or Target Crashes*	Crash Severity(-ies)*	Crashes Year 1 (Before)*	Crashes Year 2 (Before)*	Crashes Year 3 (Before)*	Crashes Year 4 (Before)*	Crashes Year 5 (Before)*	Crashes Year 1 (After)*	Crashes Year 2 (After)*	Crashes Year 3 (After)*	Crashes Year 4 (After)*	Crashes Year 5 (After)*	Actual Construction Cost*	Annual Maintenance Cost	Total Number of Crashes at Comparison Sites (Before)^	Total Number of Crashes at Comparison Sites (After)^
3	All	KABCO	12	10	1			3	16	9	21	16	$ 183,984			
4	Target	KABCO	10	3				7	11	10	8	8	$ 2,459,009			
5	All	KABC	29	12				9	28	36	34	27	$ 1,705,111			
6	Target	KABC	58	38				33	47	61	97	88	$ 893,533			
7	All	KAB	0	1				0	1	0	0	1	$ 1,452,002			
8	Target	KAB	4	2				1	1	2	2	3	$ 1,662,400			
9	All	KABCO	1	0				0	1	0	1	3	$ 1,259,321			
10	Target	KAB	6	5				1	1	0	1	3	$ 2,482,886			
11	Target	KABCO	25	7				0	26	13	20	13	$ 296,805			
12	Target	KABCO	4	1				0	3	4	12	13	$ 519,648			
13	Target	KABCO	13	8				4	12	19	16	21	$ 1,237,071			
14	All	KABCO	12	8	1			7	11	15	16	13	$ 1,098,213			
15	All	KABCO	15	18				21	34	22	24	23	$ 634,743			
16	All	KABCO	55	23				47	46	44	69	81	$ 650,717			
17	All	KABCO	47	24				21	41	40	38	46	$ 1,102,724			
18	All	KABCO	42	28				22	48	57	78	50	$ 991,787			
19	All	KABCO	15	5				6	8	13	7	18	$ 447,301			

Figure 31. Input Sheet (Columns AG–AV).



EB Method (+required for the EB method only)

	Functional Class and Rural/Urban Code+	Number of Lanes+	Median Type+	Observed Multi-Vehicle (MV) Crashes Before	Observed Single-Vehicle (SV) Crashes Before	Observed Multi-Vehicle (MV) Crashes After	Observed Single-Vehicle (SV) Crashes After	Median Width (ft)	Lane Width (ft)	Inside Shoulder Width (ft)	Outside Shoulder Width (ft)	CMF Product	Local Calibration Factor	Proportion of SPF Target Crashes
3	U4 - Urban Minor Arterial	2	Undivided					0	12	5	1			
4	U3 - Urban Other Principal Ar	4	Non-Restrictive Median					15	12	8	1			
5	U4 - Urban Minor Arterial	2	Undivided					0	10	4	1			
6	U2 - Urban Freeway and Expr	6	No Barrier Median					68	12	20	1			
7	R5 - Rural Major Collector	2	Undivided					0	12	2	1			
8	R6 - Rural Minor Collectors	2	Undivided					0	12	3	1			
9	R5 - Rural Major Collector	2	Undivided					0	10	2	3			
10	R5 - Rural Major Collector	2	Undivided					0	11	1	1			
11	U5 - Urban Major Collector	4	Undivided					0	12	4	0.5			
12	R3 - Rural Other Principal Art	4	Non-Restrictive Median					68	12	8	1			
13	R4 - Rural Minor Arterial	2	Undivided					0	12	1	0.5			
14	R5 - Rural Major Collector	2	Undivided					0	11	3.5	3			
15	U4 - Urban Minor Arterial	4	Undivided					0	14	1.5	0.5			
16	U3 - Urban Other Principal Ar	4	Restrictive Median					8	12	11	1			
17	U3 - Urban Other Principal Ar	4	Undivided					0	12	5	0.5			
18	U3 - Urban Other Principal Ar	2	Undivided					0	19	7	1			
19	U3 - Urban Other Principal Ar	3	Undivided					0	12	10	1			

Figure 32. Input Sheet (Columns AW–BJ).

Some fields are required, other fields are optional, and some fields are automatically populated by the tool. A red asterisk (*) indicates the required fields. Note that some fields are required only for certain methods. For example, the comparison group method (Figure 31) requires the total number of crashes at comparison sites in the before period (column AU) and the after period (column AV). These two fields are indicated using a red caret/hat (^). Likewise, the EB method requires data for three fields that are indicated with a red cross (+), as shown in Figure 32.

The field [Work Code Description] (Figure 29) is highlighted in gray, indicating that the field is automatically populated by the tool. In this case, the field is populated after the user selects a work code in column F. Likewise, columns M through V (years for which AADT is needed; Figure 30) are highlighted in gray because they are automatically populated based on the start and end dates that the user has to enter in columns I through L.

When the user clicks on any data field name in row 2, a message appears that provides descriptive information about the selected field. For example, Figure 33 shows the messages that pop up when the fields [Work Code(s)*] and [End Date*] (of the before period) are selected. Appendix D provides more information about each field.

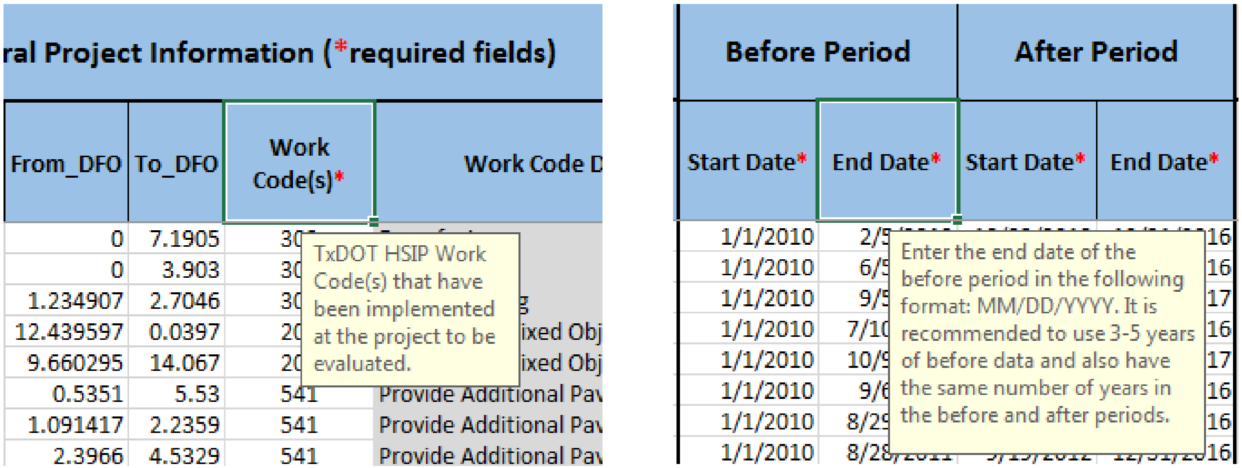


Figure 33. Examples of Messages Shown When Fields [Work Code(s)] and [End Date] of Before Period Are Selected.

The data of each project must be entered in a single row (i.e., one row per project) starting with row 3, as shown in Figure 29 through Figure 32. Some fields have drop-down menus to choose from. For example, the field [Work Code(s)*] (column F) includes a drop-down menu that lists 83 single WCs and 302 combinations of work codes (Figure 34). These are the WCs that have been used over the last few years in TxDOT's HSIP. Note that the last worksheet, "Menu Lists," includes all the menu list items and other information and data tables that are used in the "Input" and other sheets of the tool.

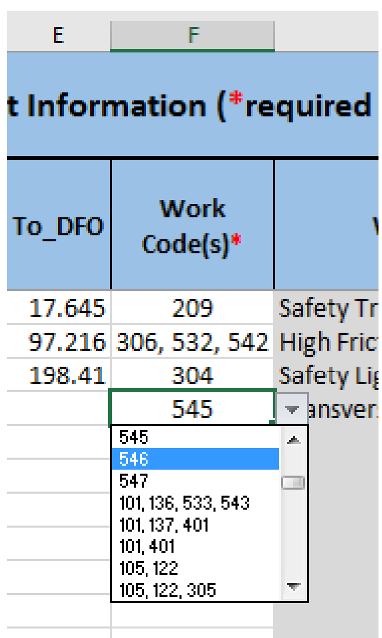
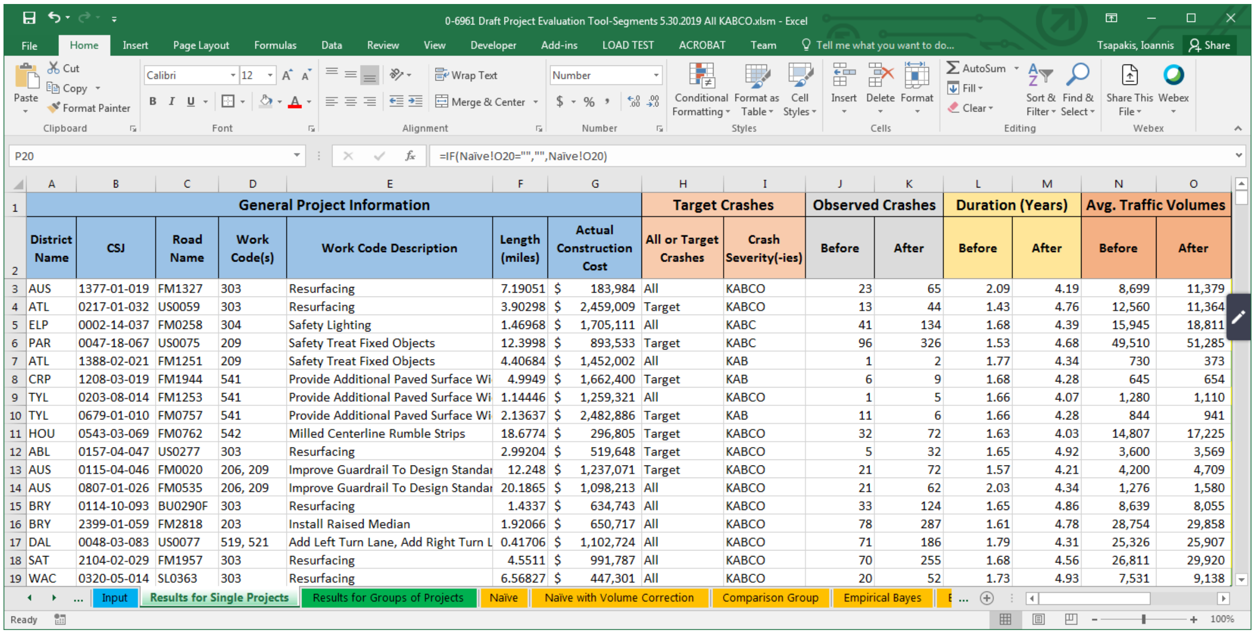


Figure 34. Drop-Down Menu That Includes WCs.

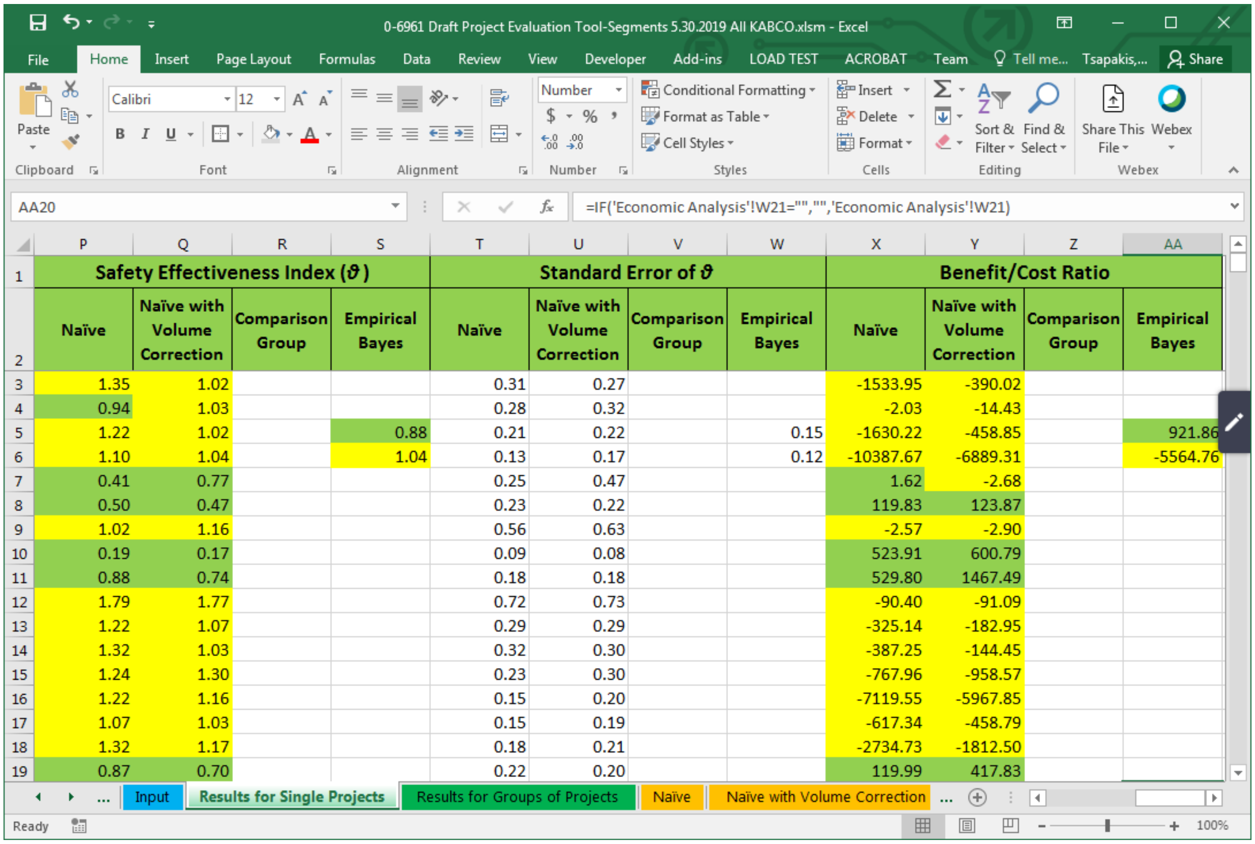
5.3 RESULTS FOR SINGLE PROJECTS

After entering data in the “Input” sheet, users have the option to view the evaluation results of each individual project (one line per project) in the “Results for Single Projects” sheet. Figure 35 and Figure 36 show 27 data fields that are included in this sheet. The values of these fields are extracted from other worksheets of the tool.



General Project Information							Target Crashes		Observed Crashes		Duration (Years)		Avg. Traffic Volumes	
District Name	CSJ	Road Name	Work Code(s)	Work Code Description	Length (miles)	Actual Construction Cost	All or Target Crashes	Crash Severity(-ies)	Before	After	Before	After	Before	After
AUS	1377-01-019	FM1327	303	Resurfacing	7.19051	$ 183,984	All	KABCO	23	65	2.09	4.19	8,699	11,379
ATL	0217-01-032	US0059	303	Resurfacing	3.90298	$ 2,459,009	Target	KABCO	13	44	1.43	4.76	12,560	11,364
ELP	0002-14-037	FM0258	304	Safety Lighting	1.46968	$ 1,705,111	All	KABC	41	134	1.68	4.39	15,945	18,811
PAR	0047-18-067	US0075	209	Safety Treat Fixed Objects	12.3998	$ 893,533	Target	KABC	96	326	1.53	4.68	49,510	51,285
ATL	1388-02-021	FM1251	209	Safety Treat Fixed Objects	4.40684	$ 1,452,002	All	KAB	1	2	1.77	4.34	730	373
CRP	1208-03-019	FM1944	541	Provide Additional Paved Surface Wi	4.9949	$ 1,662,400	Target	KAB	6	9	1.68	4.28	645	654
TYL	0203-08-014	FM1253	541	Provide Additional Paved Surface Wi	1.14446	$ 1,259,321	All	KABCO	1	5	1.66	4.07	1,280	1,110
TYL	0679-01-010	FM0757	541	Provide Additional Paved Surface Wi	2.13637	$ 2,482,886	Target	KAB	11	6	1.66	4.28	844	941
HOU	0543-03-069	FM0762	542	Milled Centerline Rumble Strips	18.6774	$ 296,805	Target	KABCO	32	72	1.63	4.03	14,807	17,225
ABL	0157-04-047	US0277	303	Resurfacing	2.99204	$ 519,648	Target	KABCO	5	32	1.65	4.92	3,600	3,569
AUS	0115-04-046	FM0020	206, 209	Improve Guardrail To Design Standar	12.248	$ 1,237,071	Target	KABCO	21	72	1.57	4.21	4,200	4,709
AUS	0807-01-026	FM0535	206, 209	Improve Guardrail To Design Standar	20.1865	$ 1,098,213	All	KABCO	21	62	2.03	4.34	1,276	1,580
BRY	0114-10-093	BU0290F	303	Resurfacing	1.4337	$ 634,743	All	KABCO	33	124	1.65	4.86	8,639	8,055
BRY	2399-01-059	FM2818	203	Install Raised Median	1.92066	$ 650,717	All	KABCO	78	287	1.61	4.78	28,754	29,858
DAL	0048-03-083	US0077	519, 521	Add Left Turn Lane, Add Right Turn L	0.41706	$ 1,102,724	All	KABCO	71	186	1.79	4.31	25,326	25,907
SAT	2104-02-029	FM1957	303	Resurfacing	4.5511	$ 991,787	All	KABCO	70	255	1.68	4.56	26,811	29,920
WAC	0320-05-014	SL0363	303	Resurfacing	6.56827	$ 447,301	All	KABCO	20	52	1.73	4.93	7,531	9,138

Figure 35. Results for Single Projects (Columns A–O).



Row	Safety Effectiveness Index (θ)				Standard Error of θ				Benefit/Cost Ratio			
	P	Q	R	S	T	U	V	W	X	Y	Z	AA
2	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes
3	1.35	1.02			0.31	0.27			-1533.95	-390.02		
4	0.94	1.03			0.28	0.32			-2.03	-14.43		
5	1.22	1.02		0.88	0.21	0.22		0.15	-1630.22	-458.85		921.86
6	1.10	1.04		1.04	0.13	0.17		0.12	-10387.67	-6889.31		-5564.76
7	0.41	0.77			0.25	0.47			1.62	-2.68		
8	0.50	0.47			0.23	0.22			119.83	123.87		
9	1.02	1.16			0.56	0.63			-2.57	-2.90		
10	0.19	0.17			0.09	0.08			523.91	600.79		
11	0.88	0.74			0.18	0.18			529.80	1467.49		
12	1.79	1.77			0.72	0.73			-90.40	-91.09		
13	1.22	1.07			0.29	0.29			-325.14	-182.95		
14	1.32	1.03			0.32	0.30			-387.25	-144.45		
15	1.24	1.30			0.23	0.30			-767.96	-958.57		
16	1.22	1.16			0.15	0.20			-7119.55	-5967.85		
17	1.07	1.03			0.15	0.19			-617.34	-458.79		
18	1.32	1.17			0.18	0.21			-2734.73	-1812.50		
19	0.87	0.70			0.22	0.20			119.99	417.83		

Figure 36. Results for Single Projects (Columns P–AA).

As shown in Figure 35, the first nine attributes (columns A–I) include general project information and data extracted from the "Input" sheet. These fields help the user identify each project. The remaining 18 attributes (columns J–AA) show a summary of the most important evaluation results that have been produced in the five orange worksheets that perform the calculations required by each method. The results include the following:

- Total number of crashes observed in the before period and after period.
- Duration (in years) of the before period and after period. The durations are calculated as decimals based on the total number of days contained between the start and end dates provided by users. For example, if the before period spans across three years and includes 40 days from Year 1, 365 days from Year 2, and 25 days from Year 3, the entire duration of the before period would be (40+365+25) / 365 = 1.18 years.
- Average AADT before and after construction. The AADT is weighted by the number of days within a year that are included in the before and after periods.
- Safety effectiveness index, θ, by evaluation method (*29*). This index captures the safety effectiveness of a project. The calculation formula of θ is:

$$\theta = \frac{N_{Observed,After}}{N_{Expected,After}} \times \frac{1}{\left(1+\frac{V_{Expected,After}}{N_{Expected,After}^{2}}\right)} \qquad (4)$$

Where:

- $N_{Observed,After}$ = total number of crashes observed in the after period.
- $N_{Expected,After}$ = number of expected crashes in the after period.
- $V_{Expected,After}$ = variance of expected crashes in the after period (*29*).

An index greater than one ($\theta > 1.0$) suggests that the project has not been effective from a safety perspective, and vice versa. In general, the smaller the index, the more effective the project. The cells are color coded to help the user visually review the results. The cells are highlighted in green when $\theta < 1.0$ (effective projects) and in yellow when $\theta > 1.0$ (not effective projects). When θ cannot be determined, the cells are empty and not highlighted.

- Standard error of θ by evaluation method.

$$SE_\theta = \sqrt{Var_\theta} \quad (5)$$

Where:

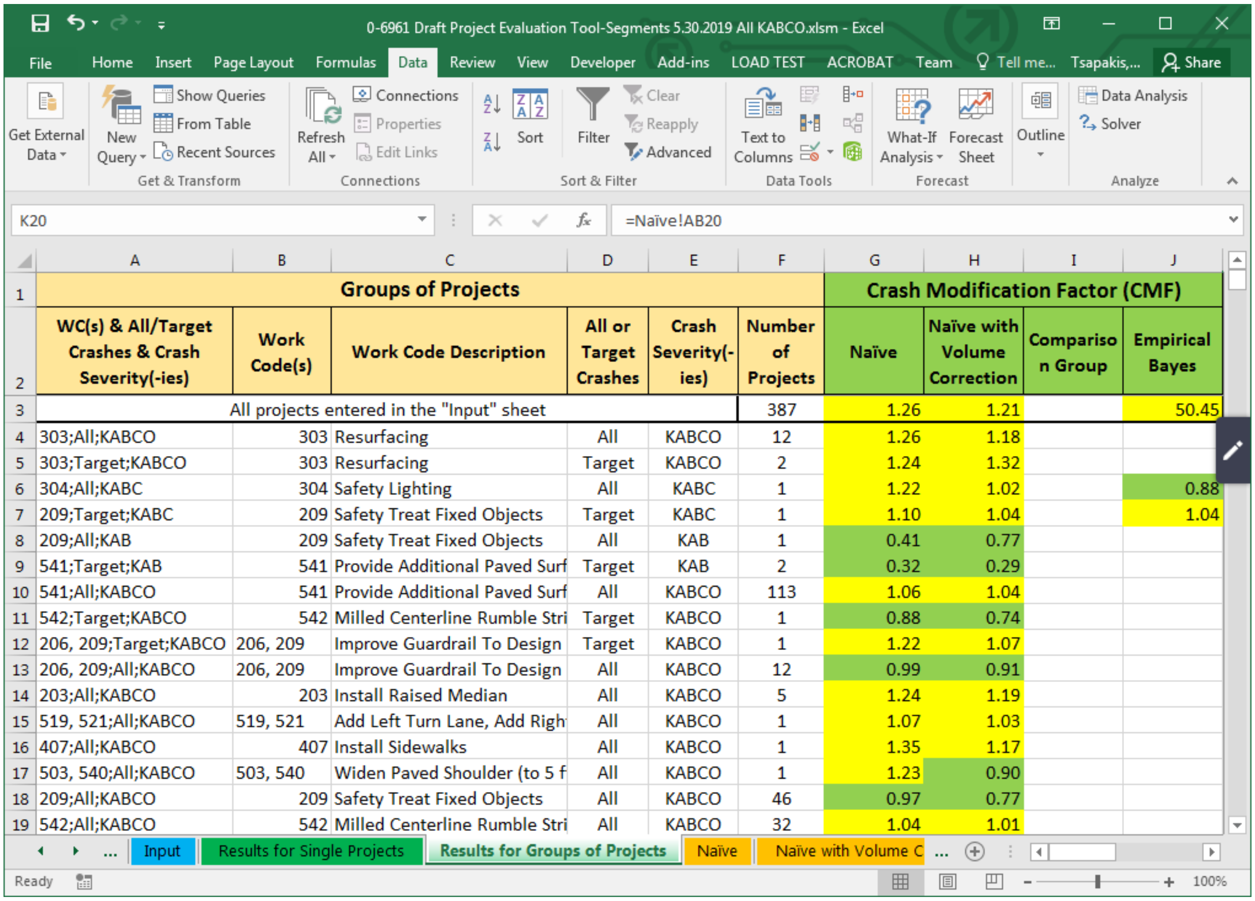
- SE_θ = standard error of safety effectiveness index.
- Var_θ = variance of safety effectiveness index (*29*).

- Benefit/cost ratio by evaluation method. B/C ratios greater than 1.0 indicate cost-effective projects, and B/C ratios less than 1.0 suggest the opposite. The higher the B/C ratio, the more cost effective the project. The cells are color coded to help the user visually review the results. A green cell indicates that the project is cost effective (B/C > 1.0), and a yellow cell suggests that the project is not cost effective (B/C < 1.0). Cells that are empty and not highlighted mean that the B/C ratios cannot be calculated.

Appendix E provides a general description and the Excel formula of each field included in the "Results for Single Projects" worksheet.

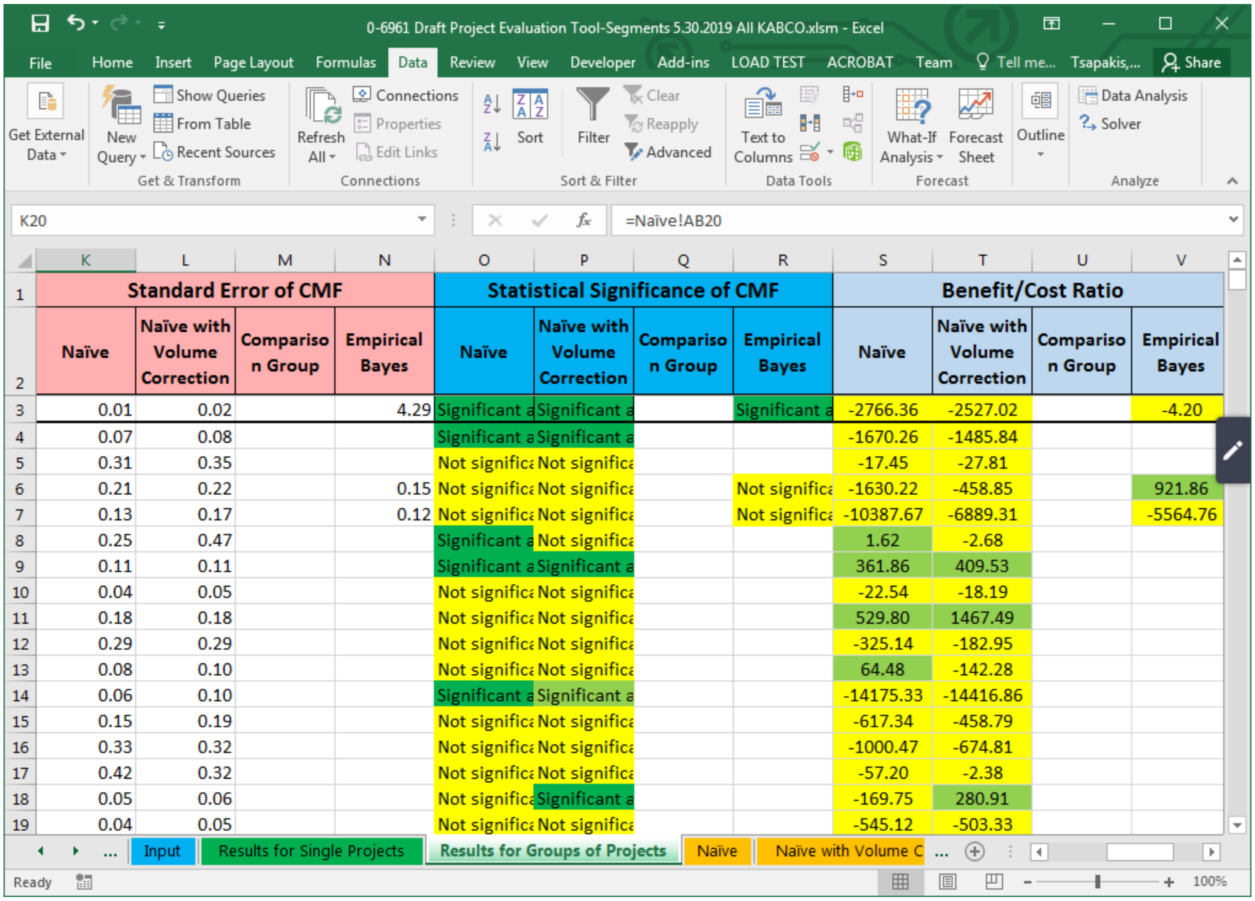
5.4 RESULTS FOR GROUPS OF PROJECTS

After entering data in the "Input" sheet, users can also view a summary of evaluation results for all projects entered in the "Input" sheet and/or for groups of similar types of projects. Figure 37 and Figure 38 show 22 data fields that are included in the "Results for Groups of Projects" worksheet. The values of these fields are extracted from the orange worksheets of the tool (bottom part of Figure 28) that perform the various calculations needed for each method.



	A	B	C	D	E	F	G	H	I	J
1	Groups of Projects						Crash Modification Factor (CMF)			
2	WC(s) & All/Target Crashes & Crash Severity(-ies)	Work Code(s)	Work Code Description	All or Target Crashes	Crash Severity(-ies)	Number of Projects	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes
3	All projects entered in the "Input" sheet					387	1.26	1.21		50.45
4	303;All;KABCO	303	Resurfacing	All	KABCO	12	1.26	1.18		
5	303;Target;KABCO	303	Resurfacing	Target	KABCO	2	1.24	1.32		
6	304;All;KABC	304	Safety Lighting	All	KABC	1	1.22	1.02		0.88
7	209;Target;KABC	209	Safety Treat Fixed Objects	Target	KABC	1	1.10	1.04		1.04
8	209;All;KAB	209	Safety Treat Fixed Objects	All	KAB	1	0.41	0.77		
9	541;Target;KAB	541	Provide Additional Paved Surf	Target	KAB	2	0.32	0.29		
10	541;All;KABCO	541	Provide Additional Paved Surf	All	KABCO	113	1.06	1.04		
11	542;Target;KABCO	542	Milled Centerline Rumble Stri	Target	KABCO	1	0.88	0.74		
12	206, 209;Target;KABCO	206, 209	Improve Guardrail To Design	Target	KABCO	1	1.22	1.07		
13	206, 209;All;KABCO	206, 209	Improve Guardrail To Design	All	KABCO	12	0.99	0.91		
14	203;All;KABCO	203	Install Raised Median	All	KABCO	5	1.24	1.19		
15	519, 521;All;KABCO	519, 521	Add Left Turn Lane, Add Righ	All	KABCO	1	1.07	1.03		
16	407;All;KABCO	407	Install Sidewalks	All	KABCO	1	1.35	1.17		
17	503, 540;All;KABCO	503, 540	Widen Paved Shoulder (to 5 f	All	KABCO	1	1.23	0.90		
18	209;All;KABCO	209	Safety Treat Fixed Objects	All	KABCO	46	0.97	0.77		
19	542;All;KABCO	542	Milled Centerline Rumble Stri	All	KABCO	32	1.04	1.01		

Figure 37. Results for Groups of Projects (Columns A–J).



	K	L	M	N	O	P	Q	R	S	T	U	V
1	Standard Error of CMF				Statistical Significance of CMF				Benefit/Cost Ratio			
2	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes
3	0.01	0.02		4.29	Significant a	Significant a		Significant a	-2766.36	-2527.02		-4.20
4	0.07	0.08			Significant a	Significant a			-1670.26	-1485.84		
5	0.31	0.35			Not significa	Not significa			-17.45	-27.81		
6	0.21	0.22		0.15	Not significa	Not significa		Not significa	-1630.22	-458.85		921.86
7	0.13	0.17		0.12	Not significa	Not significa		Not significa	-10387.67	-6889.31		-5564.76
8	0.25	0.47			Significant a	Not significa			1.62	-2.68		
9	0.11	0.11			Significant a	Significant a			361.86	409.53		
10	0.04	0.05			Not significa	Not significa			-22.54	-18.19		
11	0.18	0.18			Not significa	Not significa			529.80	1467.49		
12	0.29	0.29			Not significa	Not significa			-325.14	-182.95		
13	0.08	0.10			Not significa	Not significa			64.48	-142.28		
14	0.06	0.10			Significant a	Significant a			-14175.33	-14416.86		
15	0.15	0.19			Not significa	Not significa			-617.34	-458.79		
16	0.33	0.32			Not significa	Not significa			-1000.47	-674.81		
17	0.42	0.32			Not significa	Not significa			-57.20	-2.38		
18	0.05	0.06			Not significa	Significant a			-169.75	280.91		
19	0.04	0.05			Not significa	Not significa			-545.12	-503.33		

Figure 38. Results for Groups of Projects (Columns K–V).

The evaluation results include the following:

- Characteristics of groups of projects. As shown in Figure 37, the first six columns (column A–F) show the characteristics of each group of similar projects. Both evaluation tools automatically group the projects entered in the "Input" sheet by:
  - WC(s) (column B).
  - All or target (preventable) crashes (column D).
  - Target crash severity(-ies) (column E).

  Row 3 shows the evaluation results for all projects entered in the "Input" sheet, regardless of project work code, crash type, and crash severity. In other words, all projects entered in the "Input" sheet are treated and evaluated as a single group of projects and the results are shown in row 3. On the contrary, rows 4–499, show the unique groups of similar types of projects. For example, the first group shown in row 4 (Figure 37) includes 12 projects (column F) where WC 303 (resurfacing) has been implemented and users have entered in the "Input" sheet crash data for all KABCO crashes observed before and after the construction of these projects. The group shown in row 5 includes two projects (column F) where WC 303 has been implemented but users have provided crash data for target KABCO crashes observed before and after the construction of these projects. This functionality allows users to evaluate whether a particular WC has been effective in reducing all KABCO, all KABC, all KAB, target KABCO, target KABC, and target KAB crashes separately. This is important because WCs are selected by TxDOT staff to prevent specific types of crashes that happen at high-risk locations or sites. Consequently, the evaluation of a WC should focus on the specific types of crashes that each WC can theoretically target according to the preventable crash criteria provided in TxDOT's *HSIP Work Codes Table* (*27*). In addition, TxDOT HSIP projects are identified, selected, prioritized, and constructed with the goal of reducing fatal and serious injury crashes. Therefore, it is more important to evaluate the effectiveness of these projects and WCs in reducing KAB crashes rather than KABC or KABCO crashes.

- CMFs by evaluation method. Columns G–J provide CMFs developed using the four evaluation methods incorporated into the tool. Note that the EB method can be applied only in the case of KABC crashes. The calculation of CMF is similar to that of the safety effectiveness index of an individual project. The main difference is that it accounts for multiple projects. The calculation formula of CMF is:

$$\text{CMF} = \frac{\sum_{p=1}^{n} N_{Observed,After,p}}{\sum_{p=1}^{n} N_{Expected,After,p}} \times \frac{1}{\left(1+\frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)} \quad (6)$$

Where:

  - n = total number of similar projects.
  - $N_{Observed,After,p}$ = total number of crashes observed in the after period for project *p*.
  - $N_{Expected,After,p}$ = number of expected crashes in the after period for project *p*.
  - $Var_{Expected,After,Total}$ = variance of expected crashes in the after period (*29*).

Overall, a CMF greater than 1 (CMF > 1.0) indicates an expected increase in crash frequency, while a CMF less than 1 (CMF < 1.0) suggests an expected decrease in crashes. The cells are color coded to help the user visually review the results. The cells are highlighted in green when CMF < 1.0 and in yellow when CMF > 1.0. The cells are empty and not highlighted when CMFs cannot be determined.

- Standard error of CMFs by evaluation method. Columns K–N provide the standard error of each CMF. The standard error is used to calculate the statistical significance of each CMF.

$$SE_{\text{CMF}} = \sqrt{Var_{\text{CMF}}} \quad (7)$$

Where:

  - SE_{CMF} = standard error of CMF.
  - Var_{CMF} = variance of CMF (*29*).

- Statistical significance of CMFs by evaluation method. Columns O–R show whether each CMF is statistically significant or not. They also indicate whether they are significant at 90 percent or 95 percent confidence levels. The cells in columns O–R are color coded accordingly. They are highlighted in yellow when the CMFs are not significant, in light green when they are significant at the 90 percent confidence level, and in dark green when they are significant at the 95 percent confidence level.

- B/C ratio by evaluation method. Columns S–V provide B/C ratios estimated using the four methods. B/C ratios greater than 1.0 indicate cost-effective projects, and B/C ratios less than 1.0 suggest the opposite. The higher the B/C ratio, the more cost effective the project. The cells are color coded to help the user visually review the results. A green cell indicates that the project is cost effective (B/C > 1.0), and a yellow cell suggests that the project is not cost effective (B/C < 1.0). Cells that are empty and not highlighted mean that the B/C ratios cannot be calculated.

Appendix F provides a general description and the Excel formula of each field included in the "Results for Groups of Projects" worksheet.

5.5 CALCULATION SHEETS

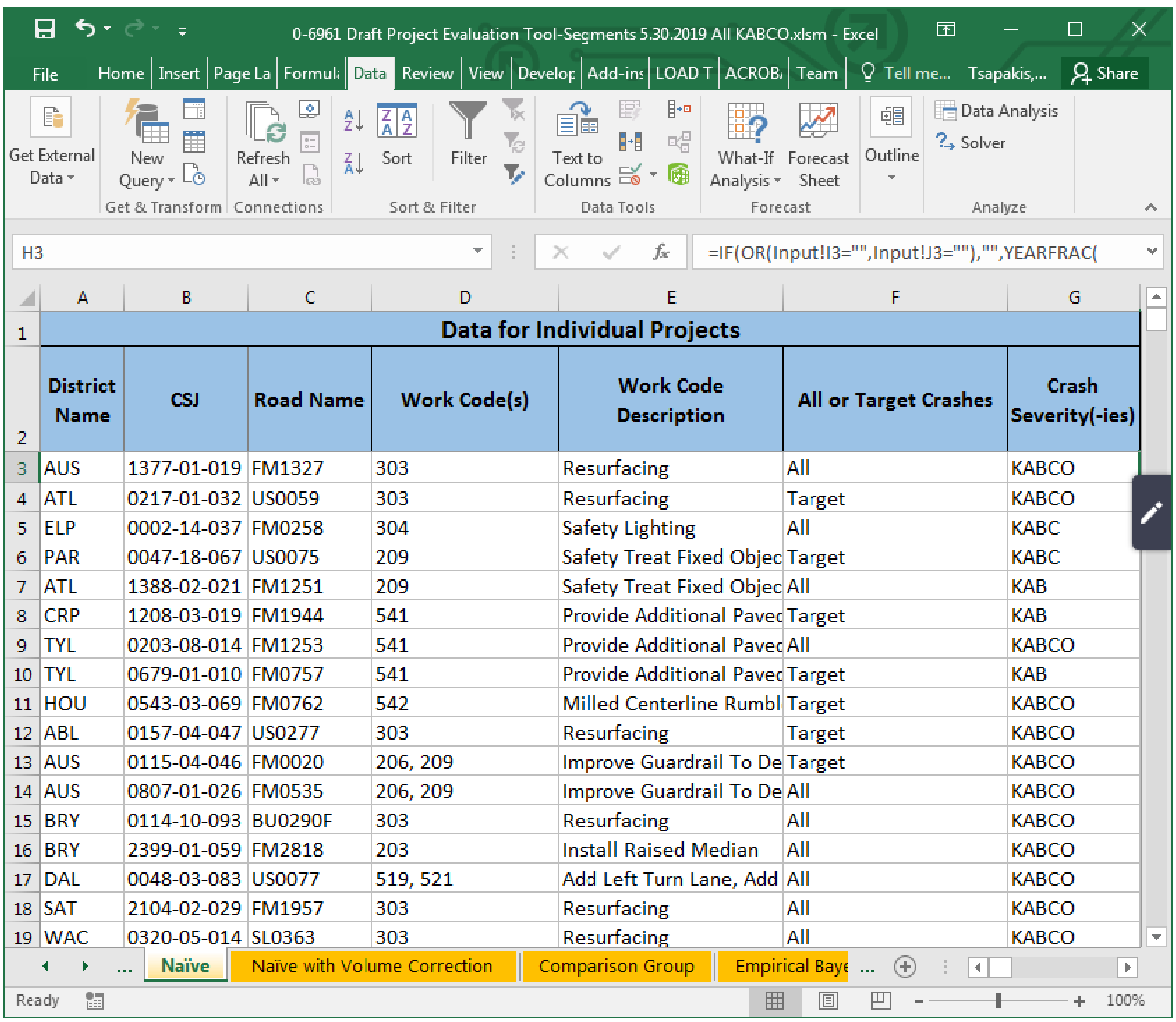
In addition to the three main worksheets presented in the previous section, each tool includes five worksheets that perform the various calculations required for each method incorporated into the tools. The five worksheets correspond to the orange tabs shown at the bottom of Figure 28 and include the following:

- Naïve.
- Naïve with Volume Correction.
- Comparison Group.
- Empirical Bayes.
- Economic Analysis.

Users do not have to make changes or enter data in these worksheets. They can simply use them to review all formulas and calculations and find additional results that are not included in the "Results for Single Projects" and "Results for Groups of Projects" sheets. Though the data inputs and calculations are different from one method to another, each of the worksheets includes four major groups (or types) of data fields:

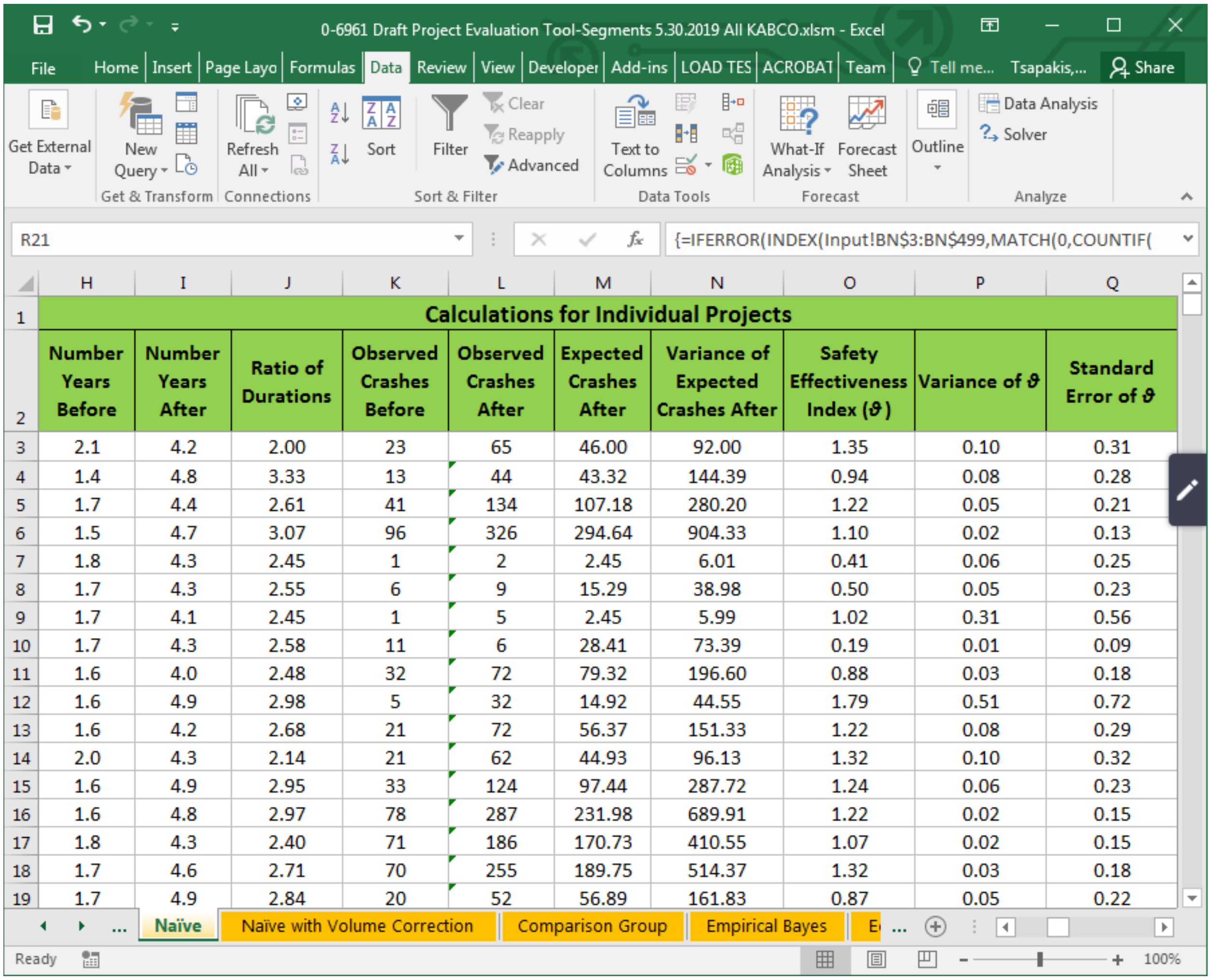
- Data for individual projects (Figure 39). These are general project-specific data (e.g., CSJ, road name, WC, all or target crashes, etc.) that are extracted from the "Input" sheet. The projects are listed in the same order as they were entered by the user in the "Input" sheet. These data fields help users identify each project as they review calculations and results within each worksheet.
- Calculations for individual projects (Figure 40). This group of data fields includes all calculations performed for individual projects. Figure 40 illustrates the calculations involved in the naïve method. Note that the "Results for Single Projects" sheet shows only the most important results, which include the safety effectiveness index (θ), the standard error of θ, and the B/C ratio extracted from the "Economic Analysis" worksheet.

- Data for groups of projects (Figure 41). These fields include the general characteristics of unique groups of projects identified by the tool (i.e., WCs, all or target crashes, crash severities, and number of projects within each group). These fields are also shown in the "Results for Groups of Projects" sheet. These data fields help users identify each group of projects as they review calculations and results for each group.
- Calculations for groups of projects (Figure 42). These data fields include all calculations performed for groups of projects. Figure 42 illustrates the calculations involved in the naïve method. Note that the "Results for Groups of Projects" sheet shows only the most important results, which include the CMF, the standard error of CMF, the statistical significance of CMF, and the B/C ratio extracted from the "Economic Analysis" worksheet.



Data for Individual Projects						
District Name	CSJ	Road Name	Work Code(s)	Work Code Description	All or Target Crashes	Crash Severity(-ies)
AUS	1377-01-019	FM1327	303	Resurfacing	All	KABCO
ATL	0217-01-032	US0059	303	Resurfacing	Target	KABCO
ELP	0002-14-037	FM0258	304	Safety Lighting	All	KABC
PAR	0047-18-067	US0075	209	Safety Treat Fixed Objec	Target	KABC
ATL	1388-02-021	FM1251	209	Safety Treat Fixed Objec	All	KAB
CRP	1208-03-019	FM1944	541	Provide Additional Pavec	Target	KAB
TYL	0203-08-014	FM1253	541	Provide Additional Pavec	All	KABCO
TYL	0679-01-010	FM0757	541	Provide Additional Pavec	Target	KAB
HOU	0543-03-069	FM0762	542	Milled Centerline Rumbl	Target	KABCO
ABL	0157-04-047	US0277	303	Resurfacing	Target	KABCO
AUS	0115-04-046	FM0020	206, 209	Improve Guardrail To De	Target	KABCO
AUS	0807-01-026	FM0535	206, 209	Improve Guardrail To De	All	KABCO
BRY	0114-10-093	BU0290F	303	Resurfacing	All	KABCO
BRY	2399-01-059	FM2818	203	Install Raised Median	All	KABCO
DAL	0048-03-083	US0077	519, 521	Add Left Turn Lane, Add	All	KABCO
SAT	2104-02-029	FM1957	303	Resurfacing	All	KABCO
WAC	0320-05-014	SL0363	303	Resurfacing	All	KABCO

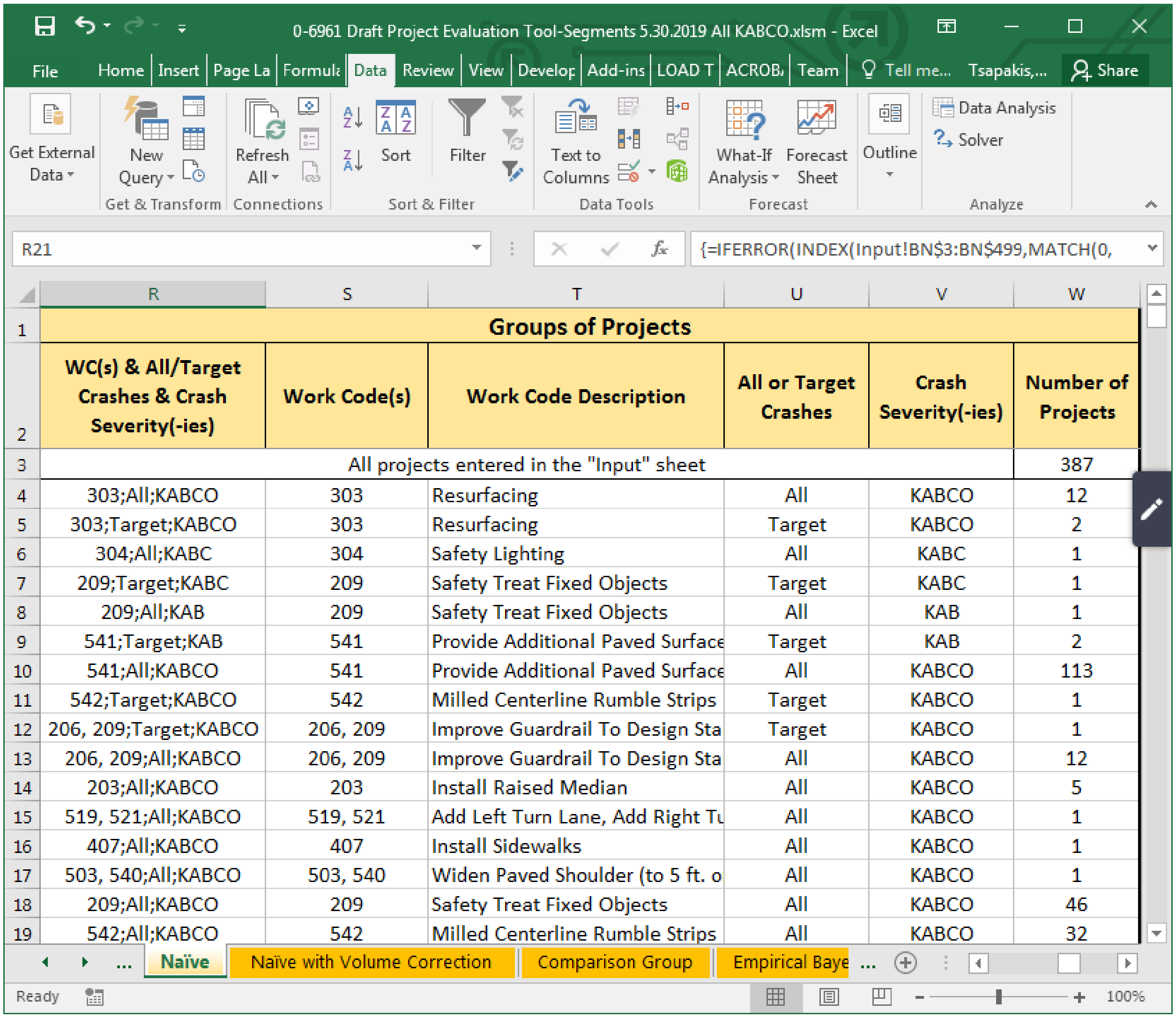
Figure 39. Data for Individual Projects (Naïve Method).



Calculations for Individual Projects

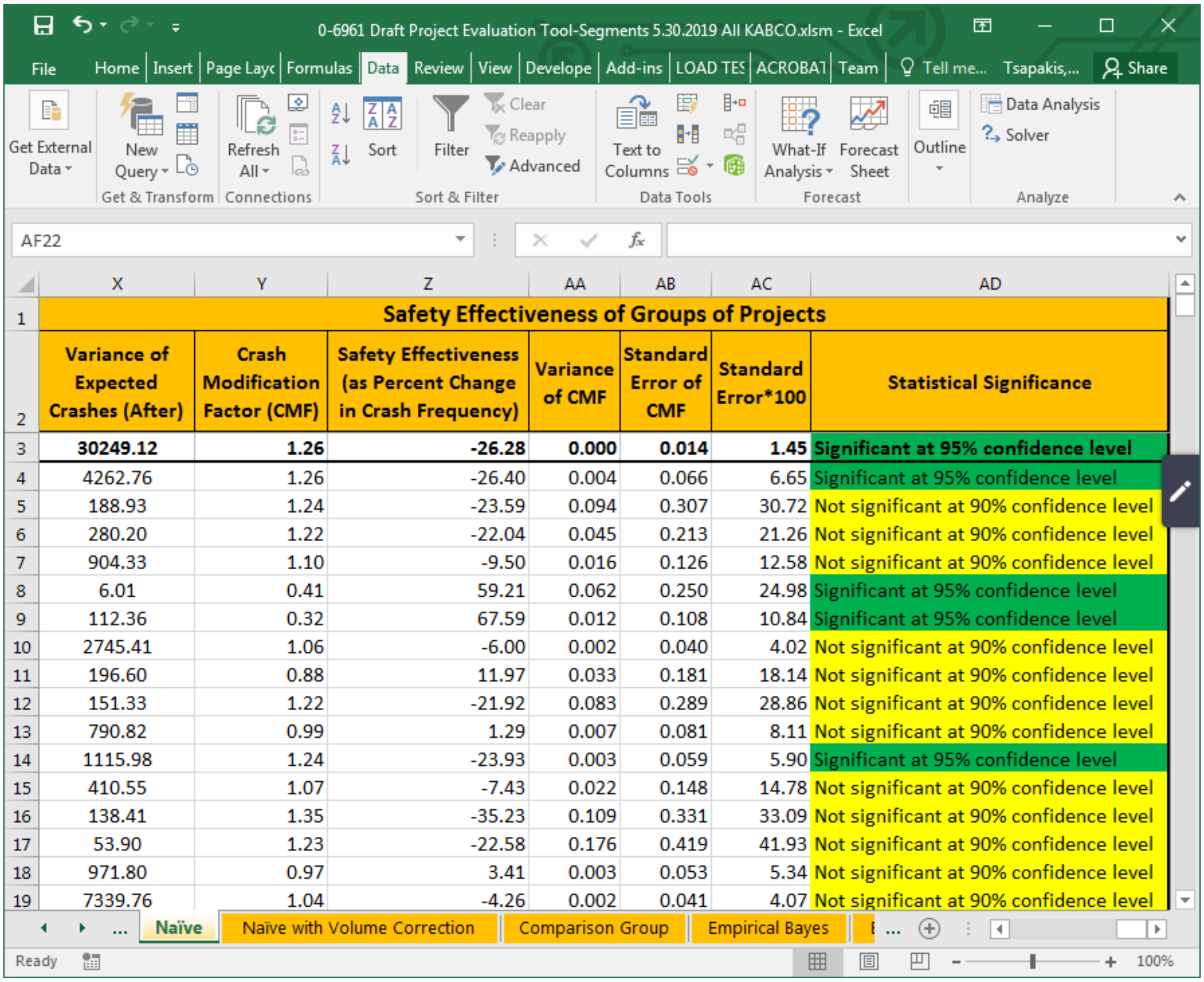
Number Years Before	Number Years After	Ratio of Durations	Observed Crashes Before	Observed Crashes After	Expected Crashes After	Variance of Expected Crashes After	Safety Effectiveness Index (ϑ)	Variance of ϑ	Standard Error of ϑ
2.1	4.2	2.00	23	65	46.00	92.00	1.35	0.10	0.31
1.4	4.8	3.33	13	44	43.32	144.39	0.94	0.08	0.28
1.7	4.4	2.61	41	134	107.18	280.20	1.22	0.05	0.21
1.5	4.7	3.07	96	326	294.64	904.33	1.10	0.02	0.13
1.8	4.3	2.45	1	2	2.45	6.01	0.41	0.06	0.25
1.7	4.3	2.55	6	9	15.29	38.98	0.50	0.05	0.23
1.7	4.1	2.45	1	5	2.45	5.99	1.02	0.31	0.56
1.7	4.3	2.58	11	6	28.41	73.39	0.19	0.01	0.09
1.6	4.0	2.48	32	72	79.32	196.60	0.88	0.03	0.18
1.6	4.9	2.98	5	32	14.92	44.55	1.79	0.51	0.72
1.6	4.2	2.68	21	72	56.37	151.33	1.22	0.08	0.29
2.0	4.3	2.14	21	62	44.93	96.13	1.32	0.10	0.32
1.6	4.9	2.95	33	124	97.44	287.72	1.24	0.06	0.23
1.6	4.8	2.97	78	287	231.98	689.91	1.22	0.02	0.15
1.8	4.3	2.40	71	186	170.73	410.55	1.07	0.02	0.15
1.7	4.6	2.71	70	255	189.75	514.37	1.32	0.03	0.18
1.7	4.9	2.84	20	52	56.89	161.83	0.87	0.05	0.22

Figure 40. Calculations for Individual Projects (Naïve Method).



WC(s) & All/Target Crashes & Crash Severity(-ies)	Work Code(s)	Work Code Description	All or Target Crashes	Crash Severity(-ies)	Number of Projects
All projects entered in the "Input" sheet					387
303;All;KABCO	303	Resurfacing	All	KABCO	12
303;Target;KABCO	303	Resurfacing	Target	KABCO	2
304;All;KABC	304	Safety Lighting	All	KABC	1
209;Target;KABC	209	Safety Treat Fixed Objects	Target	KABC	1
209;All;KAB	209	Safety Treat Fixed Objects	All	KAB	1
541;Target;KAB	541	Provide Additional Paved Surface	Target	KAB	2
541;All;KABCO	541	Provide Additional Paved Surface	All	KABCO	113
542;Target;KABCO	542	Milled Centerline Rumble Strips	Target	KABCO	1
206, 209;Target;KABCO	206, 209	Improve Guardrail To Design Sta	Target	KABCO	1
206, 209;All;KABCO	206, 209	Improve Guardrail To Design Sta	All	KABCO	12
203;All;KABCO	203	Install Raised Median	All	KABCO	5
519, 521;All;KABCO	519, 521	Add Left Turn Lane, Add Right Tu	All	KABCO	1
407;All;KABCO	407	Install Sidewalks	All	KABCO	1
503, 540;All;KABCO	503, 540	Widen Paved Shoulder (to 5 ft. o	All	KABCO	1
209;All;KABCO	209	Safety Treat Fixed Objects	All	KABCO	46
542;All;KABCO	542	Milled Centerline Rumble Strips	All	KABCO	32

Figure 41. Data for Groups of Projects (Naïve Method).



Variance of Expected Crashes (After)	Crash Modification Factor (CMF)	Safety Effectiveness (as Percent Change in Crash Frequency)	Variance of CMF	Standard Error of CMF	Standard Error*100	Statistical Significance
30249.12	**1.26**	**-26.28**	**0.000**	**0.014**	**1.45**	**Significant at 95% confidence level**
4262.76	1.26	-26.40	0.004	0.066	6.65	Significant at 95% confidence level
188.93	1.24	-23.59	0.094	0.307	30.72	Not significant at 90% confidence level
280.20	1.22	-22.04	0.045	0.213	21.26	Not significant at 90% confidence level
904.33	1.10	-9.50	0.016	0.126	12.58	Not significant at 90% confidence level
6.01	0.41	59.21	0.062	0.250	24.98	Significant at 95% confidence level
112.36	0.32	67.59	0.012	0.108	10.84	Significant at 95% confidence level
2745.41	1.06	-6.00	0.002	0.040	4.02	Not significant at 90% confidence level
196.60	0.88	11.97	0.033	0.181	18.14	Not significant at 90% confidence level
151.33	1.22	-21.92	0.083	0.289	28.86	Not significant at 90% confidence level
790.82	0.99	1.29	0.007	0.081	8.11	Not significant at 90% confidence level
1115.98	1.24	-23.93	0.003	0.059	5.90	Significant at 95% confidence level
410.55	1.07	-7.43	0.022	0.148	14.78	Not significant at 90% confidence level
138.41	1.35	-35.23	0.109	0.331	33.09	Not significant at 90% confidence level
53.90	1.23	-22.58	0.176	0.419	41.93	Not significant at 90% confidence level
971.80	0.97	3.41	0.003	0.053	5.34	Not significant at 90% confidence level
7339.76	1.04	-4.26	0.002	0.041	4.07	Not significant at 90% confidence level

Figure 42. Calculations for Groups of Projects (Naïve Method).

Data field descriptions, Excel formulas, and equations are provided in Appendices G through K.

5.6 OTHER SHEETS

Each tool includes two additional worksheets that are shown in gray at the bottom of Figure 28. These worksheets are “SPFs_CMFs” and “Menu Lists.” The “SPFs_CMFs” worksheet contains a list of SPFs and CMFs published in TxDOT’s *Roadway Safety Design Workbook* (*28*). The SPFs are used only in the EB method and are suitable for predicting only KABC crashes. The worksheet provides the following characteristics of each SPF:

- SPF Code—the unique ID of each SPF.
- Model Name—the combined multiple abbreviations that refer to the main characteristics of each SPF.
- Number of Lanes—the number of through lanes that are considered to be the base conditions of each SPF.

- Median Type—the type of median that is considered to be the base condition of each SPF.
- Rural/Urban, Functional Class—the rural/urban code combined with the roadway functional class that corresponds to each SPF.
- Crash Severity—the crash severities that each SPF can predict.
- Crash Type—the crash type(s) that each SPF can predict.
- SPF Formula—the equation of each SPF.
- β_0—a constant.
- AADT Coefficient—the coefficient of the AADT.
- Segment Length Coefficient—the coefficient of the segment length.
- Overdispersion Parameter (*k*)—the overdispersion parameter of the SPF.
- Proportion of Undeveloped or Single-Family Residential Land Use—the estimated average proportion of undeveloped or single-family residential land use.
- Proportion of Industrial Land Use—the estimated average proportion of industrial land use.
- Proportion of Business Land Use—the estimated average proportion of business land use.
- Proportion of Office Land Use—the estimated average proportion of office land use.
- CMF for Median Width (Wm)—the CMF for median width.
- CMF for Lane Width (Wl)—the CMF for lane width.
- CMF for Inside Shoulder Width (Wis)—the CMF for inside shoulder width.
- CMF for Outside Shoulder Width (Wos)—the CMF for outside shoulder width.

The "Menu Lists" worksheet provides drop-down menu list items and other information and data that are used in other sheets of both tools. Specifically, the sheet contains the following menu list items:

- Number of Lanes.
- Median Type.
- Functional Class.
- Target Crash Severity.
- All or Target Crashes.
- WC.
- WC Description.
- Reduction Factor.
- Service Life.
- Maintenance Cost.
- District.

Further, the “Menu Lists” worksheet provides the following tables that are used to perform calculations in other sheets of the tools.

- Comprehensive crash unit cost by crash severity: used in the “Economic Analysis” sheet.
- Proportion of crashes by crash severity, rural/urban code, and functional class: used in the “Economic Analysis” sheet.
- Proportion of multi-vehicle and single-vehicle crashes by rural/urban code and functional class: used in the “Empirical Bayes” sheet.
- Proportion of adjacent land use by median type and number of through lanes: values transferred to the “SPF_CMFs” sheet.

CHAPTER 6:
EFFECTIVENESS OF COMPLETED HSIP PROJECTS AND WORK CODES

6.1 INTRODUCTION

This chapter presents the results obtained from safety and cost-effectiveness evaluations of completed HSIP projects and WCs in Texas. To perform these evaluations, TTI used the data described in Chapter 4 and the spreadsheet tools presented in Chapter 5. The research team evaluated 387 segment projects, 70 intersection projects, 46 segment WCs, 21 intersection WCs, and other larger groups of projects (e.g., all 387 segment projects together as one group). For completeness, TTI evaluated the effectiveness of each project and group of projects in relation to six different crash types:

- All KABCO crashes.
- All KABC crashes.
- All KAB crashes.
- Target KABCO crashes.
- Target KABC crashes.
- Target KAB crashes.

The target crashes refer to specific types of crashes that each WC can theoretically prevent according to the preventable crash criteria provided in the TxDOT *HSIP Work Codes Table* (*27*). Among the six crash types, the target KAB crashes are of particular interest in these evaluations because the HSIP focuses on reducing target KAB crashes. In other words, during the HSIP project selection process, TxDOT districts select appropriate WCs in order to reduce the specific types of KAB crashes that are observed along each candidate HSIP project (prior to construction). Further, the SII of each candidate HSIP project accounts only for the KAB crashes that each WC can theoretically prevent.

For completeness, the evaluations were performed using three methods: naïve, naïve with traffic volume correction, and empirical Bayes using SPFs. As explained in previous chapters, the EB method is generally more reliable than other simpler B/A observational methods (*2*); however, in this study, there were several limitations associated with the EB method:

- In the absence of updated Texas-specific SPFs, TTI applied the EB method using the workbook SPFs that were developed more than a decade ago and thus may need to be calibrated with current data.
- The workbook includes a small number of SPFs that apply to specific roadway types with certain characteristics. In the absence of applicable SPFs for all road types, some HSIP projects could not be evaluated.

- Certain data attributes (e.g., number of driveways and land use) that are needed to apply the SPFs were not readily available, so TTI had to make appropriate assumptions.
- The EB method was applied only in the case of all KABC crashes and target KABC crashes because the SPFs included in TxDOT's *Roadway Safety Design Workbook* are appropriate for predicting only KABC crashes.
- Some roadway design attributes needed to apply the EB method were extracted from RHiNo, in which some data may not be up to date.

Therefore, the applicability and reliability of the EB results produced in this study may be compromised by these limitations. The results obtained from the EB method are not presented in this chapter; however, all the study results are provided in the Excel database developed in this research project. TTI used the EB method for demonstration purposes and to ensure that the evaluation tools fully support it. This is one of the first attempts in the state of Texas to apply an advanced data-driven method to evaluate the safety effectiveness of a significant number of HSIP projects and WCs.

For each evaluated project and WC, the research team calculated, where applicable, three B/C ratios—one B/C ratio for each evaluation method. After evaluating all projects and WCs, TTI conducted t-tests to determine whether the three evaluation methods produce statistically different results. Further, the research team developed empirical methods that can be used to improve the results obtained from the naïve method if other methods cannot be applied (e.g., in the absence of traffic volume data).

Sections 6.2 and 6.3 present the evaluation results for the study segments and intersections, respectively. Section 6.4 presents the statistical analysis performed in this study.

6.2 EVALUATION OF PROJECTS ON SEGMENTS

Subsections 6.2.1 and 6.2.2 present the evaluation results obtained for individual HSIP projects and groups of projects, respectively.

6.2.1 Effectiveness of Individual Projects

TTI performed 5,418 individual project evaluations—14 evaluations for each individual project—as explained below:

- The naïve method was applied six times, corresponding to the six crash types listed above.
- The naïve method with traffic volume correction was applied six times, corresponding to the six crash types listed above.
- The EB method was applied two times: one time for all KABC crashes and another time for target KABC crashes.

Table 18 shows a summary of the safety effectiveness evaluation results for individual projects constructed on roadway segments. Appendix L provides a sample of the evaluation results. In addition, TTI developed a Microsoft Excel database that contains all the evaluation results produced in this study for both segments and intersections.

Table 18. Summary of Safety Effectiveness Evaluation Results for Individual Projects on Segments.

Safety Effectiveness of Individual Projects			Number of Project Evaluations			Percent of All
			Naïve	Naïve with Vol. Correct.	EB	
θ<1.0		Effective	1,084	1,153	287	46.6%
θ>1.0		Not effective	662	593	241	27.6%
θ cannot be determined	# Crashes before > 0 # Crashes after = 0	Potentially Effective	405	405	144	17.6%
	# Crashes before = 0 # Crashes after > 0	Potentially Not effective	98	98	5	3.7%
	# Crashes before = 0 # Crashes after = 0	Effectiveness cannot be determined	73	73	23	3.1%
	# Crashes before > 0 # Crashes after > 0	Effectiveness cannot be determined	-	-	74	1.4%
Subtotal			**2,322**	**2,322**	**774**	**100%**
Total			**5,418**			**100%**

The performance measure that captures the safety effectiveness of an individual project is the safety effectiveness index, θ. The calculation of θ is provided in Chapter 5 (Section 5.3) and in Appendices G through J. It is worth noting that in some cases, the safety effectiveness index cannot be computed. For example, θ cannot be calculated using the naïve method and the naïve method with traffic volume correction method when the sum of crashes in the before period or the sum of crashes in the after period is zero. Although the EB method can be applied if the sum of crashes in the before period is zero, there were several projects for which there was no applicable SPF (e.g., lower functional classes); thus, θ could not be calculated.

As a result of these limitations, a safety effectiveness index was calculated for 74 percent (4,020 evaluations) of all 5,418 project evaluations. Specifically, 46.6 percent of all project evaluations resulted in $\theta < 1.0$ (effective projects), 27.6 percent resulted in $\theta > 1.0$, and in the remaining 25.8 percent, θ could not be computed. Of the remaining 25.8 percent of the evaluations, 17.6 percent had one or more crashes in the before period and zero crashes in the after period. This finding can be used only as an inconclusive indication that these projects may have potentially been effective if the durations of the two periods were similar, traffic volumes did not decrease in the after period, and other external factors did not affect the roadway safety at the examined sites. Overall, of the 4,020 project evaluations where the calculation of θ was feasible, 62.8 percent resulted in $\theta < 1.0$ (effective projects) and 37.2 percent resulted in $\theta > 1.0$.

The B/C ratio captures the cost effectiveness of a project. B/C ratios were calculated for 91 percent of all segment project evaluations. The B/C ratio cannot be determined if there are no crashes in the before period. Table 19 shows a summary of the cost-effectiveness evaluation results for individual projects.

Table 19. Summary of Cost-Effectiveness Evaluation Results for Individual Projects on Segments.

B/C Ratio of Individual Projects			Number of Project Evaluations			Percent of All
			Naïve	Naïve with Vol. Correct.	EB	
B/C>1.0		Effective	1,277	1,315	340	54%
B/C<1.0		Not effective	874	836	271	37%
B/C cannot be determined	# Crashes before > 0 # Crashes after = 0	Potentially Effective	-	-	29	1%
	# Crashes before = 0 # Crashes after > 0	Potentially Not effective	98	98	37	4%
	# Crashes before = 0 # Crashes after = 0	Effectiveness cannot be determined	73	73	23	3%
	# Crashes before > 0 # Crashes after > 0	Effectiveness cannot be determined	-	-	74	1%
Subtotal			**2,322**	**2,322**	**774**	**100%**
Total			**5,418**			**100%**

As shown in Table 19, 54 percent of all project evaluations resulted in B/C > 1.0, 37 percent produced B/C < 1.0, and in the remaining 9 percent, the calculation of B/C was not feasible.

6.2.2 Effectiveness of Groups of Projects

Initially, TTI evaluated each of the 46 segment-related WCs that were implemented at the 387 segment projects. Note that the minimum number of projects recommended to develop a CMF for a particular WC is 20–30 (*2*, *6*). Among the 46 WCs evaluated in this study, only four included 30 or more projects. Table 20 shows the top 10 WCs sorted by sample size. Together, the top four WCs include 235 projects, which is approximately 61 percent of all 387 segment projects.

Table 20. Top 10 Work Codes Sorted by Sample Size.

WC(s)	WC Description	Sample Size
541	Provide Additional Paved Surface Width	115
209	Safety Treat Fixed Objects	48
502	Widen Lane(s)	39
542	Milled Centerline Rumble Strips	33
532	Milled Edgeline Rumble Strips	17
303	Resurfacing	14
532, 542	Milled Edgeline Rumble Strips, Milled Centerline Rumble Strips	14
206, 209	Improve Guardrail to Design Standards, Safety Treat Fixed Objects	13
201	Install Median Barrier	12
533, 542	Profile Edgeline Markings, Milled Centerline Rumble Strips	11

Because each of the remaining 42 WCs had a small sample size (<30 projects), which is not recommended for CMF development, this report shows the evaluation results (Table 21) for only the top four WCs. The results are shown in the last six columns of the table and include:

- The CMF calculated based on the naïve method and the naïve method with traffic volume correction. A CMF greater than 1 indicates an expected increase in crash frequency (yellow cells), while a CMF less than 1 indicates an expected decrease in crashes (green cells).
- The statistical significance of each CMF. The cells highlighted in yellow indicate non-significant CMFs at the 90 percent confidence level, and the green cells represent statistically significant CMFs at the 95 percent confidence level.
- The B/C ratio calculated based on the naïve method and the naïve method with traffic volume correction.

Table 21. Evaluation Results for Top Four Segment-Related WCs.

WC	Crash Type	CMF		Significance of CMF		B/C	
		Naïve	Naïve with Correct.	Naïve	Naïve with Correct.	Naïve	Naïve with Correct.
541 Provide Additional Paved Surface Width	All KABCO	1.04	1.02	Not Sig.	Not Sig.	-21.4	-17.0
	All KABC	0.98	0.95	Not Sig.	Not Sig.	0.2	5.9
	All KAB	0.92	0.90	Not Sig.	Not Sig.	15.3	17.7
	Target KABCO	0.89	0.88	Sig.	Sig.	11.4	10.4
	Target KABC	0.87	0.85	Sig.	Sig.	9.1	8.2
	Target KAB	0.82	0.81	Sig.	Sig.	12.8	11.1
209 Safety Treat Fixed Objects	All KABCO	1.00	0.85	Not Sig.	Sig.	-224.6	227.1
	All KABC	0.92	0.73	Not Sig.	Sig.	369.3	636.3
	All KAB	0.94	0.73	Not Sig.	Sig.	417.3	613.1
	Target KABCO	0.93	0.77	Not Sig.	Sig.	142.1	209.9
	Target KABC	0.78	0.62	Sig.	Sig.	176.0	238.9
	Target KAB	0.84	0.65	Not Sig.	Sig.	146.6	196.8
502 Widen Lane(s)	All KABCO	0.78	0.79	Sig.	Sig.	16.6	17.0
	All KABC	0.68	0.69	Sig.	Sig.	21.4	22.4
	All KAB	0.55	0.56	Sig.	Sig.	27.3	27.6
	Target KABCO	0.61	0.62	Sig.	Sig.	13.8	14.2
	Target KABC	0.56	0.57	Sig.	Sig.	18.0	18.7
	Target KAB	0.48	0.48	Sig.	Sig.	17.4	17.7
542 Milled Centerline Rumble Strips	All KABCO	1.04	1.00	Not Sig.	Not Sig.	-530.4	-476.3
	All KABC	1.01	0.97	Not Sig.	Sig.	50.5	93.1
	All KAB	0.90	0.85	Not Sig.	Sig.	145.8	193.7
	Target KABCO	0.84	0.82	Sig.	Sig.	134.5	153.6
	Target KABC	0.80	0.77	Sig.	Sig.	154.0	174.4
	Target KAB	0.74	0.70	Sig.	Sig.	160.7	179.0

The most important findings from Table 21 are provided below. The findings are based on the results obtained from the naïve method with traffic volume correction, which is more reliable than the naïve method that does not account for traffic volumes.

- Overall, all four WCs have been effective from a safety and cost perspective in reducing not only target KAB crashes, which is the goal of the HSIP, but other crash types as well. Most CMFs and B/C ratios indicate positive results (i.e., CMF < 1.0 and B/C > 1.0) with the exception of all KABCO crashes for WCs 541 and 542, in which the CMFs calculated using the naïve method with traffic volume correction are slightly higher than 1.0;

however, the CMFs are not statistically significant at the 90 percent confidence level, suggesting that additional data from more HSIP projects may be needed.

- The safety effectiveness of all four WCs is higher in the case of target crashes, as opposed to all crashes. In other words, the CMFs computed for target KABCO, target KABC, and target KAB crashes are lower that the corresponding CMFs calculated for all KABCO, all KABC, and all KAB crashes, respectively.
- Overall, the safety effectiveness of all WCs tends to be higher in the case of KAB crashes, followed by KABC crashes, and then KABCO crashes. This trend is consistent throughout the table and applies to both all crashes and target crashes. For example, the CMFs of WC 542 that correspond to all KABCO, all KABC, and KAB crashes are 1.00, 0.97, and 0.85, respectively (the lower the CMF, the better). Likewise, a similar improvement in the safety effectiveness of WC 542 is observed by comparing the CMFs of target KABCO crashes (0.82), target KABC crashes (0.77), and target KAB crashes (0.70).
- WC 541 Provide Additional Paved Surface Width led to a reduction in target crashes of between 21 percent (CMF value of 0.89) and 29 percent (CMF value of 0.81). The results are statistically significant at the 95 percent confidence level. The B/C ratio computed for target crashes ranged from 8 to 11.
- WC 209 Safety Treat Fixed Objects reduced target crashes by 23–38 percent. All CMFs obtained from the naïve method with traffic volume correction were statistically significant at the 95 percent confidence level. The B/C ratios calculated for target crashes were between 197 and 239.
- WC 502 Widen Lanes led to a reduction in target KABCO, target KABC, and target KAB crashes by 38 percent, 43 percent, and 52 percent, respectively. The results are statistically significant at the 95 percent confidence level. The B/C ratios computed for target crashes were between 14 and 19.
- WC 542 Milled Centerline Rumble Strips reduced the target KABCO crashes by 18 percent, target KABC crashes by 23 percent, and target KAB crashes by 30 percent. The B/C ratios calculated for target crashes ranged from 154–179.

After evaluating the performance of each of the top four WCs separately, the research team evaluated all four WCs as one group that included 235 individual HSIP projects. The results from these evaluations are shown in Table 22.

Table 22. Evaluation Results for Top Four Segment-Related WCs Treated as a Single Group.

WC	Crash Type	CMF		Significance of CMF		B/C	
		Naïve	Naïve with Correct.	Naïve	Naïve with Correct.	Naïve	Naïve with Correct.
Top 4 WCs as a Single Group (235 projects)	All KABCO	1.03	0.97	Not Sig.	Not Sig.	−18.4	−1.7
	All KABC	0.97	0.90	Not Sig.	Sig.	40.3	70.2
	All KAB	0.91	0.83	Sig.	Sig.	59.4	80.7
	Target KABCO	0.87	0.83	Sig.	Sig.	10.4	12.9
	Target KABC	0.82	0.77	Sig.	Sig.	31.6	37.7
	Target KAB	0.78	0.73	Sig.	Sig.	31.5	35.7

Overall, the results produced from the naïve method with traffic volume correction confirm the findings described above. The entire group of projects has been effective from a safety and cost perspective in reducing all six crash types (all KABCO, all KABC, all KAB, target KABCO, target KABC, target KAB). Not surprisingly, the group is clearly more effective in reducing the target crashes that each WC can theoretically prevent rather than all types of crashes. The expected percent reduction of target KABCO, target KABC, and target KAB crashes is 17 percent, 23 percent, and 27 percent, respectively. These results are statistically significant at the 95 percent confidence level. The B/C ratios calculated for target crashes ranged from 13 to 38.

For completeness, TTI evaluated the safety and cost effectiveness of all 387 segment projects as a single group. The results produced from the naïve method with traffic volume correction reveal that the entire group of all 387 segment projects has been effective from both a safety and cost perspective in reducing target KAB crashes by 16 percent (CMF = 0.84). The CMF is statistically significant at the 95 percent confidence level. Note that the sole purpose of calculating this CMF was to determine the overall safety effectiveness of all 387 projects as a group, not to use the CMF in future HSIP evaluations. The group B/C ratio computed for target KAB crashes was 71.9.

6.3 EVALUATION OF PROJECTS AT INTERSECTIONS

Subsections 6.3.1 and 6.3.2 present the evaluation results obtained for individual HSIP projects and groups of projects, respectively.

6.3.1 Effectiveness of Individual Projects

TTI performed 980 evaluations of 70 intersection projects—14 evaluations for each individual project—as explained below:

- The naïve method was applied six times, corresponding to the six crash types listed above.
- The naïve method with traffic volume correction was applied six times, corresponding to the six crash types listed above.
- The EB method was applied two times: one time for all KABC crashes and a second time for target KABC crashes.

Table 23 shows a summary of the safety effectiveness evaluation results for individual projects at intersections. Appendix L provides a sample of the evaluation results. The Microsoft Excel database developed in this study contains all the results for the evaluated HSIP segment and intersection projects.

Table 23. Summary of Safety Effectiveness Evaluation Results for Individual Projects at Intersections.

Safety Effectiveness of Individual Projects			Number of Project Evaluations			Percent of All
			Naïve	Naïve with Vol. Correct.	EB	
θ<1.0		Effective	194	209	73	48.6%
θ>1.0		Not effective	139	124	41	31.0%
θ cannot be determined	# Crashes before > 0 # Crashes after = 0	Potentially Effective	34	34	12	8.2%
	# Crashes before = 0 # Crashes after > 0	Potentially Not effective	26	26	6	5.9%
	# Crashes before = 0 # Crashes after = 0	Effectiveness cannot be determined	27	27	8	6.3%
	# Crashes before > 0 # Crashes after > 0	Effectiveness cannot be determined	-	-	-	0.0%
Subtotal			**420**	**420**	**140**	**100%**
Total			**980**			**100%**

As explained in Section 6.2.1 and shown in Table 23, in some cases the safety effectiveness index, θ, cannot be computed. For example, θ cannot be calculated using the naïve method and the naïve method with traffic volume correction when the sum of crashes in the before period or the sum of crashes in the after period is zero. Although the EB method can be applied if the sum of crashes in the before period is zero, there were some projects for which there was no applicable SPF; thus, θ could not be calculated.

As a result of these limitations, a safety effectiveness index was calculated for 80 percent (780 evaluations) of all 980 project evaluations. Specifically, 48.6 percent of all project evaluations resulted in $\theta < 1.0$ (effective projects), 31.0 percent resulted in $\theta > 1.0$, and in the remaining 20.4 percent, θ could not be computed. Of the remaining 20.4 percent of the evaluations, 8.2 percent had one or more crashes in the before period and zero crashes in the after period. This finding can be used as an inconclusive indication that these projects may have potentially been effective if the durations of the two periods were similar, traffic volumes did not decrease in the after period, and other external factors did not affect the roadway safety at the examined sites. Overall, of the 780 project evaluations where the calculation of θ was feasible, 61.0 percent resulted in $\theta < 1.0$ (effective projects) and 39.0 percent resulted in $\theta > 1.0$.

B/C ratios were calculated for 88 percent of all intersection project evaluations. The B/C ratio cannot be determined if there are no crashes in the before period. Table 24 shows a summary of the cost-effectiveness evaluation results for individual projects.

Table 24. Summary of Cost-Effectiveness Evaluation Results for Individual Projects at Intersections.

B/C Ratio of Individual Projects			Number of Project Evaluations			Percent of All
			Naïve	Naïve with Vol. Correct.	EB	
B/C>1.0		Effective	199	216	71	50%
B/C<1.0		Not effective	168	151	49	38%
B/C cannot be determined	# Crashes before > 0 # Crashes after = 0	Potentially Effective	-	-	1	0%
	# Crashes before = 0 # Crashes after > 0	Potentially Not effective	26	26	9	6%
	# Crashes before = 0 # Crashes after = 0	Effectiveness cannot be determined	27	27	8	6%
	# Crashes before > 0 # Crashes after > 0	Effectiveness cannot be determined	-	-	2	0%
Subtotal			**420**	**420**	**140**	**100%**
Total			**980**			**100%**

As shown in the table, 50 percent of all project evaluations resulted in B/C > 1.0, 38 percent produced B/C < 1.0, and in the remaining 12 percent, the calculation of B/C was not feasible.

6.3.2 Effectiveness of Groups of Projects

Table 25 shows all 21 intersection-related WCs sorted by sample size. Note that none of these WCs includes 30 or more projects, which is the minimum sample size recommended to develop a CMF (*2*, *6*). For completeness and demonstration purposes, TTI evaluated all WCs, but the report shows the results for only the top two WCs that together include 39 projects, which is approximately 56 percent of all 70 intersection projects. The evaluation results are shown in Table 26.

Table 25. Intersection Work Codes and Number of Projects

Work Code	Work Code Description	Sample Size
108	Improve Traffic Signals	26
107	Install Traffic Signal	13
105	Install Intersection Flashing Beacon	7
105, 305	Install Intersection Flashing Beacon, Safety Lighting at Intersection	4
519	Add Left Turn Lane	3
108, 508, 519, 520	Improve Traffic Signals, Realign Intersection, Add Left Turn Lane, Lengthen Left Turn Lane	2
132, 305	Install Advance Warning Signals, Signs, Safety Lighting	1
108, 132	Improve Traffic Signals, Install Advance Warning Signals and Signs	1
105, 307	Install Intersection Flashing Beacon, High Friction Surface Treatment	1
122	Install Advance Warning Signals (Existing Warning Signs)	1
305, 520	Safety Lighting at Intersection, Lengthen Left Turn Lane	1
107, 305	Install Traffic Signal, Safety Lighting at Intersection	1
105, 521	Install Intersection Flashing Beacon, Add Right Turn Lane	1
105, 545	Install Intersection Flashing Beacon, Transverse Rumble Strips	1
108, 520	Improve Traffic Signals, Lengthen Left Turn Lane	1
508	Realign Intersection	1
108, 519	Improve Traffic Signals, Add Left Turn Lane	1
132	Install Advance Warning Signals and Signs	1
105, 519	Install Intersection Flashing Beacon, Add Left Turn Lane	1
105, 124	Install Intersection Flashing Beacon, Install Advance Warning Signals and Signs (Intersection)	1
305	Safety Lighting at Intersection	1

Table 26. Evaluation Results for Top Two Intersection-Related WCs.

WC	Crash Type	CMF		Significance of CMF		B/C	
		Naïve	Naïve with Correct.	Naïve	Naïve with Correct.	Naïve	Naïve with Correct.
108 Improve Traffic Signals	All KABCO	1.11	1.06	Sig.	Not Sig.	−848.6	−541.0
	All KABC	1.10	1.04	Not Sig.	Not Sig.	444.6	491.2
	All KAB	1.10	1.04	Not Sig.	Not Sig.	91.4	130.3
	Target KABCO	1.02	0.98	Not Sig.	Not Sig.	141.4	297.7
	Target KABC	1.03	0.98	Not Sig.	Not Sig.	227.5	239.5
	Target KAB	0.99	0.94	Not Sig.	Not Sig.	93.6	122.4
107 Install Traffic Signal	All KABCO	0.87	0.76	Not Sig.	Sig.	329.0	523.5
	All KABC	0.71	0.61	Sig.	Sig.	691.7	938.3
	All KAB	0.49	0.42	Sig.	Sig.	737.3	963.9
	Target KABCO	0.79	0.69	Sig.*	Sig.	281.5	415.3
	Target KABC	0.65	0.55	Sig.	Sig.	578.2	770.8
	Target KAB	0.43	0.36	Sig.	Sig.	601.5	779.1

*Statistically significant CMF at 90 percent confidence level.

The most important findings from Table 26 are provided below. The findings are based on the results obtained from the naïve method with traffic volume correction.

- The safety effectiveness of both WCs is higher in the case of target crashes, as opposed to all crashes. In other words, the CMFs computed for target KABCO, target KABC, and target KAB crashes are lower that the corresponding CMFs calculated for all KABCO, all KABC, and all KAB crashes, respectively.
- The safety effectiveness of both WCs tends to be higher in the case of KAB crashes, followed by KABC crashes, and then KABCO crashes. This trend applies to both all crashes and target crashes. For example, the CMFs of WC 107 that correspond to all KABCO, all KABC, and all KAB crashes are 0.76, 0.61, and 0.42, respectively (the lower the CMF, the better). Likewise, a similar improvement in the safety effectiveness of WC 542 is observed by comparing the CMFs of target KABCO crashes (0.69), target KABC crashes (0.55), and target KAB crashes (0.36).
- WC 108 Improve Traffic Signals led to a reduction in target crashes of between 2 percent (CMF = 0.98) and 6 percent (CMF = 0.94). However, the results are not statistically significant at the 90 percent confidence level, indicating insufficient sample size for CMF development. The B/C ratio computed for target crashes ranged from 130 to 298, suggesting that the low implementation cost of the WC has yielded significant benefits from an economic standpoint.

- WC 107 Install Traffic Signal led to a significant reduction in all six crash types of between 24 percent (all KABCO crashes) and 63 percent (target KAB crashes). All CMFs obtained from the naïve method with traffic volume correction were statistically significant at the 95 percent confidence level. The B/C ratios calculated for target crashes ranged from 415 (target KABCO crashes) to 964 (all KAB crashes).
- The reliability and accuracy of the evaluation results for all 21 intersection-related WCs can be improved by increasing the sample size.

For completeness, the research team evaluated all 70 intersection projects as one group. The results from these evaluations are shown in Table 27.

Table 27. Evaluation Results for All 70 Intersection-Related Projects Treated as a Single Group.

WC	Crash Type	CMF		Significance of CMF		B/C	
		Naïve	Naïve with Correct.	Naïve	Naïve with Correct.	Naïve	Naïve with Correct.
All 21 WCs as a Single Group (70 projects)	All KABCO	1.05	0.98	Not Sig.	Not Sig.	−256.0	−119.3
	All KABC	0.95	0.88	Not Sig.	Sig.	293.5	345.2
	All KAB	0.87	0.79	Not Sig.	Sig.	137.6	183.7
	Target KABCO	0.97	0.91	Not Sig.	Sig.*	83.4	159.1
	Target KABC	0.88	0.82	Sig.*	Sig.	188.9	221.5
	Target KAB	0.81	0.74	Sig.	Sig.	111.9	145.6

*Statistically significant CMF at 90 percent confidence level.

The entire group of all 70 intersection projects has been effective from a safety and cost perspective in reducing all six crash types (all KABCO, all KABC, all KAB, target KABCO, target KABC, target KAB). The safety effectiveness of the group in reducing target crashes is higher than in reducing all crashes. The expected percent reduction of target KABCO, target KABC, and target KAB crashes is 9 percent (CMF = 0.91), 18 percent (CMF = 0.82), and 26 percent (CMF = 0.74), respectively. These results are statistically significant, as indicated in the table. Note that the sole purpose of calculating these CMFs was to determine the overall safety effectiveness of all 70 projects as a group, not to use the CMFs in future evaluations. The group B/C ratios calculated for target crashes were between 146 and 222.

6.4 STATISTICAL ANALYSIS

TTI compared the results produced by the naïve method against those from the naïve method with traffic volume correction. The purpose of this comparison was to examine the relationship between the two methods and identify potential differences in the evaluation results. To perform the comparison, TTI developed scatterplots, fitted linear trendlines, and conducted t-tests.

Figure 43 shows a scatterplot that displays the safety effectiveness indexes calculated for individual HSIP segment and intersection projects using the two methods. The results include all evaluations conducted for the six different crash types (all KABCO, all KABC, all KAB, target KABCO, target KABC, target KAB). In other words, each dot corresponds to a pair of indexes calculated for a specific individual project and crash type (e.g., target KAB). The scatterplot includes two time series. The orange dots represent the safety effectiveness indexes for segments, and the blue dots show those for intersections. The dotted black line is the dichotomous (i.e., 45-degree angle) line. Further, a linear regression line with no intercept has been fitted in each data series. The regression lines are shown as dotted lines in Figure 43. Each line has the same color as that of the data series in which it has been fitted. The scatterplot shows the linear regression equation and the correlation coefficient (R-square) of each line.

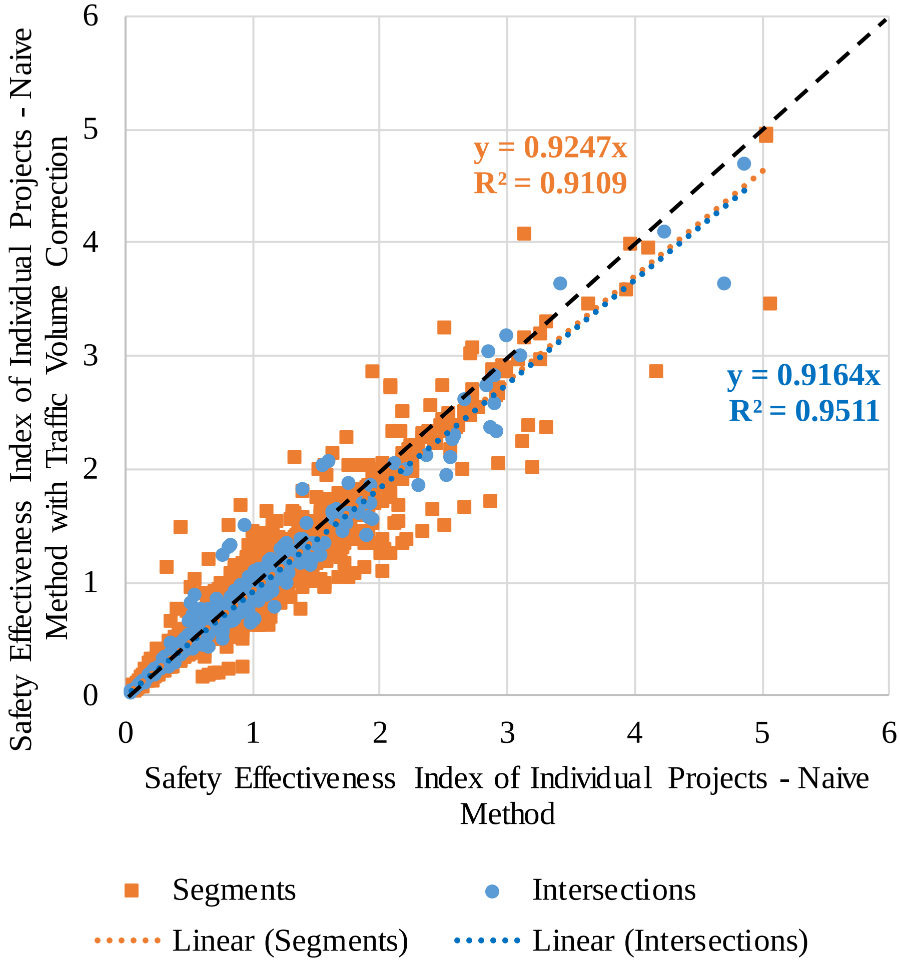


Figure 43. Scatterplot of Safety Effectiveness Indexes Obtained from Naïve Method vs. Naïve Method with Traffic Volume Correction.

From Figure 43, it can be observed that the naïve method with traffic volume correction tends to produce lower safety effectiveness indexes than the naïve method by a factor of 0.92. This factor is the (rounded up/down) slope of both regression equations shown in Figure 43. In these equations, the dependent variable (*y*) is the safety effectiveness index calculated using the naïve method with traffic volume correction and *x* is the safety effectiveness index derived from the naïve method. Both regression lines are below the 45-degree line, indicating that the naïve method with traffic volume correction results on average in lower indexes (i.e., higher project effectiveness). This finding can be attributed to the fact that traffic volumes tend to increase over time; however, the naïve method does not account for traffic volumes.

Table 28 shows the results of a t-test conducted to determine whether the two evaluation methods produce statistically different safety effectiveness indexes for individual segment projects. Table 29 shows the results of a second t-test conducted to determine whether the two evaluation methods produce statistically different safety effectiveness indexes for individual intersection projects. Both t-tests were performed at 95 percent confidence levels assuming unequal variances of the two samples.

Table 28. Results of t-Test Performed on Safety Effectiveness Indexes of Individual Segment Projects.

Statistic	Naïve	Naïve with Traffic Volume Correction
Mean	0.962	0.900
Variance	0.403	0.356
Observations	1746	1746
Hypothesized mean difference	0	
df	3477	
t stat	2.939	
P(T<=t) one-tail	0.002	
t critical one-tail	1.645	
P(T<=t) two-tail	0.003	
t critical two-tail	1.961	

Table 29. Results of t-Test Performed on Safety Effectiveness Indexes of Individual Intersection Projects.

Statistic	Naïve	Naïve with Traffic Volume Correction
Mean	1.004	0.930
Variance	0.525	0.445
Observations	333	333
Hypothesized mean difference	0	
df	659	
t stat	1.378	
P(T<=t) one-tail	0.084	
t critical one-tail	1.647	
P(T<=t) two-tail	0.169	
t critical two-tail	1.964	

The null hypothesis in both tests is that the two methods have equal means. Table 28 shows that $P(T<=t) < 0.05$, which means that the null hypothesis can be rejected. In other words, the t-test shows that the two methods produce statistically different means at the 95 percent confidence level. Note that the mean of the naïve method is 0.96, whereas that of the naïve method that accounts for traffic volumes is lower (0.90), confirming the findings described above. Table 29 also shows that the naïve method with traffic volume correction results in lower means than the naïve method; however, the two means are not statistically different ($P(T<=t) > 0.05$). Additional observations (i.e., intersection projects) may be needed to confirm the validity of these t-test results.

TTI also compared the CMFs developed using the two methods. Figure 44 shows a scatterplot that displays the safety effectiveness indexes calculated for segment and intersection CMFs using the two methods. The results include all evaluations conducted for the six different crash types (all KABCO, all KABC, all KAB, target KABCO, target KABC, target KAB). In other words, each dot corresponds to a pair of CMFs calculated for a given WC and crash type (e.g., target KAB). The scatterplot includes two time series. The orange dots represent the CMFs for segments, and the blue dots show those for intersections. The dotted black line is the dichotomous (i.e., 45-degree angle) line. Further, a linear regression line with no intercept has been fitted in each data series. The regression lines are shown as dotted lines in Figure 44. Each line has the same color as that of the data series in which it has been fitted. The scatterplot shows the linear regression equation and the correlation coefficient (R-square) of each line.

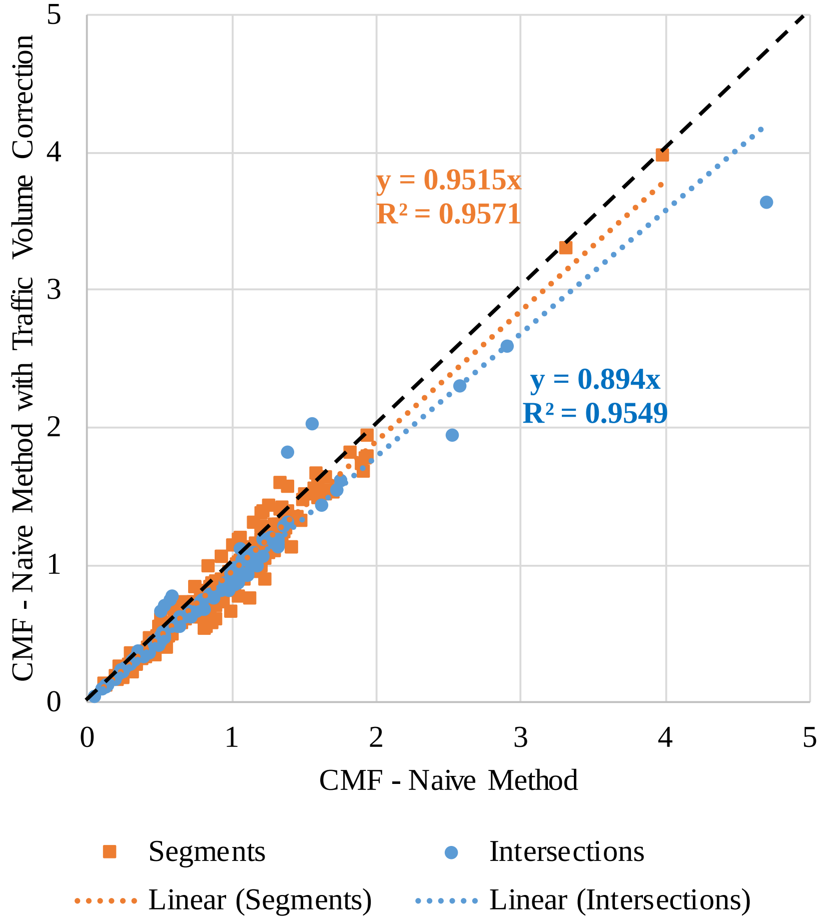


Figure 44. Scatterplot of CMFs Obtained from Naïve Method vs. Naïve Method with Traffic Volume Correction.

From Figure 44, it can be observed that the naïve method with traffic volume correction tends to produce lower CMFs than the naïve method by a factor of 0.95 in the case of segments and 0.89 in the case of intersections. In these equations, the dependent variable (y) is the CMF calculated using the naïve method with traffic volume correction, and x is the CMF derived from the naïve method. Both regression lines are below the 45-degree line, indicating that the naïve method with volume correction results on average in lower CMFs (i.e., higher safety effectiveness). This finding can be attributed to the fact that traffic volumes tend to increase over time; however, the naïve method does not account for traffic volumes.

Table 30 and Table 31 show the results of two t-tests conducted to determine whether the two evaluation methods produce statistically different CMFs for segment and intersection projects, respectively. Both t-tests were performed at 95 percent confidence levels assuming unequal variances of the two samples.

Table 30. Results of t-Test Performed on CMFs Derived for Groups of Segment Projects.

Statistic	Naïve	Naïve with Traffic Volume Correction
Mean	0.943	0.890
Variance	0.215	0.216
Observations	236	236
Hypothesized mean difference	0	
df	470	
t stat	1.236	
P(T<=t) one-tail	0.109	
t critical one-tail	1.648	
P(T<=t) two-tail	0.217	
t critical two-tail	1.965	

Table 31. Results of t-Test Performed on CMFs Derived for Groups of Intersection Projects.

Statistic	Naïve	Naïve with Traffic Volume Correction
Mean	0.921	0.847
Variance	0.453	0.337
Observations	103	103
Hypothesized mean difference	0	
df	200	
t stat	0.843	
P(T<=t) one-tail	0.200	
t critical one-tail	1.653	
P(T<=t) two-tail	0.400	
t critical two-tail	1.972	

Though the results from both t-tests reveal that the sample means (CMFs) are not statistically different at the 95 percent confidence level, the means of the naïve method with traffic volume correction are smaller than those of the naïve method. To increase the reliability of these results, larger sample size may be needed.

CHAPTER 7: CONCLUSIONS AND RECOMMENDATIONS

7.1 INTRODUCTION

Over the last few years, TxDOT has been trying to improve its HSIP by placing emphasis on implementing data-driven safety predictive methods and modern visualization tools. In 2016, TxDOT funded research project 0-6912, which aimed to improve and streamline the network screening, safety diagnosis, countermeasure selection, and project prioritization processes at TxDOT (*3*). The project developed a network screening process, innovative CAVS products, and project prioritization process and tool. Based on positive feedback received about the 0-6912 project deliverables, TxDOT funded another study (project 5-6912) to further improve and refine the 0-6912 network screening process and implement the CAVS products statewide to assist all TxDOT districts in selecting candidate HSIP projects (*4*). Though projects 0-6912 and 5-6912 yielded significant benefits for TxDOT, they did not focus on the safety effectiveness evaluation aspects of the HSIP.

The goal of research project 0-6961 was to find ways to advance TxDOT's HSIP evaluation processes and practices. To address this goal, TTI reviewed safety and cost-effectiveness evaluation methods as well as state evaluation practices and tools; gathered, compiled, and assessed TxDOT data and evaluated the applicability of various evaluation methods and tools in Texas; developed evaluation tools for segments and intersections; and evaluated the safety and cost effectiveness of HSIP projects and countermeasures that have been implemented in Texas over the last few years.

The next section summarizes the research findings and conclusions from this research study. Section 7.3 provides a list of implementation recommendations for TxDOT.

7.2 FINDINGS AND CONCLUSIONS

At the beginning of this research, TTI reviewed safety and cost-effectiveness evaluation methods available in the literature, examined state HSIP evaluation practices, and determined general trends. The main findings from these activities include the following:

- Of the 10 safety effectiveness evaluation methods reviewed and presented in Chapter 2, the most frequently used method is the naïve B/A observational method, used by 37 states. This method involves estimating the change in number of crashes before and after project construction. Naïve B/A methods are simple to understand and apply but have several shortcomings, such as not accounting for RTM effects.
- Among all evaluation methods examined, the EB method that uses SPFs produces the most reliable results by accounting for RTM bias, changes in traffic volumes, and roadway characteristics.

- Most states have established HSIP planning and implementation processes without placing particular emphasis on the evaluation of individual projects, countermeasures, or entire programs. About half of the states provided project evaluation data in their annual HSIP reports. In 2016 and 2017, 25 and 27 states, respectively, included evaluation data for completed HSIP projects or countermeasures. In 2017, 16 states reported that they conducted countermeasure effectiveness evaluations. Based on 2017 HSIP report data, North Carolina, Florida, and Pennsylvania have evaluated more projects than other states—1,714, 1,082, and 243 projects, respectively. Note that some of these evaluations have been conducted over a number of years, not during a single annual HSIP reporting cycle.
- Most states use one or two measures to determine the effectiveness of their HSIP, with the exception of Delaware, New Jersey, and Pennsylvania, which use four measures. Changes in fatal and injury crashes are used by 37 states, while 23 states have estimated B/C ratios to capture the effectiveness of their programs.
- The most frequently used indicators that demonstrate the effectiveness and success of state HSIPs are "increased awareness of safety and data-driven process" (32 states) and "more systemic programs" (30 states).
- The most frequently evaluated SHSP emphasis areas are intersections (44 states), pedestrians (43 states), and bicyclists (40 states).

The research team gathered and processed roadway, traffic, crash, and construction data for 2,281 HSIP projects that have been implemented in Texas over the last few years. The main TxDOT data sources that can be used to feed HSIP evaluations are the CAT8 project database, DCIS, SiteManager, RHiNo, CRIS, and *Roadway Safety Design Workbook* (Table 12). Additional data can be found in individual project files and local databases that some district offices maintain. After comparing the data requirements of various evaluation methods against existing TxDOT attributes, the researchers concluded that TxDOT databases can support all evaluation methods; however, the applicability and reliability of each method may be limited due to the following reasons:

- *Difficulty in geolocating frontage road crashes*. CRIS typically maps frontage road crashes to the centerline of freeway and expressway mainlanes. The CRIS attribute [Road Part] can be used to separate frontage road crashes from mainlane crashes. However, frontage roads often exist on both sides of mainlanes (left and right), so sometimes it is difficult to determine whether a crash happened on the left or the right frontage road. To overcome this challenge, analysts need to examine the following: (a) direction of vehicles involved in each crash; (b) direction of adjacent roadway segments; (c) crash narrative; (d) crash diagram; (e) crash DFO; (f) traffic control devices, if any, on frontage roads; and (g) aerial and street images (e.g., Google maps and street view).
- *Crash DFOs generated from an unknown version of RHiNo resulting in inaccurate crash geolocation*. RHiNo is the underlying LRS in CRIS based on which crash DFOs are

extracted. CRIS does not store the version of RHiNo that was used to extract the DFO of each crash. While CRIS is typically updated with the latest version of RHiNo toward the end of the summer of each year, the schedule of updating CRIS has not been fixed over time. Since DFOs may change along a route from one RHiNo version to the next, mapping crashes on an incorrect version of RHiNo may result in inaccurate crash locations (assuming that crashes are geolocated using the highway name and the DFO of each crash), which can affect the reliability and accuracy of the evaluation results.

- *Limited roadway and traffic data for certain types of roads*. RHiNo contains several attributes that can be used for HSIP evaluations; however, it has limited roadway inventory and AADT data for certain road parts, such as ramps, U-turns/turnarounds, connectors, and off-system roads. Therefore, the evaluation of these road parts may require additional data collection activities in the field or using aerial and street view images.
- *Limited inventory data to calculate the SPFs and CMFs included in TxDOT's Roadway Safety Design Workbook*. RHiNo does contain some data attributes (e.g., number of driveways, land use, curb miles, etc.) that are required to calculate the workbook SPFs and CMFs.
- *SPF limitations*. The HSM and the TxDOT *Roadway Safety Design Workbook* do not include SPFs for certain types of roads, such as freeways with 12 lanes or more, highways with managed lanes, and local roads. In addition, the Texas workbook SPFs were developed several years ago and need to be calibrated for current conditions. Further, the workbook SPFs are appropriate for predicting only KABC crashes; however, the goal of the HSIP is to reduce KAB crashes.
- *Lack of comprehensive intersection database*. The 2017 RHiNo includes new data attributes for intersections. However, currently, there is not a comprehensive database for intersections in Texas. This creates difficulties in performing data-demanding safety analyses such as network screening and safety effectiveness evaluations.

The assessment of the evaluation tools developed by other agencies showed that most tools can be transferable to TxDOT if modified accordingly and tailored to TxDOT datasets. Each of the tools reviewed in this study incorporates one or more of the following observational B/A methods: naïve, naïve with linear traffic volume correction, comparison group, EB that uses SPFs. None of the tools can fully support all of the following functions:

- Perform both project and countermeasure evaluations.
- Apply all four methods listed above.
- Calculate B/C ratios for each method listed above.

To address these limitations, TTI developed two safety and cost-effectiveness evaluations tools, one for segment projects and another for intersection projects. The tools have similar structures, formats, data inputs, and outputs. They are customized to TxDOT's needs, data availability, and

HSIP requirements and perform evaluations at both the project and countermeasure levels. Both tools incorporate the four safety effectiveness evaluation methods listed above and calculate four B/C ratios—one ratio for each of the four methods. TxDOT can use these tools in the future to evaluate the safety and cost effectiveness of completed HSIP projects and countermeasures.

TTI used the tools to evaluate the safety and cost effectiveness of 457 completed HSIP projects (457 = 387 segments + 70 intersections) that had complete (non-missing) data and the corresponding WCs of these projects (67 WCs = 46 segment-related WCs + 21 intersection-related WCs). TTI performed these evaluations by applying the naïve method, the naïve method with traffic volume correction, and the EB method.[3] For completeness, TTI evaluated the effectiveness of each project and WC in reducing the following six crash types:

- All KABCO crashes.
- All KABC crashes.
- All KAB crashes.
- Target KABCO crashes.
- Target KABC crashes.
- Target KAB crashes.

Among these crash types, the results for target KAB crashes are of particular interest in these evaluations because the HSIP is focusing on target KAB crashes. In other words, each completed HSIP project includes one or more WCs that TxDOT districts selected in order to reduce the specific types of KAB crashes that were observed along each project. Further, the SII calculated for each HSIP project accounts for the KAB crashes that each WC can theoretically prevent. Therefore, it is important to determine whether the HSIP projects have been effective in reducing target KAB crashes rather than other crash types, such as all KABCO crashes.

Overall, the results show that the evaluated HSIP projects have been effective from both a safety and cost perspective in reducing target KAB crashes. The most important evaluation results are provided below:

- The safety effectiveness index of all segment projects (treated as one group) was 0.84, indicating an overall reduction in target KAB crashes after the projects were constructed.[4] The index is statistically significant at the 95 percent confidence level.

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[3] The EB method was applied for only KABC crashes for tool testing and demonstration purposes. Chapter 4 provides a discussion on data limitations associated with the EB method and existing SPFs in Texas.

[4] The safety effective index is also known as the CMF. The smaller the index, the higher the effectiveness of the project(s). An index greater than 1.0 indicates an increase in crash frequency after project construction. Note that the safety effectiveness index cannot be calculated in situations where the total number of crashes in the before or the after period is zero.

- The safety effectiveness index of all intersection projects (treated as one group) was 0.74, indicating an overall reduction in target KAB crashes after the projects were constructed.[4] The index is statistically significant at the 95 percent confidence level.
- The overall B/C ratio of all segment projects (treated as one group) was 71.9, which is significantly greater than 1.0.[5]
- The overall B/C ratio of all intersection projects (treated as one group) was 145.6, which is significantly greater than 1.0.[5]

Among the 46 segment-related WCs that were evaluated in this study, four included 30 or more projects with complete (non-missing) data.[6] According to guidelines (*2, 6*), the minimum number of projects needed for HSIP evaluation purposes is 20–30. Of the 21 intersection-related WCs, WC 108 (Improve Traffic Signals) and WC 107 (Install Traffic Signal) contained 26 and 13 projects, respectively, with complete data. The remaining intersection-related WCs had a sample size of seven projects or fewer. Overall, the results show (Table 32) that all six WCs have been effective in reducing target KAB crashes.

Table 32. Safety and Cost Effectiveness of WCs in Reducing Target KAB Crashes.

WC	Number of Projects with Complete Data	CMF	B/C
541 Provide Additional Paved Surface Width	115	0.81[a]	11.09
209 Safety Treat Fixed Objects	48	0.65[a]	196.82
502 Widen Lane(s)	39	0.48[a]	17.68
542 Milled Centerline Rumble Strips	33	0.70[a]	179.05
108 Improve Traffic Signal	26	0.94[b]	122.36
107 Install Traffic Signal	13	0.34[a]	779.07

[a] Statistically significant at 95 percent confidence level.
[b] Not statistically significant at 90 percent confidence level.

The reliability and accuracy of the evaluation results for WCs 108 and 107 as well as for the remaining 61 WCs not shown in Table 32 can be improved if the sample size of each WC is increased by finding missing data for more completed HSIP projects. Priority may be given to the following datasets:

- Around 70 percent of all (2,281) HSIP projects have missing construction dates and costs in SiteManager.
- Around 16 percent of all HSIP projects do not have geographic coordinates in DCIS.
- Around 17 percent of all projects are grouped with other projects in the CAT8 database. As a result, the database contains aggregated data for each group of projects rather than

[5] The B/C ratio cannot be calculated when the number of crashes in the before period is zero.
[6] Among all 2,281 HSIP projects compiled in this study, several projects had missing data and were excluded from HSIP evaluations.

for each individual project. Project-specific data are needed for HSIP evaluation purposes.

- The construction of around 4 percent of all HSIP projects started prior to 2011, making the evaluation of these projects challenging because (a) there is a need to use historical (2003–2009) crash records (not stored in CRIS) that contain a significant amount of missing data, such as geographic coordinates; and (b) there are several differences between the historical crash databases and CRIS in regard to data attributes, data definitions, data format, and database structure—these differences can create additional challenges when data from both databases need to be combined and analyzed.

7.3 RECOMMENDATIONS

Based on findings and lessons learned from this project, TTI developed the following recommendations for implementation by TxDOT:

- **Find missing data for completed HSIP projects.** Of the 2,281 completed HSIP projects stored in the CAT8 database, this research study evaluated the effectiveness of 457 projects (20 percent of all projects) that had complete (non-missing) data. To evaluate more projects and countermeasures in the future, TxDOT needs to find missing data for the remaining 1,824 completed HSIP projects. The HSIP project database developed in this study can be used as a starting point to identify the missing data for each project. Among all data attributes required for evaluations, emphasis should be placed on determining the missing construction dates and costs that are not available in SiteManager for 70 percent of the projects. Engaging district and area office staff in this effort may be necessary because some of the missing data can potentially be found in local databases and files managed by districts. Considering the high number of HSIP projects constructed in Texas, TxDOT has a great opportunity to evaluate more projects and WCs and be one of the best-in-class state agencies in HSIP evaluations.
- **Develop new CMFs.** After finding missing HSIP project data, TxDOT should evaluate the effectiveness of implemented WCs and develop new CMFs. The 0-6961 evaluation tools can be used for this purpose. Further, the tools determine whether a CMF is statistically significant at the 95 and 90 percent confidence levels. After developing new CMFs, TxDOT should update its *HSIP Work Codes Table Manual* accordingly.
- **Establish safety and cost-effectiveness evaluation process and incorporate it into HSIP**. TxDOT should establish a safety and cost-effectiveness evaluation process and incorporate it into its HSIP, making it a standard practice. To facilitate the implementation of this process, TxDOT should develop guidelines and criteria for evaluating the effectiveness of projects and WCs. The guidelines should provide pertinent information such as who should conduct the evaluations; which data, methods, and tools to use; when a project needs to be evaluated (e.g., three to five years after project construction); how often the evaluations need to be conducted; expected

outputs/format/structure of the results; reporting requirements; internal and external submission processes; and relevant deadlines. After establishing an HSIP evaluation process, TxDOT should update its HSIP manual accordingly.

- **Implement 0-6961 evaluation tools statewide.** In recent years, there has been an increasing interest by many TxDOT districts in monitoring and evaluating the safety and cost effectiveness of projects funded not only through the HSIP but through other programs and sources. Considering that the 0-6961 tools can be used to evaluate both HSIP and non-HSIP projects, TxDOT should conduct a statewide implementation of these tools and provide training to all districts on how to use them and interpret the evaluation results.
- **Apply advanced data-driven evaluation methods**. The general guideline is to use data-driven crash-predictive methods, such as the EB method, that account for RTM effects, natural spatial/temporal fluctuations in crashes, roadway characteristics, and other external factors (*2, 6*). While simple B/A comparisons are relatively easy to conduct, they have several shortcomings. For example, they assume that possible safety changes are due solely to safety improvements without considering RTM effects, traffic volume fluctuations, land use changes, and other factors. For completeness, the 0-6961 evaluation tools incorporate both simple and advanced evaluation methods.
- **Assess the need for calibrating existing SPFs and develop new SPFs**. TxDOT's *Roadway Safety Design Workbook* does not provide SPFs for all types of roads. The SPFs were developed several years ago and can be used to predict only KABC crashes. TxDOT should validate the accuracy of existing SPFs and assess the need for calibrating them. In addition, there is a need to develop new SPFs for use in network screening and safety effectiveness evaluations. SPFs that predict KAB crashes would be in line with the HSIP goal. Further, SPFs that focus on unique crash types would enable TxDOT to directly evaluate candidate countermeasures. For example, widening a shoulder can be expected to minimize roadway departure crashes, head-on collisions, and opposite-direction sideswipe crashes. SPFs that address these unique crash types could be used to assess the need for a countermeasure such as widening the shoulder or evaluate its effectiveness if the countermeasure already exists.
- **Assess the need for collecting more roadway inventory and other types of data**. RHiNo has limited roadway inventory and AADT data for certain road parts, such as ramps, U-turns/turnarounds, connectors, and off-system roads. Further, it does not contain some data attributes (e.g., number of driveways, land use, curb miles, etc.) that are required to calculate some SPFs included in TxDOT's *Roadway Safety Design Workbook*. If TxDOT chooses to calibrate and use existing SPFs, additional data need to be collected. If new SPFs are developed for Texas, TxDOT needs to assess whether existing RHiNo data attributes can fully support the calculation of the new SPFs or additional data need to be collected.

- **Develop intersection inventory**. TxDOT should geolocate all intersections in the state and develop a comprehensive intersection database that includes, at a minimum, the Model Inventory of Roadway Elements—Fundamental Data Elements, as well as other attributes that are needed to support safety effectiveness evaluations and network screening analysis. The data should be separately provided for each approach of an intersection.
- **Update process of geolocating frontage road crashes in CRIS**. As explained in the previous section, it is difficult to determine whether a crash happened on the left or the right frontage road using crash coordinates. There is a need to update the process of geolocating frontage road crashes and generating their geographic coordinates that are stored in CRIS. TxDOT should make necessary changes to this process so that frontage road crashes are mapped to the centerline of the correct (right or left) frontage road, not the centerline of mainlanes.
- **Save the version of RHiNo that is used to determine the DFO of each crash in CRIS**. CRIS does not currently store the version of RHiNo that was used to extract the DFO of each crash. Since DFOs may change along a route from one RHiNo version to the next, mapping crashes on an incorrect version of RHiNo may result in inaccurate crash locations that can affect the reliability and accuracy of safety analysis. A potential strategy to address this challenge is to store in a new CRIS data attribute (e.g., [DFO_RHiNo_Year]) the version or year of RHiNo that is used to determine the DFO of each crash.

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APPENDIX A:
HSM ELEMENTS

This appendix presents the basic elements of predictive models presented in the HSM.

A.1 REGRESSION TO THE MEAN

RTM describes a situation in which crash rates are artificially high during the before period and would have been reduced even without an improvement to the site (*2*). Due to its focus on high hazard locations, the HSIP is vulnerable to the RTM bias as a primary cause of erroneous conclusions in highway-related evaluations. The RTM bias is greatest when sites are chosen because of their extreme value (e.g., high number of crashes or crash rate) during a given time period. Variations at a site are usually due to the normal randomness of crash occurrence. Figure 45 shows an example of RTM effects.

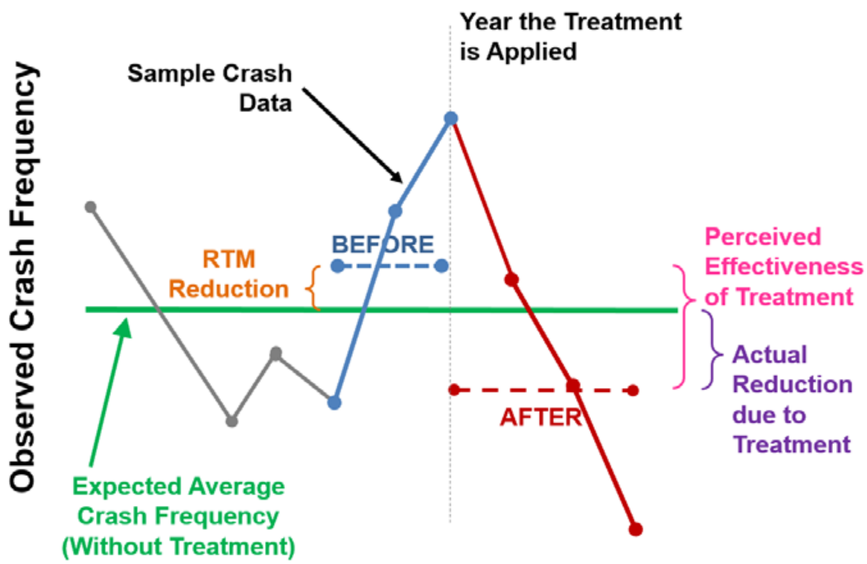

Figure 45. Regression-to-the-Mean Example.

Because of random variation, the extreme cases chosen in one period are very likely to experience lower crash frequencies in the next period—the highest become lower and the lowest become higher. A common concern in traffic safety is that analysts should not select sites for treatment if there is a high count in only one year because the count will tend to regress back toward the mean in subsequent years. Put more directly, what happens before is only one of many indicators as to what might occur after a countermeasure is implemented.

A.2 SAFETY PERFORMANCE FUNCTIONS

Statistical models are used to predict the average crash frequency for a facility type with specified base conditions. Negative binomial models are typically used to build SPFs. The average crash frequency is estimated given some base conditions. For example, one of the base conditions for a rural two-lane road segment is lane width of 12 ft. If the selected site meets the base conditions, then the *estimated crash frequency* at the site can be determined using an SPF, which can have different forms such as the one below:

$$C_{tot} = 0.0537 * (0.001 * AADT)^{1.30} * L \qquad (8)$$

Where:

- C_{tot} is crash frequency estimated by the SPF.
- $AADT$ is annual average daily traffic.
- L is segment length.

SPFs represent the change in mean crash frequency as AADT (or other exposure measure) increases or decreases. SPFs can be used to reduce the effects of RTM and, when included in an EB analysis, to estimate the expected number of crashes for a roadway segment or intersection based on similar facilities.

SPFs are constructed using crash and exposure data from multiple comparable sites. The resulting curve or statistical equation is known as the SPF. The SPFs have been compiled into safety analysis tools, such as SafetyAnalyst and the HSM (*2*). However, since crash patterns may vary by space and time, SPFs must be calibrated to reflect local current conditions (e.g., driver population, climate, etc.). Different entities have SPFs with different curves and use differing measures to represent exposure (e.g., AADT). A unique SPF is usually developed for each road type that has specific characteristics (e.g., median type, number of lanes, etc.).

A.3 CRASH MODIFICATION FACTORS

A CMF is a multiplicative factor used to calculate the expected number of crashes after implementing a given countermeasure at a specific site. For example, an intersection is experiencing 50 rear-end crashes per year. If analysts apply a countermeasure that has a CMF of 0.70 for rear-end crashes, then they can expect to see 35 rear-end crashes per year (50 x 0.70 = 35) after the countermeasure is implemented.

CMFs are usually the result of evaluating countermeasures. Analysts evaluate several sites where countermeasures have been applied and quantify the impact by accounting for the overall effect of the treatment. The safety effectiveness is then calculated as:

$$Safety\ Effectiveness = 100\% - CMF_{Treatment} \times 100\% \qquad (9)$$

Assuming that the CMF is equal to 0.7, the safety effectiveness is:

$$Safety\ Effectiveness = 100\% - 0.7 \times 100\% = 30\%$$

This suggests that after implementing a countermeasure, the crash frequency can be reduced by 30 percent. SPFs and CMFs can be used to forecast or predict the crash frequency of:

- An existing roadway for existing conditions during a past or future period.
- An existing roadway for alternative conditions during a past or future period.
- A new roadway for given conditions in a future period.

The predicted crash frequency is the product of the crash frequency estimated using an SPF, applicable CMFs, and appropriate calibration factors:

$$C_{Predicted} = C_{SPF} \times (CMF_{Treatment1} \times CMF_{Treatment2} \times \ldots) \times CF_{location} \qquad (10)$$

Where:

- $C_{Predicted}$ is predicted number of crashes.
- C_{SPF} is crash frequency of base conditions.
- $CMF_{Treatment}$ is crash modification factor of a given treatment. Since more than one improvement can be made to a site, each safety improvement will have its own CMF specific to the given site.
- $CF_{location}$ is calibration factor to adjust the predicted value to local conditions.

Note that crash reduction factors (CRFs) provide an estimate of the percentage reduction in crashes, while CMFs are multiplicative factors used to compute the expected number of crashes after implementing a safety treatment. Their mathematical relationship is CMF = 1 − (CRF/100). For example, if a particular countermeasure is expected to reduce the number of crashes by 30 percent (i.e., the CRF is 30), the CMF will be 1 − (30/100) = 0.70. On the other hand, if the treatment is expected to increase the number of crashes by 30 percent (i.e., the CRF is −30), the CMF will be 1 − (−30/100) = 1.30.

APPENDIX B:
STATE HSIP EVALUATION PRACTICES AND TOOLS

In 2016 and 2017, 25 and 27 states, respectively, provided evaluation data for completed HSIP projects in their annual HSIP reports (Table 10). The research team expanded the review of state HSIP evaluation practices and tools by focusing on states that either provided evaluation data in their last two HSIP reports or had developed, presented, or published evaluation tools (e.g., New York). Table 10 (see Chapter 3) lists these states along with the evaluation tools used, if any, by each agency. This appendix provides more information on state HSIP evaluation practices and tools.

Alabama

According to the 2016 HSIP report, the Alabama Department of Transportation (ALDOT) evaluated nine sites, but the 2017 HSIP report did not include any project evaluation data. ALDOT assigns a B/C ratio to all non-systemic projects. This ratio is calculated using a spreadsheet and is used to prioritize candidate projects. The current minimum B/C ratio is 1.0 but may be moved higher as more projects are submitted for HSIP funding. ALDOT measures the effectiveness of the HSIP by determining the change in fatalities and serious injuries.

Alaska

In its 2016 and 2017 HSIP reports, the Alaska Department of Transportation and Public Facilities provides project evaluation data for 19 and 11 completed projects, respectively. A spreadsheet evaluation tool (Figure 46) is attached to the 2017 HSIP report. The spreadsheet is used to compute B/C ratios and accident reduction factors for ranked HSIP projects that have three years of post-construction crash data available (*30*).

Alaska DOT/PF
Highway Safety Improvement Program
HSIP Project Evaluation Worksheet
Computation of Actual B/C and Accident Reduction Factors - INPUT

Red fields are input fields.
Black fields are fixed, computed, or derived.

HSIP Project Name:	*Test Intersection - Regional Project for the Betterment of All Mankind*	Form Completed by:	*Joe Traffic*	Date:	*7/15/2020*

Project Identification Data	
Construction Project Name:	Test Construction Project
Federal Project Number:	TEST-PROJ-1
State (AKSAS) Proj. Number:	12345

Miscellaneous Data	
Rate of Return:	3%
Intersection (I) or Segment (S)	I
If Segment, Length in Miles:	
Date Construction Began:	4/30/15
Date Project Accepted for Traffic:	11/1/15

Accident Cost Data	
Accident Severity	**Accident Cost**
Property Damage Only:	$20,000
Minor Injury:	$200,000
Major Injury:	$1,001,000
Fatality:	$2,003,000

ACCIDENT HISTORY (All Accidents)

Period	Begin Date	End Date	No of Years	PDO	Min	Maj	Fat	Tot-al	Avg ADT
1) Before (HSIP Analysis Period)	1/1/09	12/31/13	5.0	29	12	6		47	10000
2) Before-Interim	1/1/11	12/31/14	2.0	12	3	3		18	10500
1 and 2 Combined	1/1/09	12/31/14	7.0	41	15	9		65	10143
3) After	1/1/16	12/31/18	3.0	13	6	2		21	11000

Accident Trend	
Trend Control Area:	Mjr City / Borough
Accident Rate change from Before Period (1+2) to After Period (3)	0.0%

ACCIDENT HISTORY (Accidents Susceptible to Reduction or Increase)

Improvement	Type of Accident Susceptible to Reduction or Increase Due to Improvement	BEFORE (1+2) HSIP Analysis Period 1/1/2009 to 12/31/2013 PDO	Min	Maj	Fat	Interim 1/1/2011 to 12/31/2014 PDO	Min	Maj	Fat	Total No of Acc	Total Acc Cost ($K)	AFTER (3) 1/1/2016 to 12/31/2018 PDO	Min	Maj	Fat	Total No of Acc	Total Acc Cost ($K)
Intersection Illumination	Night Accidents at unlighted intersections	6	2	1		2		1		12	2562	2				2	40
Install Lt Turn Pocket at Rural, Unsignalized Intersection (Major Road Approach Only)	Rear-ends and side-swipes involving turning cars making the target movement	5	2	2		1	1	1		12	3723	1		1		2	1021
New Traffic Signal	Angle accidents	10	5	1		6	2			24	2721	3	1			4	260
	Rear-end accidents (expected to increase)	6	5			2		1		14	2161	5	2	1		8	1501
	Totals / Averages:	27	14	4		11	3	3		62	11167	11	3	2		16	2822
	Total Accident Costs:	$11,167,000										$2,822,000					

** The "Before – Interim" time period extends from the end of the HSIP analysis period to the start of construction. Only full data years should be used. Use of partial years will skew results.*
Set Trend to 0% in the absence of a significant change in area-wide crash rate between the Before/Interim period and the After period.

Figure 46. Alaska Department of Transportation—Project Evaluation Spreadsheet (*30*).

As shown in Figure 46, the tool classifies crashes into three distinct periods (before, before-interim, and after period) and four crash categories: PDO, minor injury, major injury, and fatal accidents. The before-interim period extends from the end of the HSIP analysis period to the start of construction. A specific crash cost is associated with each crash type, and the total cost is computed for each period by multiplying it by the number of crashes in each category.

Arizona

Arizona's 2016 HSIP report does not provide any project evaluation data, but the 2017 HSIP report provides evaluation data for nine projects. The most recent Arizona HSIP manual includes a process for evaluating both distinct projects and the entire program (*31*). The intent of this process is to determine the effectiveness of the program, ensure adherence to federal regulations, and utilize data obtained by evaluation in the planning process. B/A studies of safety improvement projects compare various features and characteristics of each subject location before and after construction.

Arkansas

The Arkansas Department of Transportation (ARDOT) provides project evaluation data for three and four completed projects in its 2016 and 2017 HSIP reports, respectively. ARDOT provides companion files that show progress in achieving safety performance targets and set targets for future performance. However, no information about the evaluation methods and tools is provided. ARDOT is in the process of updating its HSIP process and manual using information and lessons learned from the HSIP peer-exchange meeting that was held in 2017.

California

The California Department of Transportation (Caltrans) provided project evaluation data for three projects in 2016 and 42 projects in 2017. Caltrans seldom conducts countermeasure effectiveness evaluations and typically refers to the CMF Clearinghouse for countermeasure effectiveness. B/C analysis was performed for all on-system projects collectively rather than per individual project.

The 2017 HSIP report mentions two methods to measure effectiveness: performance target values and B/C ratios. Safety improvement projects are measured based on performance values (the number of collisions reduced over the life of the project). In B/C analysis, the effectiveness of a safety improvement project is measured by evaluating the change in number of collisions and crash rates before and after construction. Caltrans' 2016 *Local Roadway Safety Manual* documents an empirical traditional B/A crash analysis method for evaluating the effectiveness of completed safety treatments (*32*). No evaluation tools are listed or provided by Caltrans in the HSIP report or on its website.

Colorado

The Colorado Department of Transportation (CDOT) provides project evaluation data for one project in the 2016 HSIP report and another project in the 2017 HSIP report. However, CDOT's website has published a copy of two B/A safety analyses reports prepared by third parties for CDOT (*33*). The purpose of these studies was to determine the effects of roadway improvements on safety performance at 48 sites selected by CDOT. The reports discuss the study locations and different types of B/A methods (EB and comparison group methods) suitable for evaluating individual projects and estimating CMFs.

Figure 47 shows an example of a B/A study that shows how safety improved by replacing an intersection with a roundabout. The roundabout accomplished the intended goal of reducing rear-end, sideswipe, and right/left turn crashes, but not by the anticipated total percentage.

	Before	After	No Build After
EB Correction:	Yes	No	Yes
SPF Graph	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection*	Urban, 2-lane, Undivided, Unsignalized, 4-Leg Intersection
Total Crashes:			
LOSS	LOSS IV	LOSS III*	LOSS IV
CPY	3.01	1.80	2.94
Mean CPY	1.70	1.66	1.66
Proportion of Mean	1.77	1.08	1.77
Fatal & Injury Crashes:			
LOSS	LOSS II	LOSS I*	LOSS IV
CPY	0.48	0.00	0.47
Mean CPY	0.72	0.71	0.71
Proportion of Mean	0.67	0.00	0.67

**Intersection type changed by project to Roundabout, so LOSS shown is not necessarily correct for the After period, but it provides a useful comparison.*

Figure 47. Example of B/A Study (*34*).

Analysts used the Vision Zero Suite (VZS) tool to perform HSIP evaluations (*35*). Figure 48 shows a screenshot of VZS. VZS is a suite of analytical tools designed to provide decision support analysis for solving road safety problems.

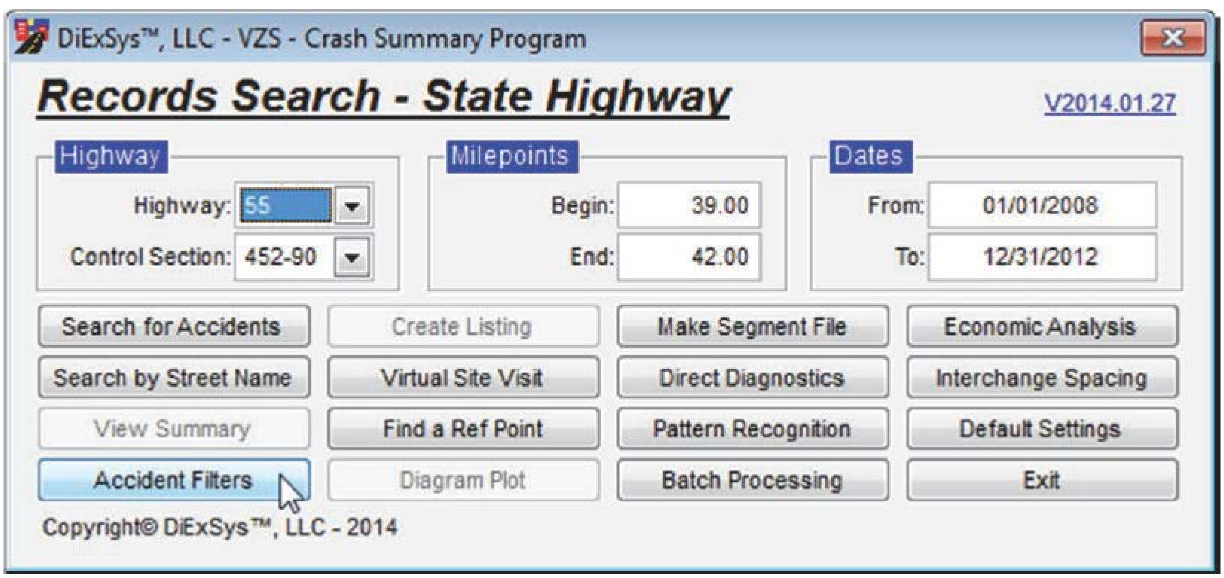

Figure 48. VZS Used by CDOT for Project Evaluation (*35*).

VZS provides predictive, diagnostic, and analysis tools that reveal the nature and magnitude of the safety problems on highway segments and at intersections. It also provides a cost-effectiveness analysis module for the evaluation of safety improvement strategies and virtual site visit capabilities. In addition to VZS, CDOT uses interactive spreadsheets that contain elements (e.g., SPFs and crash diagnostic information) necessary to support HSIP evaluations (*35*).

Connecticut

The 2016 Connecticut HSIP report provides project evaluation data for one project, whereas the 2017 report does not contain any project evaluation data. The 2016 report also states that it is premature to demonstrate effectiveness and success in the HSIP program since the agency recently started to place more emphasis on systemic safety, which now includes all public roads. No evaluation tool is mentioned or published online.

Delaware

The 2017 HSIP report provides project evaluation data, whereas in the 2016 report, no data are provided. For the high friction surface treatment projects that were evaluated, B/A crash data were categorized by total crashes, wet-weather crashes, and roadway departure crashes regardless of crash severity. The values were reported under the PDO category as the sum of the yearly average number of crashes at 23 different locations. However, additional information was presented by percent changes (per year) in wet-weather crashes, total number of crashes, and roadway departure crashes. The overall B/C for all locations where high friction surface treatment was installed was 23.97. Seventy percent of the 23 locations experienced a B/C ratio greater than 1.0. No tools are mentioned or shared in the two reports or on the website.

District of Columbia

The 2016 HSIP report provides project evaluation data (no B/C ratios) for seven projects, whereas the 2017 HSIP report does not report any project evaluation data. The 2017 HSIP report states that the District of Columbia Department of Transportation (DDOT) has not documented the impacts of improvements under previously implemented projects. DDOT, however, is embarking on a project to establish CMFs specifically for the district. The study, which will focus on high crash locations and projects that have been implemented over the last few years, will determine the safety effectiveness of these projects in relation to fatalities, serious injuries, and property damage crashes. The district will rely on crash records from the past five years, and the evaluation process is under development. No evaluation tool is provided in the HSIP reports or online.

Florida

The 2016 HSIP report includes project evaluation data for 69 projects in multiple improvement categories. The 2017 report provides countermeasure evaluation data for 135 countermeasures that account for 1,082 projects. The Florida Department of Transportation (FDOT) performs HSIP evaluations using a web application called CRASH (Figure 49) (*36*).

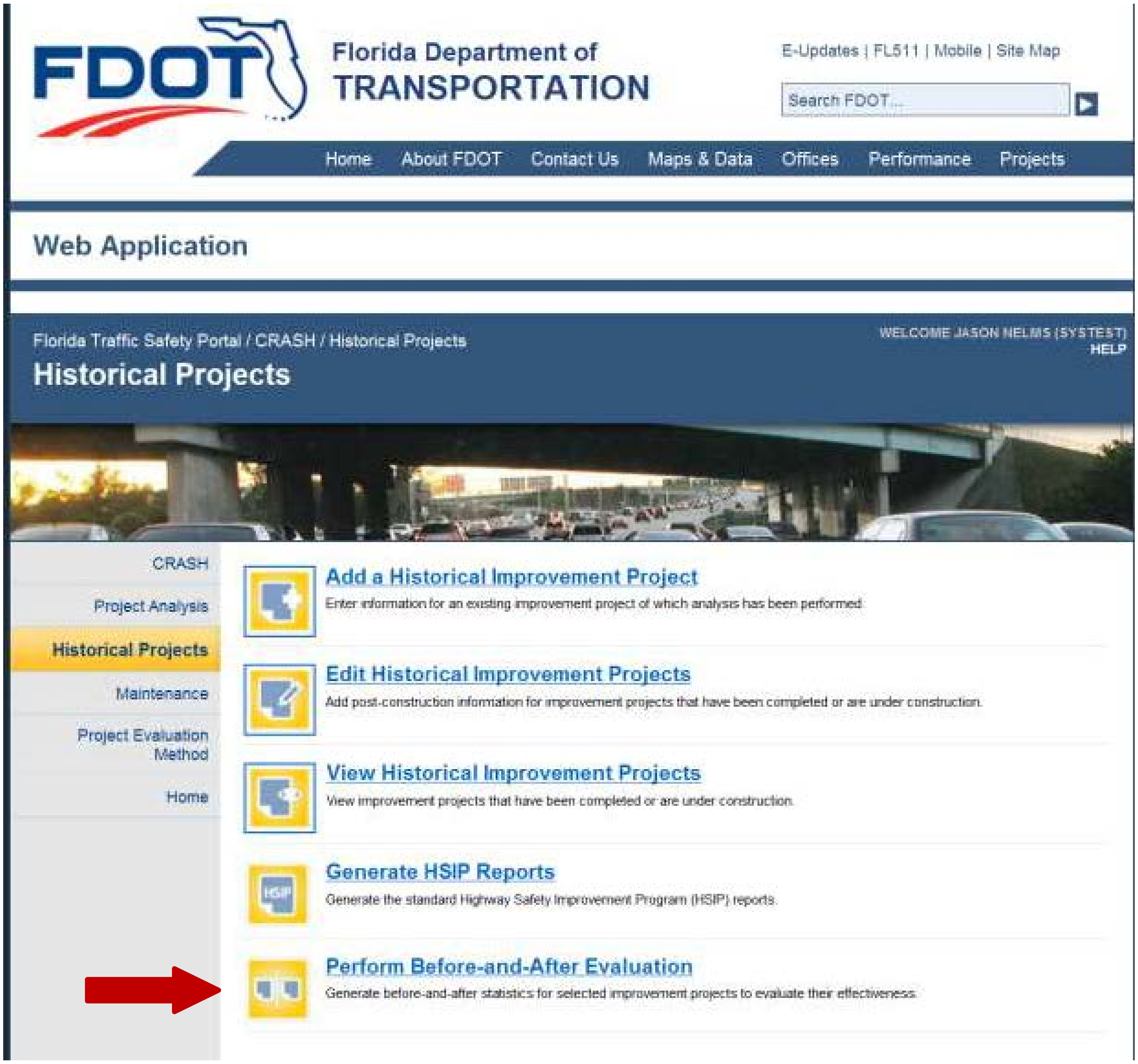

Figure 49. FDOT's CRASH Web Application (*36*).

CRASH can perform a B/A evaluation for any subset of projects using the selection parameter filters shown in Figure 50.

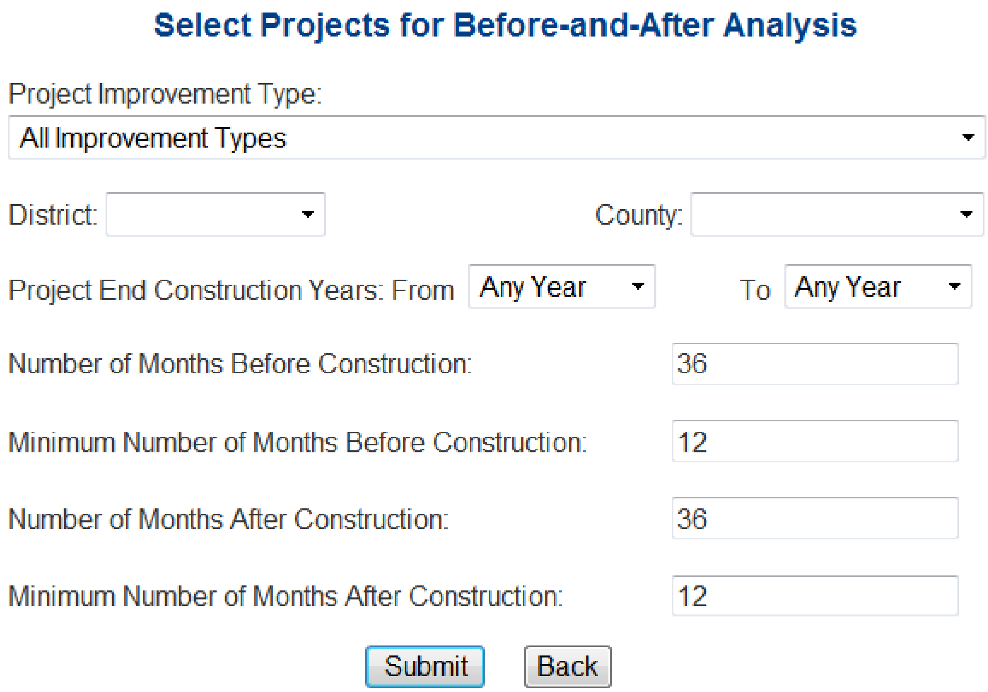

Figure 50. Project Selection Criteria in CRASH (*36*).

After completing and submitting the form (Figure 50), CRASH produces summary statistics, including crashes and crash rates in the before and after periods, the actual percent of crashes reduced, and a Poisson test for testing the statistical significance of the crashes reduced.

Georgia

The 2016 HSIP report does not include any project evaluation data, whereas the 2017 HSIP report provides project evaluation data for four projects. The HSIP report mentions that the Georgia Department of Transportation typically uses naïve B/A analysis on projects that have been completed at least three years prior to the current year. The manual also mentions that in the future, the plan is to apply statistical analysis to measure the significance of these results and eventually apply the EB method. No HSIP evaluation tool was mentioned in the reports or provided online.

Indiana

The 2016 HSIP report includes project evaluations performed for 27 projects, whereas the 2017 HSIP report includes 119 project evaluations. The Indiana Department of Transportation (INDOT) did not provide any specific tools for countermeasure and/or project evaluation, but a project evaluation procedure was listed in the 2010 *Indiana HSIP Manual*. For project or countermeasure evaluation, INDOT provides a procedure to conduct a post-construction safety performance analysis for a pre-established period before and after the construction of a project. For those projects that require analysis of crash history, there must be an analysis of crashes of the type identified in the project proposal for a minimum period of three full years before and three full years after construction. For systemic improvements, a time period is identified in the project proposal that defines the pre- and post-construction analysis process used to justify project funding. A normalization procedure is used to account for potentially different durations in the before and after time periods (*37*, *38*).

The Center for Road Safety of Purdue University developed RoadHAT software that INDOT uses to analyze locations for safety risk and perform cost-effectiveness analysis of proposed safety improvement projects (*38*). INDOT also uses the RoadHAT cost-effectiveness tool to perform post-construction analysis of HSIP projects completed at least three years prior to the analysis date. RoadHAT is a proprietary tool and as such cannot be shared with external entities.

Maine

The 2016 and 2017 HSIP reports provide evaluation data for 26 and 21 projects, respectively. Maine uses a simple spreadsheet to perform naïve B/A evaluations (Figure 51) and uses crash data from three years before and three years after project implementation. No data are used from the construction year. Maine also calculates a combined all-projects annual B/C ratio by adding all projects' annual estimated crash economic differences (B/A) divided by the total annual cost of all projects.

Safety Projects Completed in 2013

	Description	Federal Safety	Federal NHS	Federal STP	State 9095	Local-Other	Total Expended	Available Funding	Programmed Funding
		Expended Amount							
4	Intersection Improvement with Signal: Located at the intersection of Route 1 and Route 103.	$ 36,900.00		$ 873,100.00	$ 92.41	$ 335,797.90	$ 1,245,890.31	$ 1,245,890.31	$ 326,500.00
5	Intersection Improvements: Located at the intersection of Route 35 and the Whites Bridge Road.	$ 611,709.76			$ 42,649.62	$ 37,000.00	$ 691,359.38	$ 691,359.38	$ 490,000.00
6	Intersection Improvements: Located at the intersection of Route 3 and Route 230. Realign intersection with Route 230 and the installation of a signal.	$ 459,732.51			$ 451,500.25	$ 4,000.00	$ 915,232.76	$ 3,402,662.64	$ 4,150,000.00
7	Identify and remove hazardous trees along non-interstate highways to prevent trees from falling into the travel way.	$ 35,302.50			$ 3,922.50		$ 39,225.00	$ 39,225.00	$ -
8	Identify and remove hazardous trees along non-interstate highways to prevent trees from falling into the travel way.	$ 34,340.40			$ 3,815.60		$ 38,156.00	$ 38,156.00	$ -

3 Years Before (2010-2012)						3 Years After (2014-2016)								
Total Crashes	Total Fatalities	Total Incapacitating Injuries	Total Evident Injuries	Total Possible Injuries	Total Crash Cost	Total Crashes	Total Fatalities	Total Incapacitating Injuries	Total Evident Injuries	Total Possible Injuries	Total Crash Cost	Project Cost Based on Total Project Cost	Annual Crash Estimated Economic Impact Savings	Benefit to Cost (B/C)
12	0	0	1	3	$191,800.00	19	0	0	0	3	$167,700.00	$5,014.00	$8,033.33	1.6
7	0	0	0	0	$33,600.00	12	0	0	0	5	$189,100.00	$83,112.00	-$51,833.33	-0.6
5	0	0	2	0	$134,600.00	13	0	0	2	2	$225,600.00	$62,463.00	-$30,333.33	-0.4

Figure 51. Spreadsheet Tool Used for Naïve B/A Project Evaluation by Maine DOT (*39*).

Maine occasionally determines the collective performance of multiple projects over many years to see how certain types of treatments have performed (e.g., turn lanes, flashing beacons, traffic signals, rumble strips). Some of these evaluations are performed as outlined above or may be based on a different approach, such as B/A performance on a per mile of highway exposure. The countermeasure evaluations are not done on a frequent basis. Maine recently evaluated the effectiveness of rumble strips and median cable barriers (*39*).

Massachusetts

The 2017 Massachusetts HSIP report includes evaluation data for 23 projects and four countermeasures, namely median cable barrier, general signalized intersection improvements, minor leg stop control intersection to roundabout, and signalized intersection. The evaluations were performed using crash data from three years before and three years after construction. The 2016 HSIP report does not provide any project or countermeasure evaluation data.

MassDOT conducts evaluations at the site-, project-, or countermeasure-level across different projects. For site-level evaluations, effectiveness is measured using the change in fatalities and serious injuries (along with the change in total crashes, fatal plus injury crashes, and target crashes). For project-level evaluations, both changes in fatal and serious injury crashes and B/C ratios are used. B/C ratios are used on countermeasure-level evaluations. When possible, these evaluations are done using the EB B/A methodology, ideally with a comparison group. If the data requirements for EB are prohibitive, naïve B/A analyses are used, adjusted for traffic volume or using a comparison group, where applicable (*40*). In addition to the EB method, sometimes Massachusetts uses the FB method to evaluate the effectiveness of countermeasures.

MassDOT shared with the research team its HSIP tracking spreadsheet tool that performs naïve B/A analysis, B/A with comparison group, EB B/A, EB B/A comparison group analysis, and economic analysis. The tool includes a list of SPFs developed by MassDOT, the HSM, NCHRP studies, or SafetyAnalyst. Figure 52 shows a screenshot of MassDOT’s evaluation tool.

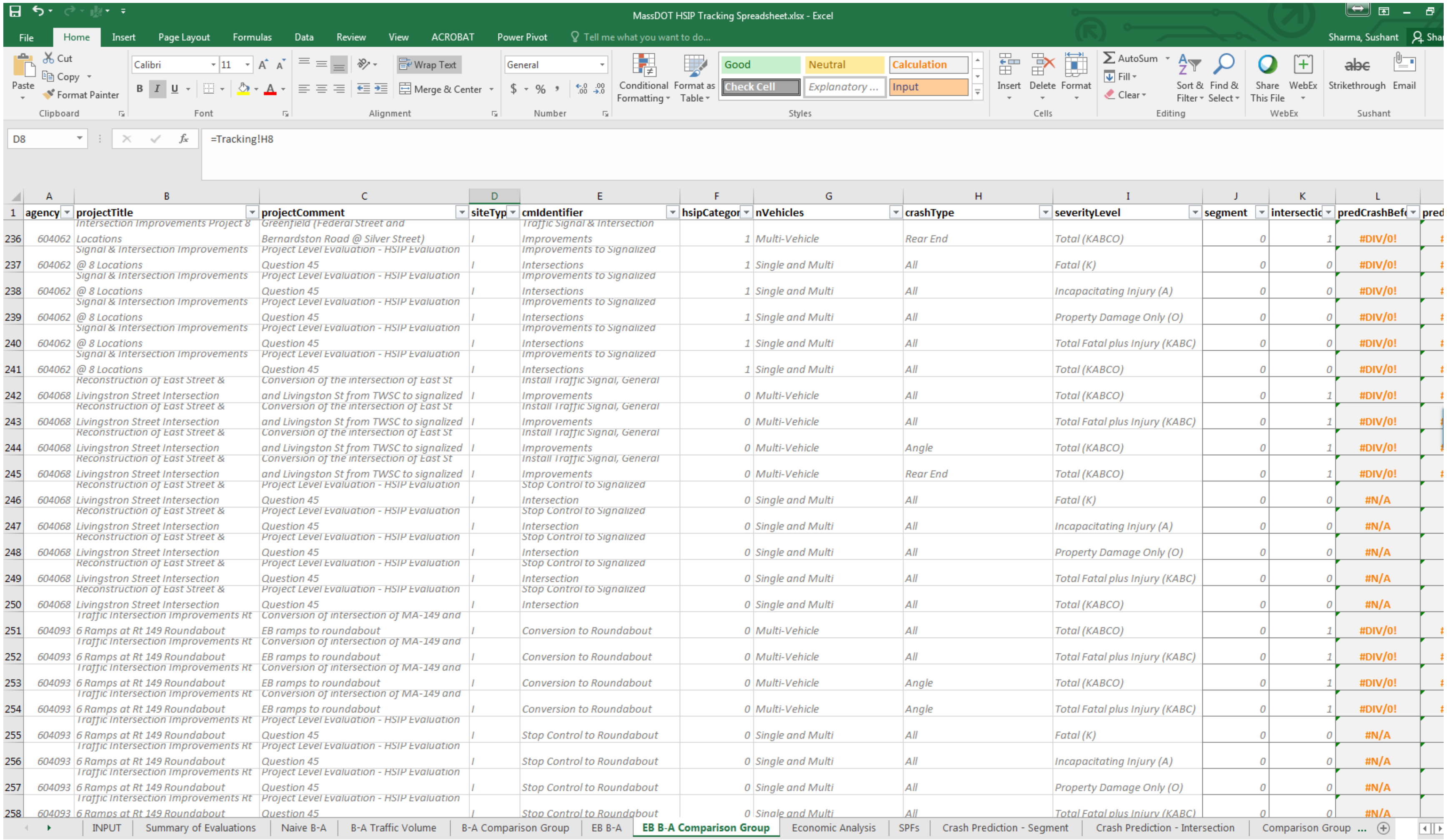

Figure 52. Screenshot of MassDOT's HSIP Evaluation Spreadsheet Tool (*40*).

Minnesota

The 2016 Minnesota HSIP report provides project evaluation data for one project. The 2016 HSIP report also documents an evaluation of auxiliary buffer lanes at interchanges that was conducted by comparing treatment sites to similar control sites. The 2017 Minnesota HSIP report does not include any project evaluation data; however, it provides countermeasure evaluation data for multilane roundabouts and reduced conflict intersections (*41*, *42*).

The Minnesota *HSIP Funding Guide* refers to a toolkit used specifically by planners for selection of crash hotspots based on critical crash rate index, along with examples of using the B/C ratio for selecting countermeasures (*43*). However, this toolkit is not for project evaluation. The HSIP report also states that Minnesota uses "Change in fatalities and serious injuries" and "Other-change in fatal and serious injury" crashes as performance measures for understanding the effectiveness of the HSIP. The report notes that the Minnesota Department of Transportation (MnDOT) is discussing adding evaluation to the initial project scope. Currently, MnDOT has begun the process with two projects by setting up evaluation plans before the project is executed; deliverables may be either data or an evaluation report.

Mississippi

The 2016 Mississippi HSIP report includes 153 project evaluations performed for locations that had at least one year of post-construction crash data, whereas the 2017 report includes 91 project evaluations. There is no tool provided except the mention of basic B/A studies with crash rate calculations. The B/C ratio is not computed. The report mentions that for numerous HSIP projects, the after period was much shorter than the before period, which can effectively skew how project performance appears in the given format. With crash rate calculations, a better representation is apparent for how the projects are performing thus far, even in shorter study periods.

Missouri

Missouri's state HSIP report provides project evaluation data for 37 projects in 2016 and 50 projects in 2017. The project evaluation results were based on a B/C ratio of the net reduction in crashes over the cost to implement the improvement. The project evaluation had before and after crashes based on roadway functional class, improvement category, improvement type, and injury type. The methodology used for this analysis was a simple B/A study with a B/C ratio. Missouri also evaluated restricted crossing U-turn intersections or J-turns countermeasures for the 2017 HSIP report. This evaluation was done based on a simple B/A study, and the results showed that the net benefit of the 19 J-turn locations across the state was significant. No tool is mentioned in or provided with the report.

Montana

Montana provided project evaluation data for four countermeasures evaluated in 2016, but they were reported in the 2017 HSIP report. The project evaluation results were based on a B/C analysis of the reduction in crashes over the project cost. Montana did the evaluations using simple spreadsheets. According to the 2017 HSIP, Montana is developing intersection SPFs and diagnostic norms to improve intersection safety.

Nebraska

Nebraska's HSIP reports provide project evaluation data for five projects in 2016 and five projects in 2017. The Highway Safety Division prepares collision diagrams, spot maps, or lists of high crash locations and presents them to a committee on a monthly basis. It coordinates with the engineering divisions to prepare estimated project costs from which they calculate B/C ratios (reduction in crashes over project costs). Simple B/A project evaluations are completed using before and after crashes. Four of the five projects evaluated in 2017 did not have statistically significant crash rate changes at the 95 percent confidence level. When aggregated, however, they had a B/C ratio of 0.26. Despite the low B/C for these projects, they did result in reductions of 14.1 percent in total crashes and 80 percent in fatal crashes. No evaluation tool is mentioned in or provided with the report.

New Hampshire

New Hampshire's HSIP report provides project evaluation data for 16 projects in 2016 and 22 projects in 2017. The project evaluation results were based on B/C ratios. For each HSIP project, the B/C ratio was calculated at the scoping stage to check that the ratio is larger than 1, but preferably larger than 2. No tool is mentioned in or provided with the report.

New Jersey

New Jersey provides evaluation data for 10 and 11 projects in its 2016 and 2017 HSIP reports, respectively. The project evaluation results were based on three years of B/A crash data and a simple B/C analysis of the reduction in crashes over the project cost. The project evaluation table had before and after crashes based on roadway functional class, improvement category, improvement type, and injury type (PDO, fatal, serious, all injury). The state currently does project evaluations manually in Excel but plans to transition to using SafetyAnalyst after it collects required inputs such as AADT for intersections and SPFs. The University Transportation Research Center has developed SPFs for the state.

New York

New York did not provide any project evaluation data in its 2016 or 2017 HSIP reports. However, the New York State Department of Transportation (NYSDOT) uses a web-based application, called PIES, which allows for actual B/A project evaluations, verification that projected crash reductions reported are reasonable and accurate, quantitative measurements of accidents reduced, safety B/C ratio, and development or updating of CRFs (*44*). The tool is also used for project development and/or prioritization.

PIES supports New York's Safety & Security Planning and Development and Transportation System Operations Bureaus. It provides information such as CRFs and B/A crash statistics of safety projects. Reports can be run at the project level or for specific countermeasures. Regions review the information on a regular basis. Figure 53 through Figure 55 show various inputs used in the tool.

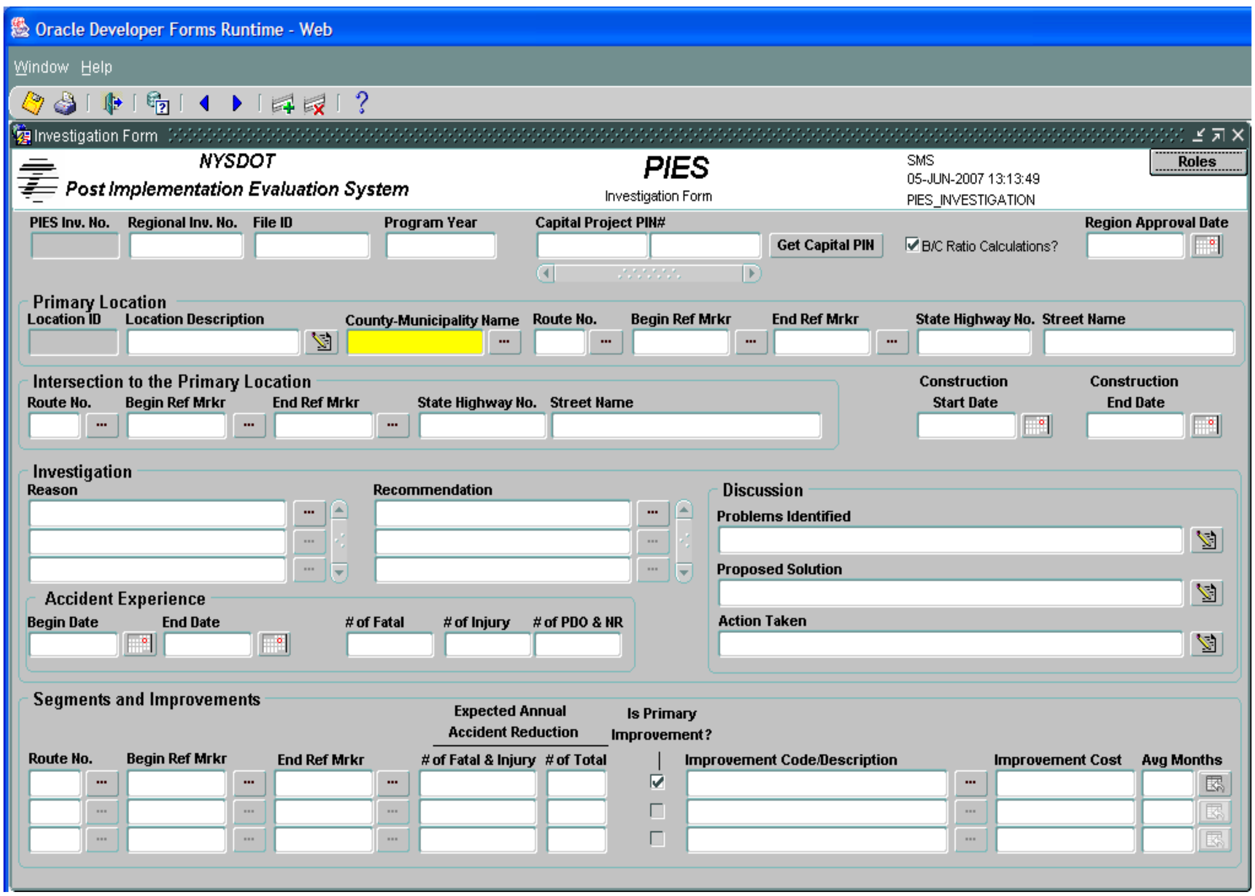

Figure 53. NYSDOT PIES Safety Investigation TE-156a Form (*44*).

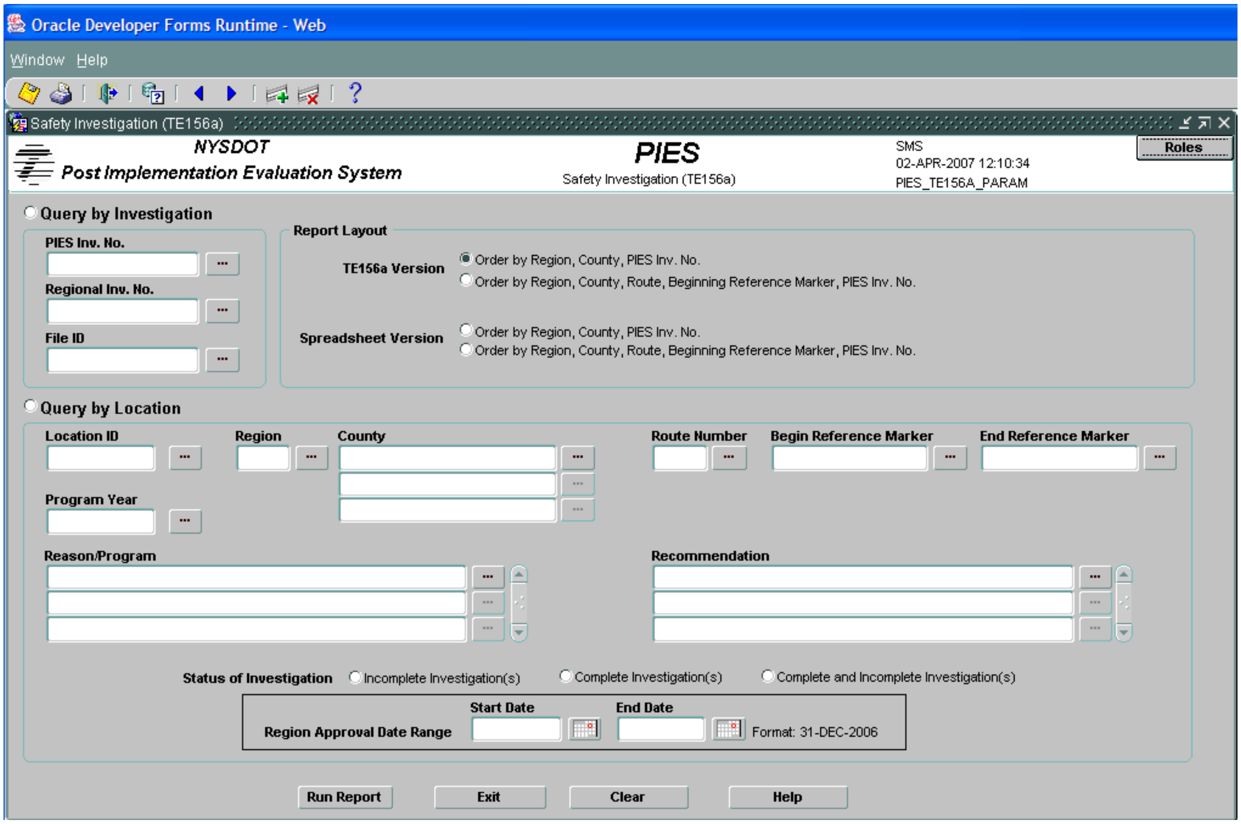

Figure 54. NYSDOT PIES Safety Investigation Report—Query Form (*44*).

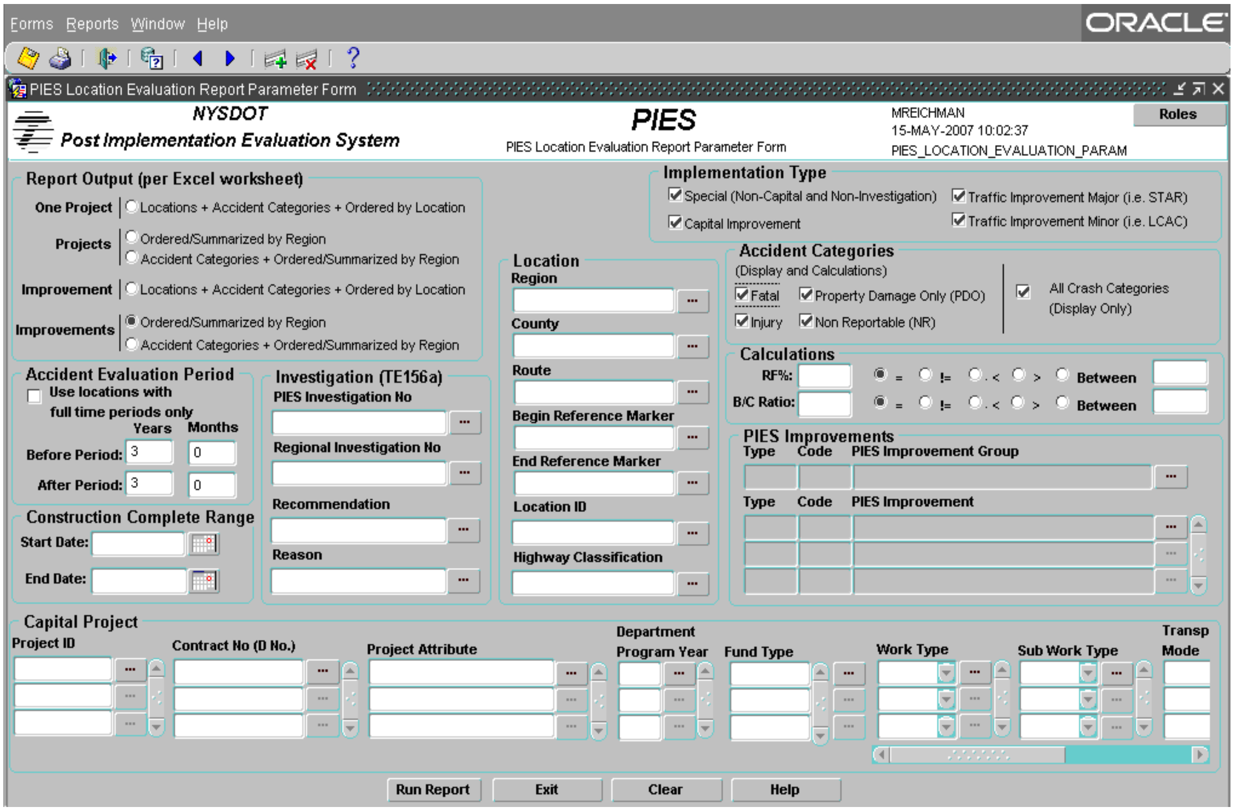

Figure 55. NYSDOT PIES Location/Improvement Evaluation Report (Query Form) (*44*).

North Carolina

In both the 2016 and 2017 HSIP reports, North Carolina provides evaluation data for over 1,700 projects that have been evaluated over several years. The North Carolina Department of Transportation (NCDOT) has a very robust project evaluation program. Every HSIP-funded project is evaluated by performing a simple B/A evaluation to determine if the target pattern of crashes were actually improved with the specific countermeasure. The evaluation includes project background and location information, data tables, and B/A collision diagrams. NCDOT has also determined a combined 14:1 B/C ratio for over 600 projects, according to the 2017 HSIP report.

NCDOT's Safety Evaluation Group of the Traffic Systems Management Section has invested considerable resources to automate the project evaluation reporting process as much as possible. NCDOT has developed and maintains an online system that provides all project evaluation reports. Figure 56 shows the home page of the website (***Error! Reference source not found.***). Project evaluations are divided into 49 project categories. These detailed evaluations are provided to the regional and division traffic engineers so that they can see how well their projects performed.

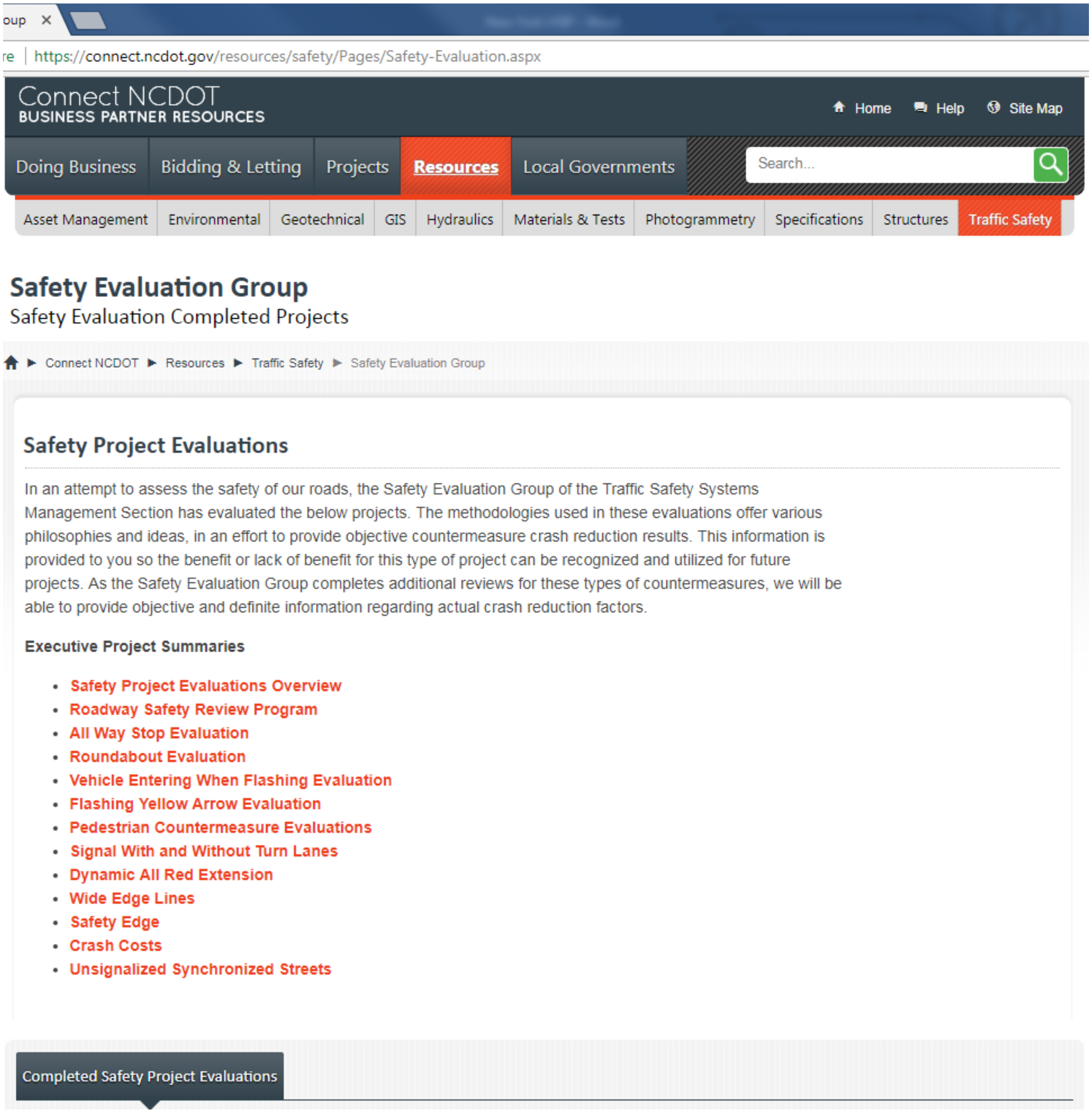

Figure 56. NCDOT Safety Evaluation Group Website (*45*).

The state also developed a spreadsheet tool to assist in predicting the B/C ratio based on selected CRFs from FHWA's clearinghouse and published value of a statistical life crash costs that are used for project development and prioritization. Figure 57 shows an example of B/C ratios for a single countermeasure (***Error! Reference source not found.***). It shows the difference in the total annual benefits if there was one fatal crash out of the total crashes ($282,881 in Example 1A) versus having one incapacitating injury crash out of the total crashes ($167,155 in Example 1B).

EXAMPLE 1A (1 Fatal Crash / 0 A-Injury Crash)

Specific Injury Crashes

			VSL (F+A)	VSL (B+C)	VSL (PDO)		Site Sample:	
			4,451,000	117,000	6,700		Total Crashes	20
Years of Data =	**5**						F Crashes	1
							A Crashes	0
	Count		F+A Benefit	B+C Benefit	PDO Benefit		B Crashes	3
Injury Level Crashes	20						C Crashes	2
Total Fatal Crashes	1		1,290,790				PDO Crashes	14
Total Injury Crashes (A)	0		-					
Total Injury Crashes (B and C)	5			93,600				
Total PDO Crashes	14				30,016			
						$ 282,881	**Total Annual Benefits**	
CRF	% Reduction							
Total Fatal Crashes	29							
Total Injury Crashes	16							
Total PDO Crashes	32							

EXAMPLE 1B (0 Fatal Crash / 1 A-Injury Crash)

Specific Injury Crashes

			VSL (F+A)	VSL (B+C)	VSL (PDO)		Site Sample:	
			4,451,000	117,000	6,700		Total Crashes	20
Years of Data =	**5**						F Crashes	0
							A Crashes	1
	Count		F+A Benefit	B+C Benefit	PDO Benefit		B Crashes	3
Injury Level Crashes	20						C Crashes	2
Total Fatal Crashes	0		-				PDO Crashes	14
Total Injury Crashes (A)	1		712,160					
Total Injury Crashes (B and C)	5			93,600				
Total PDO Crashes	14				30,016			
						$ 167,155	**Total Annual Benefits**	
CRF	% Reduction							
Total Fatal Crashes	29							
Total Injury Crashes	16							
Total PDO Crashes	32							

Figure 57. Example of Annual Benefit for Single Crash Reduction Factor Application—NCDOT (*45*).

NCDOT recently developed calibration factors for selected prediction models from HSM Part C and calibration factors for freeway models that will be part of the second edition of HSM. For some of the models, separate calibration factors were developed for three different regions in North Carolina (Coast, Mountain, and Piedmont). NCDOT also developed state-specific crash type proportions that can be used along with the calibration factors. Using this information, NCDOT is working on a spreadsheet that will provide CMF summaries in EB and simple B/A format. This spreadsheet will be used to input data from all the project evaluations and have them summarized by countermeasure to understand how these countermeasures work across the state. The state developed a draft spreadsheet for intersection treatments and is currently working on something similar for section type treatments.

Oregon

Oregon provides evaluation data for 16 projects in its 2016 and 2017 HSIP reports. The project evaluation results were based on a three-year-before and three-year-after crash comparison using simple spreadsheets. Although not as commonly used as the B/C analysis for project prioritization, Oregon has developed a cost-effectiveness analysis method. This method compares the change in crash frequency due to the implementation of a countermeasure rather than comparing the economic value of the crash reductions to the project cost. For example, the Cost-Effectiveness Index (CEI) is used to prioritize pedestrian/bicycle projects under Oregon's All Roads Transportation Safety Program (*46*). The CEI estimates the cost to reduce one crash. The lower the CEI value of a project, the higher it will rank on the prioritized list.

Pennsylvania

Pennsylvania's state HSIP report provides evaluation data for four projects in 2016 and 243 projects in 2017. The project evaluation is based on a simple B/A comparison and involves calculating a B/C ratio. The Pennsylvania Department of Transportation (PennDOT) uses a spreadsheet tool to evaluate each project. The inputs are divided into general project information, such as description and location, B/A fatalities/injuries, and actual B/C ratio based on inputs and published injury costs, as shown in Figure 58. Note that the red values indicate a disbenefit. PennDOT also developed another version of this spreadsheet to expedite filling out the HSIP project evaluation data table found in the project effectiveness section of the HSIP report. This template is formatted so that it can be easily uploaded into FHWA's website. Researchers will review the template to see if it can be used by TxDOT as part of its annual HSIP reporting process.

While it is not used for project evaluation, PennDOT also developed two tools, the *HSM and Analysis Tool* and the *Alternatives and Safety Benefit Analysis Tool*. These tools are intended to assist in performing detailed calculations required for the HSM Part C predictive method to obtain predicted and expected crash frequencies that will be used to evaluate safety performance and assist in selecting project alternatives. The *Alternatives and Safety Benefit Analysis Tool* allows users to assess the safety implications of possible project alternatives and the corresponding economic impacts. The safety benefit analysis requires implementation and maintenance costs in addition to service life for any changes from the existing project characteristics, as shown in Figure 59.

2013 Project Analysis
January 1, 2013 – December 31, 2013

								Fatalities/Injuries 3 Years Before						Fatalities/Injuries 3 Years After						Benefit/Cost	
Proj. ID	NTP or Let Date	Constr. Comp. Date	Project Title	Improvement Category	Improvement Type	Project Cost	County	Fatalities	Susp Serious Injuries	Susp Minor Injuries	Possible Injuries	Unk Injuries	PDO Crashes	Fatalities	Susp Serious Injuries	Susp Minor Injuries	Possible Injuries	Unk Injuries	PDO Crashes	Net Benefit	B/C Ratio
88621	11/29/2012	7/30/2013	Montour Street to US 11	Intersection traffic control	Modify traffic signal - miscellaneous/other/unspecified	$2,881,779	Montour	0	0	2	1	4	5	0	1	5	6	3	9	-$1,820,040	-0.63 :1
78555	10/6/2011	1/8/2013	SR 100-Claussville Int	Intersection traffic control	Modify traffic signal - miscellaneous/other/unspecifi	$4,008,160	Lehigh	0	0	5	13	7	14	0	0	0	10	3	4	$581,480	0.15 :1
48418	3/16/2009	5/31/2013	Allentown @Trxel&Orvilla(F)	Intersection traffic control	Modify traffic signal - miscellaneous/other/unspecified	$3,971,023	Montgomery	0	0	1	22	3	15	0	0	1	7	22	18	-$40,326	-0.01 :1
95391	1/22/2013	6/21/2013	2012 HSIP Rumble Strips	Roadway	Rumble strips - unspecified or other	$649,280	Fayette Greene Washington	2	2	10	22	10	24	3	4	7	22	16	24	-$9,391,984	-14.47 :1
87666	3/15/2012	11/27/2013		Roadside	Roadside - other	$5,084,744	Lycoming	2	1	0	3	2	11	0	0	1	1	0	12	$14,778,280	2.91 :1
87667	3/15/2012	11/27/2013		Roadside	Roadside - other	$4,813,555	Lycoming	1	1	2	2	1	2	0	0	0	1	0	3	$8,375,130	1.74 :1
88294	6/2/2012	12/5/2013		Roadway	Pavement surface - miscellaneous	$297,872	Beaver	1	2	4	15	4	17	0	0	6	7	9	28	$9,433,832	31.67 :1
88332	5/25/2011	1/14/2013		Roadway	Pavement surface - miscellaneous	$39,902	Adams	1	1	4	7	0	24	0	1	2	14	4	24	$6,798,510	170.38 :1

Figure 58. PennDOT HSIP Project B/C Analysis.

Safety Performance Summary				
Project Totals	Total Crashes			
	Existing Conditions	*Alternative 1*	*Alternative 2*	*Alternative 3*
Predicted Average Annual Crash Frequency	0.00	0.00	--	--
Expected Average Annual Crash Frequency	--	--	--	--
Change from Existing Conditions	--	0.00	--	--
Project Totals	Fatal and Injury Crashes			
	Existing Conditions	*Alternative 1*	*Alternative 2*	*Alternative 3*
Predicted Average Annual Crash Frequency	0.00	0.00	--	--
Expected Average Annual Crash Frequency	--	--	--	--
Change from Existing Conditions	--	0.00	--	--
Project Totals	Property Damage Only Crashes			
	Existing Conditions	*Alternative 1*	*Alternative 2*	*Alternative 3*
Predicted Average Annual Crash Frequency	0.00	0.00	--	--
Expected Average Annual Crash Frequency	--	--	--	--
Change from Existing Conditions	--	0.00	--	--

Economic Performance Summary				
	Existing Conditions	*Alternative 1*	*Alternative 2*	*Alternative 3*
Alternative Cost (Net Present Value)	--	$0	--	--
Crash Benefit/Disbenefit	--	$0	--	--
Safety Benefit Ratio (Change in crashes/Cost of Alternative)	--	0.00	--	--

Figure 59. PennDOT's *Alternatives and Safety Benefit Analysis Tool* – Safety Performance Summary.

Rhode Island

Rhode Island provided evaluation data for three projects in 2016 and one project in 2017. The methodology used for these evaluations was a simple B/A study with a B/C ratio. The project evaluated in 2017 was a statewide wrong-way driving detection system. There were no crashes in the reporting period at the locations where the systems were installed. The calculated safety B/C ratio was 21.64. No evaluation tool was mentioned or provided with the report.

South Carolina

South Carolina's state HSIP reports provide evaluation data for 26 projects in 2016 and 34 projects in 2017. The projects reported in the 2017 HSIP report resulted in an average B/C ratio of 7.56. South Carolina uses collision diagrams along with the spreadsheet tool shown in Figure 60 to perform simple B/A evaluations.

Input Cells	Output Cells

Safety Project After Study

Horry County

6/3/2015

Description of Location	
Project Description	
File Number	26.039189
PIN	39189
FAP #	SA26(015)

Before Project Crash Statistics		***After Project Crash Statistics***	
Beginning Date of Before Study	1/1/2006	Beginning Date of After Study	11/19/2012
End Date of Before Study	1/14/2011	End Date of After Study	12/31/2015
Date Range (years)	5.04	Date Range (years)	3.12
AADT	5700	AADT	5600
Total Crashes	36	Total Crashes	5
PDO Crashes	19	PDO Crashes	4
Possible Injury Crashes (Injury 1)	10	*Possible Injury Crashes (Injury 1)*	0
Evident Injury Crashes (Injury 2)	5	*Evident Injury Crashes (Injury 2)*	1
Incapacitating Injury Crashes (Injury 3)	1	*Incapacitating Injury Crashes (Injury 3)*	0
All Injury Crashes	16	All Injury Crashes	1
Fatal Crashes	1	Fatal Crashes	0
Night Crashes	5	Night Crashes	1
Wet Crashes	7	Wet Crashes	0
Manner of Collision:		**Manner of Collision:**	
Right Angle	31	Right Angle	0
Rear End	4	Rear End	1
Side Swipe	0	Side Swipe	3
Head On	0	Head On	0
Out of Control	1	Out of Control	1
Hit Pedestrian		Hit Pedestrian	
Hit Animal		Hit Animal	
Hit Object		Hit Object	
Other		Other	
Crash Rate	3.43	Crash Rate	0.79
Severity Index	7.54	Severity Index	1.10

PDO Crash Reduction =	65.95%
Injury Crash Reduction =	89.89%
Fatal Crash Reduction =	100.00%
Crash Reduction =	77.54%
Crash Rate Reduction =	77.13%
Severity Index Reduction =	85.41%

Figure 60. South Carolina Department of Transportation B/A Analysis Spreadsheet.

South Dakota

South Dakota's state HSIP report provides project evaluation data for five projects in 2016 and two projects in 2017. The methodology used for this analysis was a simple B/A study with B/C ratio. South Dakota has developed an in-house software that is used to evaluate projects (Figure 61). The proprietary software cannot be shared with external entities.

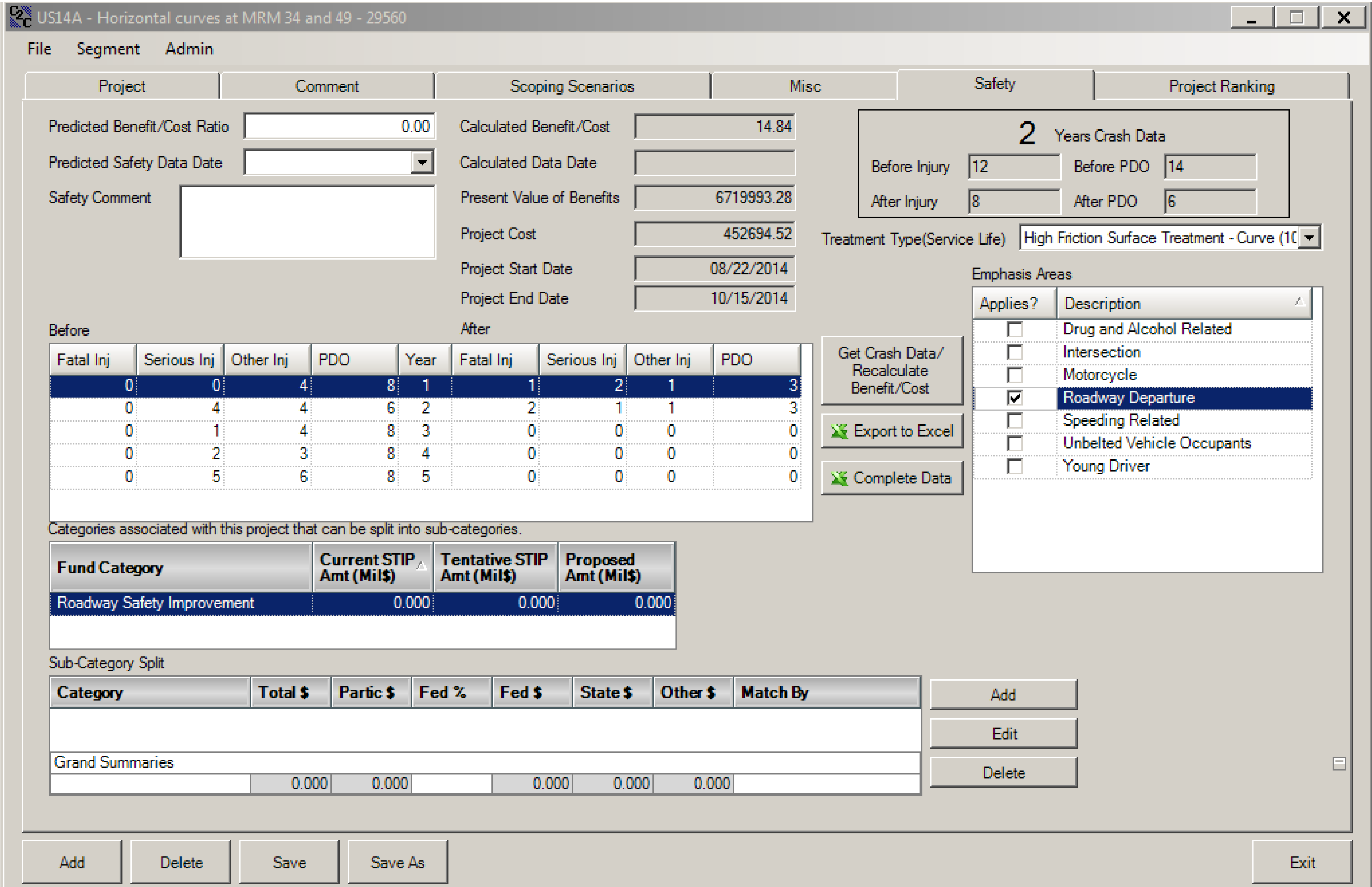

Figure 61. Screenshot from South Dakota's Safety Effectiveness Evaluation Software.

Tennessee

Tennessee's HSIP report provides evaluation data for 10 projects in 2016 and five projects in 2017. The methodology used for this analysis was a simple B/A study with a B/C ratio. No evaluation tool is mentioned in or provided with the report.

Utah

Utah provided evaluation data for 11 projects in 2017. The project evaluation results were based on a simple B/C ratio and the reduction of severe crashes. Using three years of B/A crashes, the B/C ratio ranged from −14.57 to 23.46. However, when combined, these projects had a statewide average B/C ratio of 9.43. Although fatalities rose from 278 (2015) to 281 (2016), serious injuries dropped from 1499 (2015) to 1477 (2016). The fatal and serious injury rates both decreased slightly from 2015 to 2016. No evaluation tool was mentioned, but the Utah Department of Transportation has developed online crash visualization and analysis tools so that all partners, such as metropolitan planning organizations, the Governor's Highway Safety Office, local governments, academia, FHWA, and other SHSP partners, have equal access to safety data. One of the tools, the Safety Analysis app, can be used to compare relative B/C ratios to prioritize potential safety projects (*47*).

Virginia

Virginia provided project evaluation data for 93 projects in 2016 and 28 projects in 2017. It used simple B/A evaluations. The state is working on other methods that will consider traffic volume correction and shift in proportions of target crash types. Although no project evaluation tool was specifically mentioned, the Virginia Department of Transportation noted the following practices that the state implemented to ensure that the most appropriate locations were being targeted for safety improvements.

- Developed a methodology and step-by-step process to effectively evaluate the systemic safety improvement projects (site-specific and network-level).
- Developed Virginia-specific CMFs for selected safety countermeasures.
- Developed in-house project tracking tools (in Tableau) to enhance the HSIP funding delivery process and track HSIP projects in a more intuitive and useful way. Virginia uses its Smart Portal to process project submittals and prioritize HSIP funding, which feeds the projects to its Integrated Six-Year Plan and other project tracking tools (*48*).

West Virginia

West Virginia's HSIP report provides evaluation data for 16 projects in 2016 and nine projects in 2017. The methodology used for this analysis was a simple B/A study with a B/C ratio. No evaluation tool is mentioned in or provided with the report.

APPENDIX C:
TEXAS ROADWAY SAFETY DESIGN WORKBOOK SPFS

This appendix presents the SPFs provided in the *Texas Roadway Safety Design Workbook*. The SPFs are provided in the following order:

- SPFs for urban highways.
- SPFs for rural highways.
- SPFs for urban intersections.
- SPFs for rural intersections.

The variables and equations that cannot be calculated using existing TxDOT data are highlighted in red.

C.1 URBAN HIGHWAYS

This section describes the SPFs used for predicting crashes on urban highways.

C.1.1 Interstates (U1) and Other Freeways and Expressways (U2)

SPFs are provided for four- and six-lane highways.

Four-Lane Highways (No Barrier Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{enr} + C_{exr}$$

With

$$C_{mv} = 0.00532 * (0.001 * ADT)^{1.55} * L$$
$$C_{sv} = 0.134 * (0.001 * ADT)^{0.646} * L$$
$$C_{enr} = 0.00704 * \left(\frac{ADT}{15000}\right)^{1.33} * n_{enr}$$
$$C_{exr} = 0.00174 * \left(\frac{ADT}{15000}\right)^{1.68} * n_{exr}$$

Where:

C_{tot} = Total fatal and injury crash frequency (crashes/yr).
C_{mv} = Multiple-vehicle non-ramp crash frequency (crashes/yr).
C_{sv} = Single-vehicle non-ramp crash frequency (crashes/yr).
C_{enr} = Ramp entrance crash frequency (crashes/yr).
C_{exr} = Ramp exit crash frequency (crashes/yr).
ADT = Average daily traffic volume (veh/d).
L = Segment length (mi).

Six-Lane Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{enr} + C_{exr}$$

With

$$C_{mv} = 0.00352 * (0.001 * ADT)^{1.55} * L$$
$$C_{sv} = 0.119 * (0.001 * ADT)^{0.646} * L$$
$$C_{enr} = 0.00532 * \left(\frac{ADT}{15000}\right)^{1.33} * n_{enr}$$
$$C_{exr} = 0.000640 * \left(\frac{ADT}{15000}\right)^{1.68} * n_{exr}$$

Eight-Lane Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{enr} + C_{exr}$$

With

$$C_{mv} = 0.00289 * (0.001 * ADT)^{1.55} * L$$
$$C_{sv} = 0.113 * (0.001 * ADT)^{0.646} * L$$
$$C_{enr} = 0.00199 * \left(\frac{ADT}{15000}\right)^{1.33} * n_{enr}$$
$$C_{exr} = 0.000482 * \left(\frac{ADT}{15000}\right)^{1.68} * n_{exr}$$

Ten-Lane Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{enr} + C_{exr}$$

With

$$C_{mv} = 0.00220 * (0.001 * ADT)^{1.55} * L$$
$$C_{sv} = 0.104 * (0.001 * ADT)^{0.646} * L$$
$$C_{enr} = 0.00212 * \left(\frac{ADT}{15000}\right)^{1.33} * n_{enr}$$
$$C_{exr} = 0.000491 * \left(\frac{ADT}{15000}\right)^{1.68} * n_{exr}$$

C.1.2 Other Principal Arterials (U3), Minor Arterials (U4), and Major Collectors (U5)

SPFs are provided for two-, four-, and six-lane highways.

Two-Lane Undivided Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00362 * (0.001 * ADT)^{2.31} * L * F_{lu}$$
$$C_{sv} = 0.0399 * (0.001 * ADT)^{1.06} * L * F_{lu}$$
$$C_{dw} = 0.120 * \left(\frac{ADT}{15000}\right)^{1.04} * n_e * S_d{}^{0.518}$$
$$S_d = \frac{2L}{n_{res} + n_{ind} + n_{bus} + n_{off} + 1.0}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Where:

C_{dw} = Driveway-related crash frequency (crashes/yr).
S_d = Driveway spacing (miles/driveway).
F_{lu} = Land use adjustment factor.
L_{bus} = Estimated curb miles with business land use.
L_{ind} = Estimated curb miles with industrial land use.
L_{off} = Estimated curb miles with office land use.
P_{bus} = Estimated proportion of curb miles with business land use (Table 33).
P_{ind} = Estimated proportion of curb miles with industrial land use (Table 33).
P_{off} = Estimated proportion of curb miles with office land use (Table 33).
n_e = Number of equivalent residential driveways.
n_{res} = Number of driveways serving residential land uses.
n_{ind} = Number of driveways serving industrial land uses.
n_{bus} = Number of driveways serving business land uses.
n_{off} = Number of equivalent office driveways.

Table 33. Estimated Proportion of Adjacent Land Use (*28*).

Median Type	Number of Lanes	Proportion of Adjacent Land Use		
		P_{ind}	P_{bus}	P_{off}
Undivided	2	0.068	0.202	0.028
Undivided	4	0.048	0.485	0.062
Nonrestrictive Median	2	0.004	0.434	0.125
Nonrestrictive Median	4	0.052	0.5	0.051
Nonrestrictive Median	6	0.072	0.558	0.047
Restrictive Median	4	0.026	0.471	0.044
Restrictive Median	6	0.03	0.496	0.094
Restrictive Median	8	0.025	0.655	0.092

Two-Lane Highways (Nonrestrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.0116 * (0.001 * ADT)^{1.82} * L * F_{lu}$$
$$C_{sv} = 0.0700 * (0.001 * ADT)^{0.630} * L * F_{lu}$$
$$C_{dw} = 0.103 * \left(\frac{ADT}{15000}\right)^{1.29} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Four-Lane Undivided Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00255 * (0.001 * ADT)^{2.31} * L * F_{lu}$$
$$C_{sv} = 0.0236 * (0.001 * ADT)^{1.06} * L * F_{lu}$$
$$C_{dw} = 0.102 * \left(\frac{ADT}{15000}\right)^{1.04} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Four-Lane Divided Highways (Nonrestrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00645 * (0.001 * ADT)^{1.82} * L * F_{lu}$$
$$C_{sv} = 0.0461 * (0.001 * ADT)^{0.630} * L * F_{lu}$$
$$C_{dw} = 0.0740 * \left(\frac{ADT}{15000}\right)^{1.29} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Four-Lane Divided Highways (Restrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.0236 * (0.001 * ADT)^{1.38} * L * F_{lu}$$
$$C_{sv} = 0.193 * (0.001 * ADT)^{0.201} * L * F_{lu}$$
$$C_{dw} = 0.0897 * \left(\frac{ADT}{15000}\right)^{1.25} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Six-Lane Divided Highways (Nonrestrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00527 * (0.001 * ADT)^{1.82} * L * F_{lu}$$
$$C_{sv} = 0.0609 * (0.001 * ADT)^{0.630} * L * F_{lu}$$
$$C_{dw} = 0.0734 * \left(\frac{ADT}{15000}\right)^{1.29} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Six-Lane Divided Highways (Restrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.0197 * (0.001 * ADT)^{1.38} * L * F_{lu}$$
$$C_{sv} = 0.244 * (0.001 * ADT)^{0.201} * L * F_{lu}$$
$$C_{dw} = 0.0657 * \left(\frac{ADT}{15000}\right)^{1.25} * n_e * {S_d}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

C.2 RURAL HIGHWAYS

This section describes the available SPFs developed for various types of rural highways. The variables/parameters shown in red letters are not readily available.

C.2.1 Interstates (R1) and Other Freeways and Expressways (R2)

SPFs are provided for four- and six-lane highways.

Four-Lane Highways

$$C_{tot} = 0.860 * C_{mv} + 0.991 * C_{sv} + 0.638 * C_{enr} + 3.51 * C_{exr}$$

With

$$C_{mv} = 0.00532 * (0.001 * ADT)^{1.55} * L$$
$$C_{sv} = 0.134 * (0.001 * ADT)^{0.646} * L$$
$$C_{enr} = 0.00704 * \left(\frac{ADT}{15000}\right)^{1.33} * n_{enr}$$
$$C_{exr} = 0.00174 * \left(\frac{ADT}{15000}\right)^{1.68} * n_{exr}$$

Six-Lane Highways

$$C_{tot} = 0.860 * C_{mv} + 0.991 * C_{sv} + 0.638 * C_{enr} + 3.51 * C_{exr}$$

With

$$C_{mv} = 0.00352 * (0.001 * ADT)^{1.55} * L$$
$$C_{sv} = 0.0119 * (0.001 * ADT)^{0.646} * L$$
$$C_{enr} = 0.00532 * \left(\frac{ADT}{15000}\right)^{1.33} * n_{enr}$$
$$C_{exr} = 0.000640 * \left(\frac{ADT}{15000}\right)^{1.68} * n_{exr}$$

C.2.2 Other Principal Arterials (R3)

SPFs are provided for two- and four-lane highways.

Two-Lane Highways

$$C_{tot} = 0.0537 * (0.001 * ADT)^{1.30} * L$$

Four-Lane Undivided Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00749 * (0.001 * ADT)^{1.63} * L$$
$$C_{sv} = 0.109 * (0.001 * ADT)^{0.631} * L$$
$$C_{dw} = 0.0169 * \left(\frac{ADT}{15000}\right)^{0.738} * n_e$$
$$n_e = n_{res} + 2.68 * n_{ind} + 2.33 * n_{bus} + 9.76 * n_{off}$$

Four-Lane Divided Highways (Nonrestrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00527 * (0.001 * ADT)^{1.80} * L$$
$$C_{sv} = 0.0776 * (0.001 * ADT)^{0.667} * L$$
$$C_{dw} = 0.0170 * \left(\frac{ADT}{15000}\right)^{1.44} * n_e$$
$$n_e = n_{res} + 2.68 * n_{ind} + 2.33 * n_{bus} + 9.76 * n_{off}$$

Four-Lane Divided Highways (Restrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00549 * (0.001 * ADT)^{1.49} * L$$
$$C_{sv} = 0.106 * (0.001 * ADT)^{0.707} * L$$
$$C_{dw} = 0.0152 * \left(\frac{ADT}{15000}\right)^{1.04} * n_e$$
$$n_e = n_{res} + 2.68 * n_{ind} + 2.33 * n_{bus} + 9.76 * n_{off}$$

C.2.3 Minor Arterials (R4) and Major Collectors (R5)

SPFs are provided for two-, four-, and six-lane highways.

Two-Lane Undivided Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00362 * (0.001 * ADT)^{2.31} * L * F_{lu}$$
$$C_{sv} = 0.0399 * (0.001 * ADT)^{1.06} * L * F_{lu}$$
$$C_{dw} = 0.120 * \left(\frac{ADT}{15000}\right)^{1.04} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Two-Lane Highways (Nonrestrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.0116 * (0.001 * ADT)^{1.82} * L * F_{lu}$$
$$C_{sv} = 0.0700 * (0.001 * ADT)^{0.630} * L * F_{lu}$$
$$C_{dw} = 0.103 * \left(\frac{ADT}{15000}\right)^{1.29} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Four-Lane Undivided Highways

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00255 * (0.001 * ADT)^{2.31} * L * F_{lu}$$
$$C_{sv} = 0.0236 * (0.001 * ADT)^{1.06} * L * F_{lu}$$
$$C_{dw} = 0.102 * \left(\frac{ADT}{15000}\right)^{1.04} * n_e * S_d^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Four-Lane Divided Highways (Nonrestrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00645 * (0.001 * ADT)^{1.82} * L * F_{lu}$$
$$C_{sv} = 0.0461 * (0.001 * ADT)^{0.630} * L * F_{lu}$$
$$C_{dw} = 0.0740 * \left(\frac{ADT}{15000}\right)^{1.29} * n_e * S_d^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Four-Lane Divided Highways (Restrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.0236 * (0.001 * ADT)^{1.38} * L * F_{lu}$$
$$C_{sv} = 0.193 * (0.001 * ADT)^{0.201} * L * F_{lu}$$
$$C_{dw} = 0.0897 * \left(\frac{ADT}{15000}\right)^{1.25} * n_e * S_d^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Six-Lane Divided Highways (Nonrestrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.00527 * (0.001 * ADT)^{1.82} * L * F_{lu}$$
$$C_{sv} = 0.0609 * (0.001 * ADT)^{0.630} * L * F_{lu}$$
$$C_{dw} = 0.0734 * \left(\frac{ADT}{15000}\right)^{1.29} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

Six-Lane Divided Highways (Restrictive Median)

$$C_{tot} = C_{mv} + C_{sv} + C_{dw}$$

With

$$C_{mv} = 0.0197 * (0.001 * ADT)^{1.38} * L * F_{lu}$$
$$C_{sv} = 0.244 * (0.001 * ADT)^{0.201} * L * F_{lu}$$
$$C_{dw} = 0.0657 * \left(\frac{ADT}{15000}\right)^{1.25} * n_e * S_d{}^{0.518}$$
$$F_{lu} = exp\left(\frac{0.210 * L_{ind} + 0.448 * L_{bus} + 0.113 * L_{off}}{L}\right)$$
$$L_{ind} = P_{ind} * 2L$$
$$L_{bus} = P_{bus} * 2L$$
$$L_{off} = P_{off} * 2L$$
$$n_e = n_{res} + 1.32 * n_{ind} + 4.11 * n_{bus} + 2.91 * n_{off}$$

C.3 URBAN INTERSECTIONS

C.3.1 Stop-Controlled

Three-Leg Intersections

$$C_{tot} = 0.0877\left(\frac{ADT_{major}}{1000}\right)^{0.766}\left(\frac{ADT_{minor}}{1000}\right)^{0.248}$$

Where:

C_{tot} = Total fatal and injury crash frequency (crashes/yr).
ADT_{major} = Average daily traffic volume (veh/d) of major street.
ADT_{minor} = Average daily traffic volume (veh/d) of minor street.

Four-Leg Intersections

$$C_{tot} = 0.172 \left(\frac{ADT_{major}}{1000}\right)^{0.596} \left(\frac{ADT_{minor}}{1000}\right)^{0.260}$$

C.3.2 Signalized

Three-Leg Intersections

$$C_{tot} = 0.159 \left(\frac{ADT_{major}}{1000}\right)^{0.629} \left(\frac{ADT_{minor}}{1000}\right)^{0.385}$$

Four-Leg Intersections

$$C_{tot} = 0.353 \left(\frac{ADT_{major}}{1000}\right)^{0.459} \left(\frac{ADT_{minor}}{1000}\right)^{0.397}$$

C.4 RURAL INTERSECTIONS

C.4.1 Stop-Controlled

Three-Leg Intersections

$$C_{tot} = 0.0973 \left(\frac{ADT_{major}}{1000}\right)^{0.863} \left(\frac{ADT_{minor}}{1000}\right)^{0.497}$$

Where:

$C_{tot} =$ Total fatal and injury crash frequency (crashes/yr).
$ADT_{major} =$ Average daily traffic volume (veh/d) of major street.
$ADT_{minor} =$ Average daily traffic volume (veh/d) of minor street.

Four-Leg Intersections

$$C_{tot} = 0.235 \left(\frac{ADT_{major}}{1000}\right)^{0.692} \left(\frac{ADT_{minor}}{1000}\right)^{0.514}$$

C.4.2 Signalized

Three-Leg Intersections

$$C_{tot} = 0.0973 \left(\frac{ADT_{major}}{1000}\right)^{0.782} \left(\frac{ADT_{minor}}{1000}\right)^{0.577}$$

Four-Leg Intersections

$$C_{tot} = 0.221 \left(\frac{ADT_{major}}{1000}\right)^{0.611} \left(\frac{ADT_{minor}}{1000}\right)^{0.595}$$

APPENDIX D:
INPUT SHEET

This appendix presents the data fields in the "Input" sheet of the segment evaluation tool. Similar fields are included in the "Results for Single Projects" sheet of the intersection evaluation tool.

Table 34. Data Fields of "Input" Sheet.

Column	Data Type	Data Field	Data Field Description	Example
A	General Project Information (*required fields)	District Name	Abbreviation of TxDOT district name (three letters).	AUS
B		CSJ	Control section job number.	1377-01-019
C		Road Name	Name of the road where the project has been implemented.	FM1327
D		From_DFO	From distance from origin.	0
E		To_DFO	To distance from origin.	7.190
F		Work Code(s)*	TxDOT HSIP work codes that have been implemented at the project to be evaluated.	303
G		Work Code Description	Description of selected work codes. This field is automatically populated.	Resurfacing
H		Length (miles)*	Length of project (miles). It can be calculated as follows: [End DFO] − [Start DFO].	7.2
I	Before Period	Start Date*	Enter the start date of the before period in the following format: MM/DD/YYYY.	1/1/2007
J		End Date*	Enter the end date of the before period in the following format: MM/DD/YYYY. It is recommended to use 3-5 years of before data and also have the same number of years in the before and after periods.	1/10/2010
K	After Period	Start Date*	Enter the start date of the after period in the following format: MM/DD/YYYY.	1/1/2012

Column	Data Type	Data Field	Data Field Description	Example
L		End Date*	Enter the end date of the after period in the following format: MM/DD/YYYY. It is recommended to use 3-5 years of after data and also have the same number of years in the before and after periods.	12/31/2015
M	Years for Which AADT and Crash Data Are Needed	Year 1 (Before)	Year 1 of the before period. It is automatically populated.	2007
N		Year 2 (Before)	Year 2 of the before period. It is automatically populated.	2008
O		Year 3 (Before)	Year 3 of the before period. It is automatically populated.	2009
P		Year 4 (Before)	Year 4 of the before period. It is automatically populated.	2010
Q		Year 5 (Before)	Year 5 of the before period. It is automatically populated.	
R		Year 1 (After)	Year 1 of the after period. It is automatically populated.	2012
S		Year 2 (After)	Year 2 of the after period. It is automatically populated.	2013
T		Year 3 (After)	Year 3 of the after period. It is automatically populated.	2014
U		Year 4 (After)	Year 4 of the after period. It is automatically populated.	2015
V		Year 5 (After)	Year 5 of the after period. It is automatically populated.	

Column	Data Type	Data Field	Data Field Description	Example
W	AADT (*required only for years included in the before and after periods)	AADT Year 1 (Before)*	AADT for Year 1 in the before period.	20,000
X		AADT Year 2 (Before)*	AADT for Year 2 in the before period.	21,000
Y		AADT Year 3 (Before)*	AADT for Year 3 in the before period.	22,000
Z		AADT Year 4 (Before)*	AADT for Year 4 in the before period.	23,000
AA		AADT Year 5 (Before)*	AADT for Year 5 in the before period.	
AB		AADT Year 1 (After)*	AADT for Year 1 in the after period.	20,000
AC		AADT Year 2 (After)*	AADT for Year 2 in the after period.	21,000
AD		AADT Year 3 (After)*	AADT for Year 3 in the after period.	22,000
AE		AADT Year 4 (After)*	AADT for Year 4 in the after period.	23,000
AF		AADT Year 5 (After)*	AADT for Year 5 in the after period.	

Column	Data Type	Data Field	Data Field Description	Example
AG	Target Crashes for Evaluation	All or Target Crashes*	Select whether you would like to include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table.	All
AH		Crash Severity(ies)*	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes.	KABC
AI	Number of Crashes (*required only for years included in the before and after periods)	Crashes Year 1 (Before)*	Crashes observed in Year 1 of the before period.	3
AJ		Crashes Year 2 (Before)*	Crashes observed in Year 2 of the before period. Leave this cell empty if the before period does not include Year 2.	3
AK		Crashes Year 3 (Before)*	Crashes observed in Year 3 of the before period. Leave this cell empty if the before period does not include Year 3.	3
AL		Crashes Year 4 (Before)*	Crashes observed in Year 4 of the before period. Leave this cell empty if the before period does not include Year 4.	3
AM		Crashes Year 5 (Before)*	Crashes observed in Year 5 of the before period. Leave this cell empty if the before period does not include Year 5.	
AN		Crashes Year 1 (After)*	Crashes observed in Year 1 of the after period.	3
AO		Crashes Year 2 (After)*	Crashes observed in Year 2 of the after period. Leave this cell empty if the after period does not include Year 2.	4
AP		Crashes Year 3 (After)*	Crashes observed in Year 3 of the after period. Leave this cell empty if the after period does not include Year 3.	3
AQ		Crashes Year 4 (After)*	Crashes observed in Year 4 of the after period. Leave this cell empty if the after period does not include Year 4.	3

Column	Data Type	Data Field	Data Field Description	Example
AR		Crashes Year 5 (After)*	Crashes observed in Year 5 of the after period. Leave this cell empty if the after period does not include Year 5.	
AS	Economic Analysis	Actual Construction Cost*	Total construction cost of a project.	$5,000,000.00
AT		Annual Maintenance Cost	Annual maintenance cost of a project. Leave empty if there is no maintenance cost. The maintenance cost of some WCs can be found in the "Menu Lists" sheet of the tool.	$10,000.00
AU	Comparison Group (^required for this method only)	Total Number of Crashes at Comparison Sites (Before)^	Total number of crashes observed in the before period at the comparison sites. Leave blank if no comparison sites are used in the analysis.	150
AV		Total Number of Crashes at Comparison Sites (After)^	Total number of crashes observed in the after period at the comparison sites. Leave blank if no comparison sites are used in the analysis.	200
AW	EB Method (+required for the EB method only)	Functional Class and Rural/Urban Code+	Combination of HPMS roadway functional class and rural/urban designation. TxDOT Roadway Safety Design Workbook does not provide SPFs for the lower functional classes: minor collectors (FC6) and local roads (FC7).	U1—Urban Interstate
AX		Number of Lanes+	Number of lanes on the facility to be evaluated.	6
AY		Median Type+	Type of median, if any.	No Barrier Median
AZ		Observed Multi-Vehicle (MV) Crashes Before	Total number of observed MV crashes in the entire before period. If this number is unknown, an estimate will be developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class and rural/urban designation.	

Column	Data Type	Data Field	Data Field Description	Example
BA		Observed Single-Vehicle (SV) Crashes Before	Total number of observed SV crashes in the entire before period. If this number is unknown, an estimate will be developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class and rural/urban designation.	
BB		Observed MV Crashes After	Total number of observed MV crashes in the entire after period. If this number is unknown, an estimate will be developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class and rural/urban designation.	
BC		Observed SV Crashes After	Total number of observed SV crashes in the entire after period. If this number is unknown, an estimate will be developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class and rural/urban designation.	
BD		Median Width (ft)	The width of the median if no barrier exists. If you do not know the value, leave the cell blank. The default value of the CMF for median width is 1.0.	11
BE		Lane Width (ft)	Lane width (feet). If you do not know the value, leave the cell blank. The default value of the CMF for lane width is 1.0.	12
BF		Inside Shoulder Width (ft)	The width of the inside shoulder (feet). If you do not know the value, leave the cell blank. The default value of the CMF for inside shoulder width is 1.0.	5
BG		Outside Shoulder Width (ft)	The width of the outside shoulder (feet). If you do not know the value, leave the cell blank. The default value of the CMF for outside shoulder width is 1.0.	2

Column	Data Type	Data Field	Data Field Description	Example
BH		CMF Product	The product of other applicable CMFs to adjust the predicted number of crashes to existing conditions. If you do not know the value, leave the cell blank. The default value is 1.0.	1.12
BI		Local Calibration Factor	The factor used to calibrate the SPF to local conditions. If you do not know the value, leave the cell blank. The default value is 1.0.	1.05
BJ		Proportion of SPF Target Crashes	The proportion of the crashes predicted by the SPFs that are made up of the target crash type. If you do not know the value, leave the cell blank. The default value is 1.0.	0.6

APPENDIX E:
RESULTS FOR SINGLE PROJECTS SHEET

This appendix presents the data fields in the "Results for Single Projects" sheet of the segment evaluation tool. Similar fields are included in the "Results for Single Projects" sheet of the intersection evaluation tool.

Table 35. Data Fields of "Results for Single Projects" Sheet.

Column	Data Type	Data Field	Data Field Description and Excel Formula
A	General Project Information	District Name	Abbreviation of TxDOT district name (three letters). =IF(Input!A3="","",Input!A3)
B		CSJ	Control section job number. =IF(Input!B3="","",Input!B3)
C		Road Name	Name of the road where the project has been implemented. =IF(Input!C3="","",Input!C3)
D		Work Code(s)	TxDOT HSIP work codes that have been implemented at the project to be evaluated. =IF(Input!F3="","",Input!F3)
E		Work Code Description	Description of selected work codes. This field is automatically populated. =IF(Input!G3="","",Input!G3)
F		Length (miles)	Length of project (miles). It can be calculated as follows: [End DFO] − [Start DFO] =IF(Input!H3="","",Input!H3)
G		Actual Construction Cost	Total construction cost of a project. =IF(Input!AS3="","",Input!AS3)
H	Target Crashes	All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =IF(Input!AG3="","",Input!AG3)
I		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =IF(Input!AH3="","",Input!AH3)
J	Observed Crashes	Before	Total number of observed crashes in the before period. =IF('Naïve with Volume Correction'!AI3="","",'Naïve with Volume Correction'!AI3)
K		After	Total number of observed crashes in the after period. =IF('Naïve with Volume Correction'!AJ3="","",'Naïve with Volume Correction'!AJ3)

Column	Data Type	Data Field	Data Field Description and Excel Formula
L	Duration (years)	Before	Total number of years (as decimal) included in the before period. =IF('Naïve with Volume Correction'!AB3="","",'Naïve with Volume Correction'!AB3)
M		After	Total number of years (as decimal) included in the after period. =IF('Naïve with Volume Correction'!AC3="","",'Naïve with Volume Correction'!AC3)
N	Average Traffic Volume	Before	Average traffic volume per year in the before period. =IF('Naïve with Volume Correction'!AE3="","",'Naïve with Volume Correction'!AE3)
O		After	Average traffic volume per year in the after period. =IF('Naïve with Volume Correction'!AF3="","",'Naïve with Volume Correction'!AF3)
P	Safety Effectiveness Index (θ)	Naïve	Safety effectiveness index based on the naïve method. =IF(Naïve!O3="","",Naïve!O3)
Q		Naïve with Volume Correction	Safety effectiveness index based on the naïve method with traffic volume correction. =IF('Naïve with Volume Correction'!AM3="","",'Naïve with Volume Correction'!AM3)
R		Comparison Group	Safety effectiveness index based on the comparison group method. =IF('Comparison Group'!P3="","",'Comparison Group'!P3)
S		Empirical Bayes	Safety effectiveness index based on the EB method. =IF('Empirical Bayes'!CJ3="","",'Empirical Bayes'!CJ3)
T	Standard Error of θ	Naïve	Standard error of the safety effectiveness index calculated using the naïve method. =IF(Naïve!Q3="","",Naïve!Q3)
U		Naïve with Volume Correction	Standard error of the safety effectiveness index calculated using the naïve method with traffic volume correction. =IF('Naïve with Volume Correction'!AO3="","",'Naïve with Volume Correction'!AO3)
V		Comparison Group	Standard error of the safety effectiveness index calculated using the comparison group method. =IF('Comparison Group'!R3="","",'Comparison Group'!R3)
W		Empirical Bayes	Standard error of the safety effectiveness index calculated using the EB method. =IF('Empirical Bayes'!CL3="","",'Empirical Bayes'!CL3)

Column	Data Type	Data Field	Data Field Description and Excel Formula
X	Benefit/Cost Ratio	Naïve	B/C ratio calculated based on the naïve method. =IF('Economic Analysis'!T4="","",'Economic Analysis'!T4)
Y		Naïve with Volume Correction	B/C ratio calculated based on the naïve method with traffic volume correction. =IF('Economic Analysis'!U4="","",'Economic Analysis'!U4)
Z		Comparison Group	B/C ratio calculated based on the comparison group method. =IF('Economic Analysis'!V4="","",'Economic Analysis'!V4)
AA		Empirical Bayes	B/C ratio calculated based on the EB method. =IF('Economic Analysis'!W4="","",'Economic Analysis'!W4)

APPENDIX F: RESULTS FOR GROUPS OF PROJECTS SHEET

This appendix presents the data fields in the "Results for Groups of Projects" sheet of the segment evaluation tool. Similar fields are included in the "Results for Groups of Projects" sheet of the intersection evaluation tool.

Table 36. Data Fields of "Results for Groups of Projects" Sheet.

Column	Data Type	Data Field	Data Field Description and Excel Formula
A	Groups of Projects	WC(s) & All/Target Crashes & Crash Severity(-ies)	This field determines unique groups of similar projects by: • WCs. • All/target crashes. • Crash severity groups. =Naïve!R4
B		Work Code(s)	TxDOT HSIP WCs of the group of similar types of projects to be evaluated. =Naïve!S4
C		Work Code Description	Description of WCs. =Naïve!T4
D		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =Naïve!U4
E		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =Naïve!V4
F		Number of Projects	Number of projects included in each group. =Naïve!W4
G	Crash Modification Factor	Naïve	CMF calculated based on the naïve method. A CMF greater than 1.0 indicates an expected increase in crash frequency, while a CMF less than 1.0 indicates an expected decrease in crashes. =Naïve!Y4
H		Naïve with Volume Correction	CMF calculated based on the naïve method with traffic volume correction. A CMF greater than 1.0 indicates an expected increase in crash frequency, while a CMF less than 1.0 indicates an expected decrease in crashes. ='Naïve with Volume Correction'!AW4
I		Comparison Group	CMF calculated based on the comparison group method. A CMF greater than 1.0 indicates an expected increase in crash frequency, while a CMF less than 1.0 indicates an expected decrease in crashes. ='Comparison Group'!Z4

Column	Data Type	Data Field	Data Field Description and Excel Formula
J		Empirical Bayes	CMF calculated based on the EB method. A CMF greater than 1.0 indicates an expected increase in crash frequency, while a CMF less than 1.0 indicates an expected decrease in crashes. ='Empirical Bayes'!CT4
K	Standard Error of CMF	Naïve	Standard error of the CMF calculated using the naïve method. =Naïve!AB4
L		Naïve with Volume Correction	Standard error of the CMF calculated using the naïve method with traffic volume correction. ='Naïve with Volume Correction'!AZ4
M		Comparison Group	Standard error of the CMF calculated using the comparison group method. ='Comparison Group'!AC4
N		Empirical Bayes	Standard error of the CMF calculated using the EB method. ='Empirical Bayes'!CW4
O	Statistical Significance of CMF	Naïve	Statistical significance of CMF developed using the naïve method. =Naïve!AD4
P		Naïve with Volume Correction	Statistical significance of CMF developed using the naïve method with traffic volume correction. ='Naïve with Volume Correction'!BB4
Q		Comparison Group	Statistical significance of CMF developed using the comparison group method. ='Comparison Group'!AE4
R		Empirical Bayes	Statistical significance of CMF developed using the EB method. ='Empirical Bayes'!CY4
S	Benefit/Cost Ratio	Naïve	B/C ratio calculated based on the naïve method. ='Economic Analysis'!AD5
T		Naïve with Volume Correction	B/C ratio calculated based on the naïve method with traffic volume correction. ='Economic Analysis'!AE5
U		Comparison Group	B/C ratio calculated based on the comparison group method. ='Economic Analysis'!AF5
V		Empirical Bayes	B/C ratio calculated based on the EB method. ='Economic Analysis'!AG5

APPENDIX G:
NAÏVE SHEET

This appendix presents the data fields in the "Naïve" sheet of the segment evaluation tool. Similar fields are included in the "Naïve" sheet of the intersection evaluation tool.

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Table 37. Data Fields of "Naïve" Sheet.

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
A	Data for Individual Projects	District Name	Abbreviation of TxDOT district name (three letters). =IF(Input!A3="","",Input!A3)
B		CSJ	Control section job number. =IF(Input!B3="","",Input!B3)
C		Road Name	Name of the road where the project has been implemented. =IF(Input!C3="","",Input!C3)
D		Work Code(s)	TxDOT HSIP work codes that have been implemented at the project to be evaluated. =IF(OR(Input!F3="",ISERROR(Input!F3)),"",Input!F3)
E		Work Code Description	Description of selected work codes. This field is automatically populated. =IF(OR(Input!G3="",ISERROR(Input!G3)),"",Input!G3)
F		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =IF(Input!AG3="","",Input!AG3)
G		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =IF(Input!AH3="","",Input!AH3)
H	Calculations for Individual Projects	Number Years Before (Y_{Before})	Total number (decimal) of years in the before period. =IF(OR(Input!I3="",Input!J3=""),"",YEARFRAC(Input!I3,Input!J3))
I		Number Years After (Y_{After})	Total number (decimal) of years in the after period. =IF(OR(Input!K3="",Input!L3=""),"",YEARFRAC(Input!K3,Input!L3))
J		Ratio of Durations ($r_{Duration}$)	Ratio of [duration of after period] / [duration of before period]. This ratio is used to calculate the expected number of crashes in the after period (Hauer, 1997, p. 76). =IF(OR(I3="",H3=""),"",I3/H3)
K		Observed Crashes Before ($N_{Observed,Before}$)	Number of crashes observed in the before period. =IF((Input!AI3=""),"",SUM(Input!AI3:AM3))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
L		Observed Crashes After ($N_{Observed,After}$)	Number of crashes observed in the after period. =IF(Input!AN3="","",SUM(Input!AN3:AR3))
M		Expected Crashes After ($N_{Expected,After}$)	Number of expected crashes in the after period (Hauer, 1997, p. 76, Table 7.1). =IF(OR(K3="",J3=""),"",K3*J3) $N_{Expected,After} = N_{Observed,Before} \times r_{Duration}$
N		Variance of Expected Crashes After ($V_{Expected,After}$)	Variance of the expected crashes in the after period (Hauer, 1997, p. 76, Table 7.1). =IF(OR(K3="",J3=""),"",J3^2 * K3) $V_{Expected,After} = {r_{Duration}}^2 \times N_{Observed,Before}$
O		Safety Effectiveness Index (θ)	Index of safety effectiveness (θ) calculated using the naïve B/A method (Hauer, 1997, p. 76, Eq. 6.3). =IF(OR(L3=0,M3=0),"",IF(OR(L3="",M3=""),"",(L3/M3)/(1+N3/M3^2))) $\theta = \frac{N_{Observed,After}}{N_{Expected,After}} \times \frac{1}{\left(1 + \frac{V_{Expected,After}}{{N_{Expected,After}}^2}\right)}$
P		Variance of θ (Var_θ)	Variance of the safety effectiveness index (Hauer, 1997, p. 76, Eq. 6.4). =IF(O3="","",IF(O3="Cannot Be Determined","",(O3^2)*(L3/L3^2+N3/M3^2)/(1+N3/M3^2)^2)) $Var_\theta = \theta^2 \times \left(\frac{N_{Observed,After}}{{N_{Observed,After}}^2} + \frac{V_{Expected,After}}{{N_{Expected,After}}^2}\right) \times \left(\frac{1}{\left(1 + \frac{V_{Expected,After}}{{N_{Expected,After}}^2}\right)}\right)^2$
Q		Standard Error of θ (SE_θ)	Standard error of the safety effectiveness index. =IF(O3="","",IF(O3="Cannot Be Determined","",SQRT(P3))) $SE_\theta = \sqrt{Var_\theta}$

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
R	Groups of Projects	WC(s) & All/Target Crashes & Crash Severity(-ies)	This field determines unique groups of similar projects by: - WCs. - All/target crashes. - Crash severity groups. {=IFERROR(INDEX(Input!BK$3:BK$499,MATCH(0,COUNTIF($R$3:R3,Input!BK$3:BK$499)+IF(Input!BK$3:BK$499="",1,0),0)), "")}
S		Work Code(s)	TxDOT HSIP work codes of the group of similar types of projects to be evaluated. =IF(R4="","",IFERROR(LEFT(R4,FIND(";",R4)-1)*1,LEFT(R4,FIND(";",R4)-1)))
T		Work Code Description	Description of WCs. =IF(S4="","",INDEX('Menu Lists'!I$2:I$387,MATCH(S4,'Menu Lists'!$H$2:$H$387,0)))
U		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =IF(R4="","",IFERROR(IF(FIND("All",R4)>0,"All"),IFERROR(IF(FIND("Target",R4),"Target"),"")))
V		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =IF(R4="","",IFERROR(RIGHT(R4,LEN(R4)-LEN(S4)-LEN(U4)-2),""))
W		Number of Projects	Number of projects included in each project group. =IF(S4="","",COUNTIFS(D$3:D$499,S4,F$3:F$499,U4,G$3:G$499,V4))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
X	Safety Effectiveness of Groups of Projects	Variance of Expected Crashes (After) ($V_{Expected,After,Total}$)	Variance of the expected crashes in the after period (HSM, p. 9-36, Eq. 9A.1-9). `=IFERROR(IF(OR(SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4),N$3:N$499)=0,S4="",U4="",V4=""),"",SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4),N$3:N$499)),"")` $Var_{Expected,Total} = \sum_{p=1}^{n} V_{Expected,After,p}$, where n is the total number of similar projects
Y		Crash Modification Factor	Safety effectiveness of a treatment (Hauer, 1997, p. 213, Table 11.11, Eq. 6.3; HSM, p. 9-36, Eq. 9A.1-8). A CMF greater than 1.0 indicates an expected increase in crashes, while a CMF less than 1.0 indicates an expected decrease in crashes. `=IFERROR((IF(OR(S4="",U4="",V4="",SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4),L$3:L$499)=0,SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4),M$3:M$499)=0),"",(IFERROR((SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4),L$3:L$499)/SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4),M$3:M$499))/(1+X4/(SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4),M$3:M$499))^2),"")))),"")` $\text{CMF} = \frac{\sum_{p=1}^{n} N_{Observed,After,p}}{\sum_{p=1}^{n} N_{Expected,After,p}} \times \frac{1}{\left(1+\frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)}$, where n is the total number of similar projects
Z		Safety Effectiveness (as percent change in crash frequency)	Safety effectiveness of a treatment expressed as a percent change in crashes across all projects (HSM, p. 9-37, Eq. 9A.1-10). Positive values indicate an expected decrease in crashes, while negative values indicate an expected increase in crashes. `=IF(OR(Y4="",Y4="Cannot Be Determined",Y4=0),"",100*(1-Y4))` $\text{Safety Effectiveness} = 100\% \times (1 - \text{CMF})$
AA		Variance of CMF (Var_{CMF})	Variance of the unbiased estimated safety effectiveness (HSM, p. 9-37, Eq. 9A.1-11). `{=IF(OR(Y4="",Y4="Cannot Be Determined",Y4=0),"",(Y4)^2*((1/SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4)*IF(L$3:L$499="",0,L$3:L$499)))+X4/(SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4)*IF(M$3:M$499="",0,M$3:M$499)))^2)/(1+X4/(SUMPRODUCT((D$3:D$499=S4)*(F$3:F$499=U4)*(G$3:G$499=V4)*IF(M$3:M$499="",0,M$3:M$499)))^2)^2)}` $Var_{\text{CMF}} = \text{CMF}^2 \times \left(\frac{1}{\sum_{p=1}^{n} N_{Observed,After,p}} + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right) \Bigg/ \left(1 + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)^2,$ where n is the total number of similar projects

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AB		Standard Error (SE) of CMF (SE_{CMF})	SE of the safety effectiveness of the treatment (HSM, p. 9-37, Eq. 9A.1-12). =IF(OR(Y4="",Y4="Cannot Be Determined",Y4=0),"",SQRT(AA4)) $SE_{CMF} = \sqrt{Var_{CMF}}$
AC		Standard Error*100	SE of the safety effectiveness of the treatment expressed as a percent (HSM, p. 9-37, Eq. 9A.1-13). =IF(OR(Y4="",Y4="Cannot Be Determined",Y4=0),"",100*AB4)
AD		Statistical Significance	Statistical significance of the estimated safety effectiveness of the treatment (HSM, p. 9-37, Step 14). =IF(OR(Y4="",Y4="Cannot Be Determined",Y4=0),"",IF(ABS(Z4/AC4)<1.7,"Not significant at 90% confidence level",IF(AND(ABS(Z4/AC4)>=1.7,ABS(Z4/AC4)<2),"Significant at 90% confidence level",IF(ABS(Z4/AC4)>=2,"Significant at 95% confidence level"))))

APPENDIX H:
NAÏVE WITH VOLUME CORRECTION SHEET

This appendix presents the data fields in the “Naïve with Volume Correction” sheet of the segment evaluation tool. Similar fields are included in the “Naïve with Volume Correction” sheet of the intersection evaluation tool.

Table 38. Data Fields of "Naïve with Volume Correction" Sheet.

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
A	Data for Individual Projects	District Name	Abbreviation of TxDOT district name (three letters). =IF(Input!A3="","",Input!A3)
B		CSJ	Control section job number. =IF(Input!B3="","",Input!B3)
C		Road Name	Name of the road where the project has been implemented. =IF(Input!C3="","",Input!C3)
D		Work Code(s)	TxDOT HSIP WCs that have been implemented at the project to be evaluated. =IF(OR(Input!F3="",ISERROR(Input!F3)),"",Input!F3)
E		Work Code Description	Description of selected WCs. This field is automatically populated. =IF(OR(Input!G3="",ISERROR(Input!G3)),"",Input!G3)
F		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =IF(Input!AG3="","",Input!AG3)
G		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =IF(Input!AH3="","",Input!AH3)
H	Calculations for Individual Projects	Num Days Year 1 (Before)	Number of days in Year 1 of the before period. =IF(Input!W3="","",DAYS(DATE(Input!M3+1,1,1),Input!$I3))
I		Num Days Year 2 (Before)	Number of days in Year 2 of the before period. =IF(Input!X3="","",IF(Input!O3="",DAYS(Input!$J3+1,DATE(Input!N3,1,1)),DAYS(DATE(Input!N3+1,1,1),DATE(Input!N3,1,1))))
J		Num Days Year 3 (Before)	Number of days in Year 3 of the before period. =IF(Input!Y3="","",IF(Input!P3="",DAYS(Input!$J3+1,DATE(Input!O3,1,1)),DAYS(DATE(Input!O3+1,1,1),DATE(Input!O3,1,1))))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
K		Num Days Year 4 (Before)	Number of days in Year 4 of the before period. =IF(Input!Z3="","",IF(Input!Q3="",DAYS(Input!$J3+1,DATE(Input!P3,1,1)),DAYS(DATE(Input!P3+1,1,1),DATE(Input!P3,1,1))))
L		Num Days Year 5 (Before)	Number of days in Year 5 of the before period. =IF(Input!AA3="","",DAYS(Input!$J3+1,DATE(Input!Q3,1,1)))
M		Num Days Year 1 (After)	Number of days in Year 1 of the after period. =IF(Input!AB3="","",DAYS(DATE(Input!R3+1,1,1),Input!$K3))
N		Num Days Year 2 (After)	Number of days in Year 2 of the after period. =IF(Input!AC3="","",IF(Input!T3="",DAYS(Input!$L3+1,DATE(Input!S3,1,1)),DAYS(DATE(Input!S3+1,1,1),DATE(Input!S3,1,1))))
O		Num Days Year 3 (After)	Number of days in Year 3 of the after period. =IF(Input!AD3="","",IF(Input!U3="",DAYS(Input!$L3+1,DATE(Input!T3,1,1)),DAYS(DATE(Input!T3+1,1,1),DATE(Input!T3,1,1))))
P		Num Days Year 4 (After)	Number of days in Year 4 of the after period. =IF(Input!AE3="","",IF(Input!V3="",DAYS(Input!$L3+1,DATE(Input!U3,1,1)),DAYS(DATE(Input!U3+1,1,1),DATE(Input!U3,1,1))))
Q		Num Days Year 5 (After)	Number of days in Year 5 of the after period. =IF(Input!AF3="","",DAYS(Input!$L3+1,DATE(Input!V3,1,1)))
R		Portion of Year 1 in Before Period	Ratio of [Number of days in Year 1 included in the before period] / [Total number of days in calendar Year 1]. =IF(Input!M3="","",H3/DAYS(DATE(Input!M3+1,1,1),DATE(Input!M3,1,1)))
S		Portion of Year 2 in Before Period	Ratio of [Number of days in Year 2 included in the before period] / [Total number of days in calendar Year 2]. =IF(Input!N3="","",I3/DAYS(DATE(Input!N3+1,1,1),DATE(Input!N3,1,1)))
T		Portion of Year 3 in Before Period	Ratio of [Number of days in Year 3 included in the before period] / [Total number of days in calendar Year 3]. =IF(Input!O3="","",J3/DAYS(DATE(Input!O3+1,1,1),DATE(Input!O3,1,1)))
U		Portion of Year 4 in Before Period	Ratio of [Number of days in Year 4 included in the before period] / [Total number of days in calendar Year 4]. =IF(Input!P3="","",K3/DAYS(DATE(Input!P3+1,1,1),DATE(Input!P3,1,1)))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
V		Portion of Year 5 in Before Period	Ratio of [Number of days in Year 5 included in the before period] / [Total number of days in calendar Year 5]. =IF(Input!Q3="","",L3/DAYS(DATE(Input!Q3+1,1,1),DATE(Input!Q3,1,1)))
W		Portion of Year 1 in After Period	Ratio of [Number of days in Year 1 included in the after period] / [Total number of days in calendar Year 1]. =IF(Input!R3="","",M3/DAYS(DATE(Input!R3+1,1,1),DATE(Input!R3,1,1)))
X		Portion of Year 2 in After Period	Ratio of [Number of days in Year 2 included in the after period] / [Total number of days in calendar Year 2]. =IF(Input!S3="","",N3/DAYS(DATE(Input!S3+1,1,1),DATE(Input!S3,1,1)))
Y		Portion of Year 3 in After Period	Ratio of [Number of days in Year 3 included in the after period] / [Total number of days in calendar Year 3]. =IF(Input!T3="","",O3/DAYS(DATE(Input!T3+1,1,1),DATE(Input!T3,1,1)))
Z		Portion of Year 4 in After Period	Ratio of [Number of days in Year 4 included in the after period] / [Total number of days in calendar Year 4]. =IF(Input!U3="","",P3/DAYS(DATE(Input!U3+1,1,1),DATE(Input!U3,1,1)))
AA		Portion of Year 5 in After Period	Ratio of [Number of days in Year 5 included in the after period] / [Total number of days in calendar Year 5]. =IF(Input!V3="","",Q3/DAYS(DATE(Input!V3+1,1,1),DATE(Input!V3,1,1)))
AB		Number of Years Before	Total number (decimal) of years in the before period. =IF(OR(Input!I3="",Input!J3=""),"",YEARFRAC(Input!I3,Input!J3))
AC		Number of Years After	Total number (decimal) of years in the after period. =IF(OR(Input!K3="",Input!L3=""),"",YEARFRAC(Input!K3,Input!L3))
AD		Ratio of Durations ($r_{Duration}$)	Ratio of [duration of after period] / [duration of before period]. This ratio is used to calculate the expected number of crashes in the after period (Hauer, 1997, p. 76). =IF(OR(AC3="",AB3=""),"",AC3/AB3)
AE		Average Traffic Volume Before	Average traffic volume in the before period. =IF(Input!W3="","",SUMPRODUCT(H3:L3,Input!W3:AA3)/DAYS(Input!J3+1,Input!I3))
AF		Average Traffic Volume After	Average traffic volume in the after period. =IF(Input!AB3="","",SUMPRODUCT(M3:Q3,Input!AB3:AF3)/DAYS(Input!L3+1,Input!K3))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AG		Ratio of Volumes (r_{Volume})	Ratio of [average traffic volume after] / [average traffic volume before]. This ratio is used to calculate the expected crashes in the after period (Hauer, 1997, p. 101, Eq. 8.3). =IF(AE3="","",AF3/AE3)
AH		Variance of Volume Ratio ($Var(r_{Volume})$)	Assumes that the AADT is estimated from a 24-hour count. If it is derived from longer counts or permanent stations, change the value of "1" in the formula to indicate the correct number of count days used to estimate the AADT (Hauer, 1997, p. 108, Eq. 8.9). =IF(AG3="","",AG3^2*(((1+7.7/(1)+1650/AE3^0.82)/100)^2+((1+7.7/(1)+1650/AF3^0.82)/100)^2))
AI		Observed Crashes Before ($N_{Observed,Before}$)	Total number of crashes observed in the before period. =IF((Input!AI3=""),"",SUM(Input!AI3:AM3))
AJ		Observed Crashes After ($N_{Observed,After}$)	Total number of crashes observed in the after period. =IF((Input!AI3=""),"",SUM(Input!AN3:AR3))
AK		Expected Crashes After ($N_{Expected,After}$)	Number of expected crashes in the after period (Hauer, 1997, p. 101, Table 8.2). =IF(AG3="","",AI3*AG3*AD3) $N_{Expected,After} = N_{Observed,Before} \times r_{Volume} \times r_{Duration}$
AL		Variance of Expected Crashes After ($V_{Expected,After}$)	Variance of the expected crashes in the after period (Hauer, 1997, p. 76, Table 7.1). =IF(AK3="","",AD3^2*(AG3^2*AI3+AH3*AI3^2)) $V_{Expected,After} = r_{Duration}^2 \times (r_{Volume}^2 \times N_{Observed,Before} + Var(r_{Volume}) \times N_{Observed,Before}^2)$
AM		Safety Effectiveness Index (θ)	Index of safety effectiveness (θ) calculated using the naïve B/A method with traffic volume correction (Hauer, 1997, p. 101, Table 8.3, Eq. 6.3). =IF(OR(AJ3=0,AI3=0,AJ3="",AI3="",AK3=""),"",(AJ3/AK3)/(1+AL3/AK3^2)) $\theta = \frac{N_{Observed,After}}{N_{Expected,After}} \times \frac{1}{\left(1 + \frac{V_{Expected,After}}{N_{Expected,After}^2}\right)}$

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AN		Variance of θ (Var_θ)	Variance of the safety effectiveness index (Hauer, 1997, p. 76, Eq. 6.4). =IF(OR(AM3="",AM3="Cannot Be Determined"),"",(AM3^2)*(AJ3/AJ3^2+AL3/AK3^2)/(1+AL3/AK3^2)^2) $Var_\theta = \theta^2 \times \left(\frac{N_{Observed,After}}{N_{Observed,After}^2} + \frac{V_{Expected,After}}{N_{Expected,After}^2}\right) \times \left(\frac{1}{\left(1 + \frac{V_{Expected,After}}{N_{Expected,After}^2}\right)}\right)^2$
AO		Standard Error of θ (SE_θ)	Standard error of the safety effectiveness index. =IF(OR(AM3="",AM3="Cannot Be Determined"),"",SQRT(AN3)) $SE_\theta = \sqrt{Var_\theta}$
AP	Groups of Projects	WC(s) & All/Target Crashes & Crash Severity(-ies)	This field determines unique groups of similar projects by: - WCs. - All/target crashes. - Crash severity groups. =Naïve!R4
AQ		Work Code(s)	TxDOT HSIP WCs of the group of similar types of projects to be evaluated. =Naïve!S4
AR		Work Code Description	Description of WCs. =Naïve!T4
AS		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =Naïve!U4
AT		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =Naïve!V4
AU		Number of Projects	Number of projects included in each project group. =Naïve!W4

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AV	Safety Effectiveness of Groups of Projects	Variance of Expected Crashes (After) ($V_{Expected,After,Total}$)	Variance of the expected crashes in the after period (HSM, p. 9-36, Eq. 9A.1-9). =IFERROR(IF(OR(SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4),AL$3:AL$499)=0,AQ4="",AS4="",AT4=""),"",SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4),AL$3:AL$499)),"") $Var_{Expected,Total} = \sum_{p=1}^{n} V_{Expected,After,p}$, where n is the total number of similar projects
AW		Crash Modification Factor	Safety effectiveness of a treatment (Hauer, 1997, p. 213, Table 11.11, Eq. 6.3; HSM, p. 9-36, Eq. 9A.1-8). A CMF greater than 1.0 indicates an expected increase in crashes, while a CMF less than 1.0 indicates an expected decrease in crashes. =IFERROR((IF(OR(AQ4="",AS4="",AT4="",SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4),AJ$3:AJ$499)=0,SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4),AK$3:AK$499)=0),"",(IFERROR((SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4),AJ$3:AJ$499)/SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4),AK$3:AK$499))/(1+AV4/(SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4),AK$3:AK$499))^2),"")))),"") $\mathrm{CMF} = \frac{\sum_{p=1}^{n} N_{Observed,After,p}}{\sum_{p=1}^{n} N_{Expected,After,p}} \times \frac{1}{\left(1+\frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)}$, where n is the total number of similar projects
AX		Safety Effectiveness (as Percent Change in Crash Frequency)	Safety effectiveness of a treatment expressed as a percent change in crashes across all projects (HSM, p. 9-37, Eq. 9A.1-10). Positive values indicate an expected decrease in crashes, while negative values indicate an expected increase in crashes. =IF(OR(AW4="",AW4="Cannot Be Determined",AW4=0),"",100*(1-AW4)) $\text{Safety Effectiveness} = 100\% \times (1 - \mathrm{CMF})$
AY		Variance of CMF (Var_{CMF})	Variance of the unbiased estimated safety effectiveness (HSM, p. 9-37, Eq. 9A.1-11). {=IF(OR(AW4="",AW4="Cannot Be Determined",AW4=0),"",(AW4)^2*((1/SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4)*IF(AJ$3:AJ$499="",0,AJ$3:AJ$499)))+AV4/(SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4)*IF(AK$3:AK$499="",0,AK$3:AK$499)))^2)/(1+AV4/(SUMPRODUCT((D$3:D$499=AQ4)*(F$3:F$499=AS4)*(G$3:G$499=AT4)*IF(AK$3:AK$499="",0,AK$3:AK$499)))^2)^2)} $Var_{\mathrm{CMF}} = \mathrm{CMF}^2 \times \left(\frac{1}{\sum_{p=1}^{n} N_{Observed,After,p}} + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right) \Big/ \left(1 + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)^2,$ where n is the total number of similar projects

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AZ		Standard Error of CMF (SE_{CMF})	SE of the safety effectiveness of the treatment (HSM, p. 9-37, Eq. 9A.1-12). =IF(OR(AW4="",AW4="Cannot Be Determined",AW4=0),"",SQRT(AY4)) $SE_{\mathrm{CMF}} = \sqrt{Var_{\mathrm{CMF}}}$
BA		Standard Error*100	SE of the safety effectiveness of the treatment expressed as a percent (HSM, p. 9-37, Eq. 9A.1-13). =IF(OR(AW4="",AW4="Cannot Be Determined",AW4=0),"",100*AZ4)
BB		Statistical Significance	Statistical significance of the estimated safety effectiveness of the treatment (HSM, p. 9-37, Step 14). =IF(OR(AW4="",AW4="Cannot Be Determined",AW4=0),"",IF(ABS(AX4/BA4)<1.7,"Not significant at 90% confidence level",IF(AND(ABS(AX4/BA4)>=1.7,ABS(AX4/BA4)<2),"Significant at 90% confidence level",IF(ABS(AX4/BA4)>=2,"Significant at 95% confidence level"))))

APPENDIX I: COMPARISON GROUP SHEET

This appendix presents the data fields in the “Comparison Group” sheet of the segment evaluation tool. Similar fields are included in the “Comparison Group” sheet of the intersection evaluation tool.

Table 39. Data Fields of "Comparison Group" Sheet.

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
A	Data for Individual Projects	District Name	Abbreviation of TxDOT district name (three letters). =IF(Input!A3="","",Input!A3)
B		CSJ	Control section job number. =IF(Input!B3="","",Input!B3)
C		Road Name	Name of the road where the project has been implemented. =IF(Input!C3="","",Input!C3)
D		Work Code(s)	TxDOT HSIP WCs that have been implemented at the project to be evaluated. =IF(OR(Input!F3="",ISERROR(Input!F3)),"",Input!F3)
E		Work Code Description	Description of selected WCs. This field is automatically populated. =IF(OR(Input!G3="",ISERROR(Input!G3)),"",Input!G3)
F		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =IF(Input!AG3="","",Input!AG3)
G		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =IF(Input!AH3="","",Input!AH3)
H		# Crashes at Comparison Sites (Before) ($N_{CG,Before}$)	Total number of crashes observed in the before period at the comparison sites. Leave blank if no comparison sites are used in the analysis. =IF(Input!AU3="","", Input!AU3)
I		# Crashes at Comparison Sites (After) ($N_{CG,After}$)	Total number of crashes observed in the after period at the comparison sites. Leave blank if no comparison sites are used in the analysis. =IF(Input!AV3="","", Input!AV3)
J	Calculations for Individual Projects	Observed Crashes Before ($N_{Observed,Before}$)	Total number of crashes observed in the before period. =IF((Input!AI3=""),"",SUM(Input!AI3:AM3))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
K		Observed Crashes After ($N_{Observed,After}$)	Total number of crashes observed in the after period. =IF((Input!AI3=""),"",SUM(Input!AN3:AR3))
L		Ratio of Comparison Group Crashes (r_{CG})	Ratio of [# of comparison group crashes after] / [# of comparison group crashes before] (Hauer,1997, p. 121, Table 9.3). =IF(OR(H3=0,I3=0,H3="",I3=""),"",I3/H3) $r_{CG} = \frac{\sum_{c=1}^{C} N_{CG,After}}{\sum_{c=1}^{C} N_{CG,Before}}$, where C is the number of comparison sites
M		Variance of Comparison Group Crash Ratio ($Var(r_{CG})$)	Variance of ratio of comparison group crashes (Hauer, 1997, p. 121, Table 9.3). =IF(OR(L3="",L3="Cannot Be Determined"),"",L3^2*(1/H3+1/I3)) $Var(r_{CG}) = r_{CG}^2 \times (\frac{1}{\sum_{c=1}^{C} N_{CG,Before}} + \frac{1}{\sum_{c=1}^{C} N_{CG,After}})$
N		Expected Crashes After ($N_{Expected,After}$)	Number of expected crashes in the after period (Hauer, 1997, p. 101, Table 8.2). =IF(OR(L3="Cannot Be Determined",L3=""),"",J3*L3) $N_{Expected,After} = N_{Observed,Before} \times r_{CG}$
O		Variance of Expected Crashes After ($V_{Expected,After}$)	Variance of the expected crashes in the after period (Hauer, 1997, p. 76, Table 7.1). =IF(OR(N3=0,L3="Cannot Be Determined",N3=""),"",N3^2*(1/J3+M3/L3^2)) $V_{Expected,After} = N_{Expected,After}^2 \times (\frac{1}{N_{Observed,Before}} + \frac{Var(r_{CG})}{r_{CG}^2})$
P		Safety Effectiveness Index (θ)	Index of safety effectiveness (θ) calculated using the B/A method with a comparison group (Hauer, 1997, p. 121, Table 9.4). =IFERROR(IF(OR(J3="",K3="",N3="",H3="",I3="",J3=0,K3=0,L3="Cannot Be Determined"),"",(K3/N3)/(1+O3/N3^2)),"") $\theta = \frac{N_{Observed,After}}{N_{Expected,After}} \times \frac{1}{\left(1 + \frac{V_{Expected,After}}{N_{Expected,After}^2}\right)}$

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
Q		Variance of θ (Var_θ)	Variance of the safety effectiveness index (Hauer, 1997, p. 121, Table 9.4). =IF(OR(L3="Cannot Be Determined",P3="Cannot Be Determined",P3=""),"",(P3^2)*((K3/K3^2)+O3/N3^2)/(1+O3/N3^2)^2) $Var_\theta = \theta^2 \times \left(\frac{N_{Observed,After}}{N_{Observed,After}^2} + \frac{V_{Expected,After}}{N_{Expected,After}^2}\right) \times \left(\frac{1}{\left(1 + \frac{V_{Expected,After}}{N_{Expected,After}^2}\right)}\right)^2$
R		Standard Error of θ (SE_θ)	SE of the safety effectiveness index. =IF(OR(L3="Cannot Be Determined",P3="Cannot Be Determined",P3=""),"",SQRT(Q3)) $SE_\theta = \sqrt{Var_\theta}$
S	Groups of Projects	WC(s) & All/Target Crashes & Crash Severity(-ies)	This field determines unique groups of similar projects by: - WCs. - All/target crashes. - Crash severity groups. =Naïve!R4
T		Work Code(s)	TxDOT HSIP WCs of the group of similar types of projects to be evaluated. =Naïve!S4
U		Work Code Description	Description of WCs. =Naïve!T4
V		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =Naïve!U4
W		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =Naïve!V4
X		Number of Projects	Number of projects included in each project group. =Naïve!W4

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
Y	Safety Effectiveness of Groups of Projects	Variance of Expected Crashes (After) ($V_{Expected,After,Total}$)	Variance of the expected crashes in the after period (HSM, p. 9-36, Eq. 9A.1-9). =IFERROR(IF(OR(SUMPRODUCT(($D$3:$D$499=T4)*($F$3:$F$499=V4)*($G$3:$G$499=W4),O$3:O$499)=0,T4="",V4="",W4=""),"",SUMPRODUCT(($D$3:$D$499=T4)*($F$3:$F$499=V4)*($G$3:$G$499=W4),O$3:O$499)),"") $Var_{Expected,Total} = \sum_{p=1}^{n} V_{Expected,After,p}$, where *n* is the total number of similar projects
Z		Crash Modification Factor	Safety effectiveness of a treatment (Hauer, 1997, p. 213, Table 11.11, Eq. 6.3; HSM, p. 9-36, Eq. 9A.1-8). A CMF greater than 1.0 indicates an expected increase in crashes, while a CMF less than 1.0 indicates an expected decrease in crashes. =IFERROR((IF(OR(T4="",V4="",W4="",SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4),K$3:K$499)=0,SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4),N$3:N$499)=0),"",(IFERROR((SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4),K$3:K$499)/SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4),N$3:N$499))/(1+Y4/(SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4),N$3:N$499))^2),"")))),"") $\text{CMF} = \frac{\sum_{p=1}^{n} N_{Observed,After,p}}{\sum_{p=1}^{n} N_{Expected,After,p}} \times \frac{1}{\left(1+\frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)}$, where *n* is the total number of similar projects
AA		Safety Effectiveness (as Percent Change in Crash Frequency)	Safety effectiveness of a treatment expressed as a percent change in crashes across all projects (HSM, p. 9-37, Eq. 9A.1-10). Positive values indicate an expected decrease in crashes, while negative values indicate an expected increase in crashes. =IF(OR(Z4="",Z4="Cannot Be Determined",Z4=0),"",100*(1-Z4)) $\text{Safety Effectiveness} = 100\% \times (1 - \text{CMF})$
AB		Variance of CMF (Var_{CMF})	Variance of the unbiased estimated safety effectiveness (HSM, p. 9-37, Eq. 9A.1-11). {=IF(OR(Z4="",Z4="Cannot Be Determined",Z4=0),"",(Z4)^2*((1/SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4)*IF(K$3:K$499="",0,K$3:K$499)))+Y4/(SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4)*IF(N$3:N$499="",0,N$3:N$499)))^2)/(1+Y4/(SUMPRODUCT((D$3:D$499=T4)*(F$3:F$499=V4)*(G$3:G$499=W4)*IF(N$3:N$499="",0,N$3:N$499)))^2)^2)} $Var_{\text{CMF}} = \text{CMF}^2 \times \left(\frac{1}{\sum_{p=1}^{n} N_{Observed,After,p}} + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right) \Big/ \left(1 + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)^2,$ where *n* is the total number of similar projects

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AC		Standard Error of CMF (SE_{CMF})	SE of the safety effectiveness of the treatment (HSM, p. 9-37, Eq. 9A.1-12). =IF(OR(Z4="",Z4="Cannot Be Determined",Z4=0),"",SQRT(AB4)) $SE_{\text{CMF}} = \sqrt{Var_{\text{CMF}}}$
AD		Standard Error*100	SE of the safety effectiveness of the treatment expressed as a percent (HSM, p. 9-37, Eq. 9A.1-13). =IF(OR(Z4="",Z4="Cannot Be Determined",Z4=0),"",100*AC4)
AE		Statistical Significance	Statistical significance of the estimated safety effectiveness of the treatment (HSM, p. 9-37, Step 14). =IF(OR(Z4="",Z4="Cannot Be Determined",Z4=0),"",IF(ABS(AA4/AD4)<1.7,"Not significant at 90% confidence level",IF(AND(ABS(AA4/AD4)>=1.7,ABS(AA4/AD4)<2),"Significant at 90% confidence level",IF(ABS(AA4/AD4)>=2,"Significant at 95% confidence level"))))

APPENDIX J:
EMPIRICAL BAYES SHEET

This appendix presents the data fields in the “Empirical Bayes” sheet of the segment evaluation tool. Similar fields are included in the “Empirical Bayes” sheet of the intersection evaluation tool.

Table 40. Data Fields of "Empirical Bayes" Sheet.

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
A	Data for Individual Projects	District Name	Abbreviation of TxDOT district name (three letters). =IF(Input!A3="","",Input!A3)
B		CSJ	Control section job number. =IF(Input!B3="","",Input!B3)
C		Road Name	Name of the road where the project has been implemented. =IF(Input!C3="","",Input!C3)
D		Work Code(s)	TxDOT HSIP WCs that have been implemented at the project to be evaluated. =IF(OR(Input!F3="",ISERROR(Input!F3)),"",Input!F3)
E		Work Code Description	Description of selected WCs. This field is automatically populated. =IF(OR(Input!G3="",ISERROR(Input!G3)),"",Input!G3)
F		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =IF(Input!AG3="","",Input!AG3)
G		Crash Severity (-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =IF(Input!AH3="","",Input!AH3)
H		Length (miles)	Length of project (miles). It can be calculated as [End DFO] − [Start DFO]. =IF(Input!H3="","",Input!H3)
I		Functional Class and Rural/Urban Code	Combination of HPMS roadway functional class and rural/urban designation. TxDOT Roadway Safety Design Workbook does not provide SPFs for the lower functional classes: minor collectors (FC6) and local roads (FC7). =IF(Input!AW3="","",Input!AW3)
J		Number of Lanes	Number of lanes on the facility to be evaluated. =IF(Input!AX3="","",Input!AX3)
K		Median Type	Type of median, if any. =IF(Input!AY3="","",Input!AY3)

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
L		Median Width (ft)	Width of the median if no barrier exists. The default value of the CMF for median width is 1.0. =IF(Input!BD3="","",Input!BD3)
M		Lane Width (ft)	Lane width (feet). The default value of the CMF for lane width is 1.0. =IF(Input!BE3="","",Input!BE3)
N		Inside Shoulder Width (ft)	Width of the inside shoulder (feet). The default value of the CMF for inside shoulder width is 1.0. =IF(Input!BF3="","",Input!BF3)
O		Outside Shoulder Width (ft)	Width of the outside shoulder (feet). The default value of the CMF for outside shoulder width is 1.0. =IF(Input!BG3="","",Input!BG3)
P	SPFs for Individual Projects	SPF Code (MV Crashes)	Unique ID of safety performance function for MV crashes. This ID is automatically selected from the list of SPFs provided in worksheet “SPF_CMFs” (Column A contains the unique number of each SPF). {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!$A$2:$A$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0)),""))}
Q		Constant (β_0) (MV Crashes)	Constant (β_0) of SPF (for multi-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!I$2:I$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0)),""))}
R		AADT Coefficient (MV Crashes)	AADT coefficient of SPF (for multi-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!J$2:J$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0)),""))}
S		Length Coefficient (MV Crashes)	Segment length coefficient of SPF (for multi-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!K$2:K$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0)),""))}

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
T		Overdispersion Parameter (MV Crashes)	Overdispersion parameter of the SPF (for multi-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!L$2:L$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0)),""))}
U		SPF Code (SV Crashes)	Unique ID of SPF for SV crashes. This ID is automatically selected from the list of SPFs provided in worksheet “SPF_CMFs” (Column A contains the unique number of each SPF). {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!$A$2:$A$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Single Vehicle"),0)),""))}
V		Constant (β_0) (SV Crashes)	Constant (β_0) of SPF (for single-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!I$2:I$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Single Vehicle"),0)),""))}
W		AADT Coefficient (SV Crashes)	AADT coefficient of SPF (for single-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!J$2:J$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Single Vehicle"),0)),""))}
X		Length Coefficient (SV Crashes)	Segment length coefficient of SPF (for single-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!K$2:K$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Single Vehicle"),0)),""))}
Y		Overdispersion Parameter (SV Crashes)	Overdispersion parameter of the SPF (for single-vehicle crashes) extracted from the “SPF_CMFs” worksheet based on roadway characteristics. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IFERROR(INDEX(SPFs_CMFs!L$2:L$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Single Vehicle"),0)),""))}

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
Z		Proportion of Business Land Use	Estimated proportion of business land use by median type and number of through lanes (TxDOT Project 0-4703). The characteristics of different land use types are available in the TxDOT Roadway Safety Design Workbook (Table 4-3, p. 4-8). =IF(P3="","",IF(INDEX(SPFs_CMFs!O$2:O$164,MATCH('Empirical Bayes'!$P3,SPFs_CMFs!$A$2:$A$164,0))=0,"",INDEX(SPFs_CMFs!O$2:O$164,MATCH('Empirical Bayes'!$P3,SPFs_CMFs!$A$2:$A$164,0))))
AA		Proportion of Industrial Land Use	Estimated proportion of industrial land use by median type and number of through lanes (TxDOT Project 0-4703). The characteristics of different land use types are available in the TxDOT Roadway Safety Design Workbook (Table 4-3, p. 4-8). =IF(P3="","",IF(INDEX(SPFs_CMFs!N$2:N$164,MATCH('Empirical Bayes'!$P3,SPFs_CMFs!$A$2:$A$164,0))=0,"",INDEX(SPFs_CMFs!N$2:N$164,MATCH('Empirical Bayes'!$P3,SPFs_CMFs!$A$2:$A$164,0))))
AB		Proportion of Office Land Use	Estimated proportion of office land use by median type and number of through lanes (TxDOT Project 0-4703). The characteristics of different land use types are available in the TxDOT Roadway Safety Design Workbook (Table 4-3, p. 4-8). =IF(P3="","",IF(INDEX(SPFs_CMFs!P$2:P$164,MATCH('Empirical Bayes'!$P3,SPFs_CMFs!$A$2:$A$164,0))=0,"",INDEX(SPFs_CMFs!P$2:P$164,MATCH('Empirical Bayes'!$P3,SPFs_CMFs!$A$2:$A$164,0))))
AC		Land Use Adjustment Factor	Land use adjustment factor (TxDOT Roadway Safety Design Workbook, p. 4-6, Eq. 4-6). =IF(P3="","",IF(Z3="",1,EXP((0.21*(AA3*2*H3)+0.448*(Z3*2*H3)+0.113*(AB3*2*H3))/H3)))
AD	CMFs for Individual Projects	CMF for Median Width (Formula)	CMF that is used to adjust the predicted number of crashes based on the width of the median (Wm), if any. {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IF(L3="","",IFERROR(IF(INDEX(SPFs_CMFs!Q$2:Q$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))=0,"",INDEX(SPFs_CMFs!Q$2:Q$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))),"")))}

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AE		CMF for Lane Width (Formula)	CMF that is used to adjust the predicted number of crashes based on lane width (Wl). {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IF(M3="","",IFERROR(IF(INDEX(SPFs_CMFs!R$2:R$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))=0,"",INDEX(SPFs_CMFs!R$2:R$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))),"")))}
AF		CMF for Inside Shoulder Width (Formula)	CMF that is used to adjust the predicted number of crashes based on the width of the inside shoulder (Wis). {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IF(N3="","",IFERROR(IF(INDEX(SPFs_CMFs!S$2:S$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))=0,"",INDEX(SPFs_CMFs!S$2:S$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))),"")))}
AG		CMF for Outside Shoulder Width (Formula)	CMF that is used to adjust the predicted number of crashes based on the width of the outside shoulder (Wos). {=IF(OR($G3<>"KABC",$I3="",$J3="",$K3=""),"",IF(O3="","",IFERROR(IF(INDEX(SPFs_CMFs!T$2:T$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))=0,"",INDEX(SPFs_CMFs!T$2:T$164,MATCH(1,($I3=SPFs_CMFs!$E$2:$E$164)*($J3=SPFs_CMFs!$C$2:$C$164)*($K3=SPFs_CMFs!$D$2:$D$164)*(SPFs_CMFs!$G$2:$G$164="Multiple Vehicles"),0))),"")))}
AH		CMF for Median Width (Formula with Values)	CMF that is used to adjust the predicted number of crashes based on the width of the median (Wm), if any. =IF(AD3="","",IF(AND(ISNUMBER(SEARCH("Wm",AD3)),$L3=""),"",IF(AND(ISNUMBER(SEARCH("Wl",AD3)),$M3=""),"",IF(AND(ISNUMBER(SEARCH("Wis",AD3)),$N3=""),"",SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(AD3,"Wm",$L3),"Wl",$M3),"Wis",$N3),"Wos",$O3)))))
AI		CMF for Lane Width (Formula with Values)	CMF that is used to adjust the predicted number of crashes based on lane width (Wl). =IF(AE3="","",IF(AND(ISNUMBER(SEARCH("Wm",AE3)),$L3=""),"",IF(AND(ISNUMBER(SEARCH("Wl",AE3)),$M3=""),"",IF(AND(ISNUMBER(SEARCH("Wis",AE3)),$N3=""),"",SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(AE3,"Wm",$L3),"Wl",$M3),"Wis",$N3),"Wos",$O3)))))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AJ		CMF for Inside Shoulder Width (Formula with Values)	CMF that is used to adjust the predicted number of crashes based on the width of the inside shoulder (Wis). =IF(AF3="","",IF(AND(ISNUMBER(SEARCH("Wm",AF3)),$L3=""),"",IF(AND(ISNUMBER(SEARCH("Wl",AF3)),$M3=""),"",IF(AND(ISNUMBER(SEARCH("Wis",AF3)),$N3=""),"",SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(AF3,"Wm",$L3),"Wl",$M3),"Wis",$N3),"Wos",$O3)))))
AK		CMF for Outside Shoulder Width (Formula with Values)	CMF that is used to adjust the predicted number of crashes based on the width of the outside shoulder (Wos). =IF(AG3="","",IF(AND(ISNUMBER(SEARCH("Wm",AG3)),$L3=""),"",IF(AND(ISNUMBER(SEARCH("Wl",AG3)),$M3=""),"",IF(AND(ISNUMBER(SEARCH("Wis",AG3)),$N3=""),"",SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(SUBSTITUTE(AG3,"Wm",$L3),"Wl",$M3),"Wis",$N3),"Wos",$O3)))))
AL		CMF for Median Width (Value)	Value of CMF for the given median width of the project to be evaluated. =IF(P3="","",IF(ISERROR(CMF_Median_Width),1,CMF_Median_Width))
AM		CMF for Lane Width (Value)	Value of CMF for lane width. =IF(P3="","",IF(ISERROR(CMF_Lane_Width),1,CMF_Lane_Width))
AN		CMF for Inside Shoulder Width (Value)	Value of CMF for the given inside shoulder width of the project to be evaluated. =IF(P3="","",IF(ISERROR(CMF_Inside_Shoulder_Width),1,CMF_Inside_Shoulder_Width))
AO		CMF for Outside Shoulder Width (Value)	Value of CMF for the given outside shoulder width of the project to be evaluated. =IF(P3="","",IF(ISERROR(CMF_Outside_Shoulder_Width),1,CMF_Outside_Shoulder_Width))
AP		Product of Other CMFs	Product of other applicable CMFs to adjust the predicted number of crashes to existing conditions. =IF($P3="","",IF(Input!BH3="",1,Input!BH3))
AQ		Local Calibration Factor	Factor used to calibrate the SPF to local conditions. The default value is 1.0. =IF($P3="","",IF(Input!BI3="",1,Input!BI3))
AR		Proportion of SPF Target Crashes	Proportion of the crashes predicted by the SPF that are made up of the target crash type. The default value is 1.0. =IF($P3="","",IF(Input!BJ3="",1,Input!BJ3))

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
AS	Observed Crashes at Individual Projects	Total Observed Crashes Before	Total number of observed crashes in the before period. =IF(AND(Input!AI3="",Input!AJ3="",Input!AK3="",Input!AL3="",Input!AM3=""),"",SUM(Input!AI3:AM3))
AT		Total Observed Crashes After	Total number of observed crashes in the after period. =IF(AND(Input!AN3="",Input!AO3="",Input!AP3="",Input!AQ3="",Input!AR3=""),"",SUM(Input!AN3:AR3))
AU		Observed MV Crashes Before ($N_{Observed,MV,Before}$)	Observed MV crashes in the before period. If the user does not provide this number, an estimate is developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class (see worksheet "Menu Lists"). =IF(AS3="","",IF(Input!$AZ3="",($AS3*INDEX('Menu Lists'!$AR$2:$AR$15,MATCH($I3,'Menu Lists'!$AL$2:$AL$15,0)))/((1+INDEX('Menu Lists'!$AR$2:$AR$15,MATCH($I3,'Menu Lists'!$AL$2:$AL$15,0)))),Input!$AZ3))
AV		Observed SV Crashes Before ($N_{Observed,SV,Before}$)	Observed SV crashes in the before period. If the user does not provide this number, an estimate is developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class (see worksheet "Menu Lists"). =IF(AS3="","",IF(Input!$BA3="",AS3-AU3,Input!$BA3))
AW		Observed MV Crashes After ($N_{Observed,MV,After}$)	Observed MV crashes in the after period. If the user does not provide this number, an estimate is developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class (see worksheet "Menu Lists"). =IF(AT3="","",IF(Input!$BB3="",($AT3*INDEX('Menu Lists'!$AR$2:$AR$15,MATCH($I3,'Menu Lists'!$AL$2:$AL$15,0)))/((1+INDEX('Menu Lists'!$AR$2:$AR$15,MATCH($I3,'Menu Lists'!$AL$2:$AL$15,0)))),Input!$BB3))
AX		Observed SV Crashes After ($N_{Observed,SV,After}$)	Observed SV crashes in the after period. If the user does not provide this number, an estimate is developed based on historical proportions of [MV Crashes] / [SV Crashes] by functional class (see worksheet "Menu Lists"). =IF(AT3="","",IF(Input!$BC3="",AT3-AW3,Input!$BC3))
AY	Predicted MV Crashes at Individual Projects	Predicted MV Crashes Before (Year 1)	Number of predicted MV crashes using an SPF for Year 1 of the before period. =IF(OR($P3="",Input!W3=""),"",$Q3*((0.001*Input!W3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!R3)
AZ		Predicted MV Crashes Before (Year 2)	Number of predicted MV crashes using an SPF for Year 2 of the before period. =IF(OR($P3="",Input!X3=""),"",$Q3*((0.001*Input!X3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!S3)
BA		Predicted MV Crashes Before (Year 3)	Number of predicted MV crashes using an SPF for Year 3 of the before period. =IF(OR($P3="",Input!Y3=""),"",$Q3*((0.001*Input!Y3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!T3)

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
BB		Predicted MV Crashes Before (Year 4)	Number of predicted MV crashes using an SPF for Year 4 of the before period. =IF(OR($P3="",Input!Z3=""),"",$Q3*((0.001*Input!Z3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!U3)
BC		Predicted MV Crashes Before (Year 5)	Number of predicted MV crashes using an SPF for Year 5 of the before period. =IF(OR($P3="",Input!AA3=""),"",$Q3*((0.001*Input!AA3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!V3)
BD		Predicted MV Crashes After (Year 1)	Number of predicted MV crashes using an SPF for Year 1 of the after period. =IF(OR($P3="",Input!AB3=""),"",$Q3*((0.001*Input!AB3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!W3)
BE		Predicted MV Crashes After (Year 2)	Number of predicted MV crashes using an SPF for Year 2 of the after period. =IF(OR($P3="",Input!AC3=""),"",$Q3*((0.001*Input!AC3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!X3)
BF		Predicted MV Crashes After (Year 3)	Number of predicted MV crashes using an SPF for Year 3 of the after period. =IF(OR($P3="",Input!AD3=""),"",$Q3*((0.001*Input!AD3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!Y3)
BG		Predicted MV Crashes After (Year 4)	Number of predicted MV crashes using an SPF for Year 4 of the after period. =IF(OR($P3="",Input!AE3=""),"",$Q3*((0.001*Input!AE3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!Z3)
BH		Predicted MV Crashes After (Year 5)	Number of predicted MV crashes using an SPF for Year 5 of the after period. =IF(OR($P3="",Input!AF3=""),"",$Q3*((0.001*Input!AF3)^$R3)*($H3^$S3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!AA3)
BI		Sum Predicted MV Crashes Before ($N_{Predicted,Before,MV}$)	Total number of predicted MV crashes in the before period. =IF(OR(P3="",AND(AY3="",AZ3="",BA3="",BB3="",BC3="")),"",SUM(AY3:BC3))
BJ		Sum Predicted MV Crashes After ($N_{Predicted,After,MV}$)	Total number of predicted MV crashes in the after period. =IF(OR(P3="",AND(BD3="",BE3="",BF3="",BG3="",BH3="")),"",SUM(BD3:BH3))
BK		Ratio After/Before Predicted MV Crashes ($r_{Predicted,MV}$)	Ratio of Σ[predicted MV crashes in the after period] / Σ[predicted MV crashes in the before period]. =IF(OR(AY3="",BJ3=""),"",SUM(BD3:BH3)/SUM(AY3:BC3)) $r_{Predicted,MV} = \frac{N_{Predicted,After,MV}}{N_{Predicted,Before,MV}}$

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
BL		Weight for MV Crashes (w_{MV})	Weight (w) is calculated as follows: 1/(1+[total predicted MV crashes]*(1/(k*Length))) It is used in another formula to estimate the expected number of crashes (HSM, 2010, p. 9-35, Eq. 9A.1-2). =IF(BI3="","",1/(1+BI3*(1/T3*H3))) $w_{MV} = 1/(1 + N_{Predicted,Before,MV} * \left(\frac{1}{k_{MV} * Length}\right)))$
BM	Predicted SV Crashes at Individual Projects	Predicted SV Crashes Before (Year 1)	Number of predicted SV crashes using an SPF for Year 1 of the before period. =IF(OR($U3="",Input!W3=""),"",$V3*((0.001*Input!W3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!R3)
BN		Predicted SV Crashes Before (Year 2)	Number of predicted SV crashes using an SPF for Year 2 of the before period. =IF(OR($U3="",Input!X3=""),"",$V3*((0.001*Input!X3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!S3)
BO		Predicted SV Crashes Before (Year 3)	Number of predicted SV crashes using an SPF for Year 3 of the before period. =IF(OR($U3="",Input!Y3=""),"",$V3*((0.001*Input!Y3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!T3)
BP		Predicted SV Crashes Before (Year 4)	Number of predicted SV crashes using an SPF for Year 4 of the before period. =IF(OR($U3="",Input!Z3=""),"",$V3*((0.001*Input!Z3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!U3)
BQ		Predicted SV Crashes Before (Year 5)	Number of predicted SV crashes using an SPF for Year 5 of the before period. =IF(OR($U3="",Input!AA3=""),"",$V3*((0.001*Input!AA3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!V3)
BR		Predicted SV Crashes After (Year 1)	Number of predicted SV crashes using an SPF for Year 1 of the after period. =IF(OR($U3="",Input!AB3=""),"",$V3*((0.001*Input!AB3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!W3)
BS		Predicted SV Crashes After (Year 2)	Number of predicted SV crashes using an SPF for Year 2 of the after period. =IF(OR($U3="",Input!AC3=""),"",$V3*((0.001*Input!AC3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!X3)
BT		Predicted SV Crashes After (Year 3)	Number of predicted SV crashes using an SPF for Year 3 of the after period. =IF(OR($U3="",Input!AD3=""),"",$V3*((0.001*Input!AD3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!Y3)
BU		Predicted SV Crashes After (Year 4)	Number of predicted SV crashes using an SPF for Year 4 of the after period. =IF(OR($U3="",Input!AE3=""),"",$V3*((0.001*Input!AE3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!Z3)

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
BV		Predicted SV Crashes After (Year 5)	Number of predicted SV crashes using an SPF for Year 5 of the after period. =IF(OR($U3="",Input!AF3=""),"",$V3*((0.001*Input!AF3)^$W3)*($H3^$X3)*$AC3*$AL3*$AM3*$AN3*$AO3*$AP3*$AQ3*$AR3*'Naïve with Volume Correction'!AA3)
BW		Sum Predicted SV Crashes Before ($N_{Predicted,Before,SV}$)	Total number of predicted SV crashes in the before period. =IF(OR(P3="",AND(BM3="",BN3="",BO3="",BP3="",BQ3="")),"",SUM(BM3:BQ3))
BX		Sum Predicted SV Crashes After ($N_{Predicted,After,SV}$)	Total number of predicted SV crashes in the after period. =IF(OR(Q3="",AND(BR3="",BS3="",BT3="",BU3="",BV3="")),"",SUM(BR3:BV3))
BY		Ratio After/Before Predicted SV Crashes ($r_{Predicted,SV}$)	Ratio of Σ[(predicted SV crashes by year in the after period)*(number of days within this year in the after period)]/Σ[(predicted SV crashes by year in the before period)*(number of days within this year of the before period)]. =IF(OR(BM3="",BX3=""),"",SUM(BR3:BV3)/SUM(BM3:BQ3)) $r_{Predicted,SV} = \frac{N_{Predicted,After,SV}}{N_{Predicted,Before,SV}}$
BZ		Weight for SV Crashes (w_{SV})	Weight (w) is calculated as follows: 1/(1+[total predicted SV crashes]*(1/(k*Length))) It is used in another formula to estimate the expected number of crashes (HSM, 2010, p. 9-35, Eq. 9A.1-2). =IF(BW3="","",1/(1+BW3*(1/Y3*H3))) $w_{SV} = 1/(1 + N_{Predicted,Before,SV} * \left(\frac{1}{k_{SV} * Length}\right)))$
CA	Expected Crashes at Individual Projects	Expected MV Crashes Before	Expected number of MV crashes in the before period (HSM, p. 9-35, Eq. 9A.1-1). =IF(OR(AU3="",BI3="",BL3=""),"",BL3*BI3+(1-BL3)*AU3) $N_{Expected,Before,MV} = w_{MV} \times N_{Predicted,Before,MV} + (1 - w_{MV}) \times N_{Observed,Before,MV}$
CB		Expected MV Crashes After	Expected number of MV crashes in the after period (HSM, p. 9-35, Eq. 9A.1-1). =IF(OR(CA3="",BK3=""),"",CA3*BK3) $N_{Expected,After,MV} = N_{Expected,Before,MV} \times r_{Predicted,MV}$
CC		Expected SV Crashes Before	Expected number of SV crashes in the before period (HSM, p. 9-35, Eq. 9A.1-1). =IF(OR(AV3="",BW3="",BZ3=""),"",BZ3*BW3+(1-BZ3)*AV3) $N_{Expected,Before,SV} = w_{SV} \times N_{Predicted,Before,SV} + (1 - w_{SV}) \times N_{Observed,Before,SV}$

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
CD		Expected SV Crashes After	Expected number of SV crashes in the after period (HSM, p. 9-35, Eq. 9A.1-1). =IF(CC3="","",CC3*BY3) $N_{Expected,After,SV} = N_{Expected,Before,SV} \times r_{Predicted,SV}$
CE		Expected MV+SV Crashes Before	Expected number of MV and SV crashes in the before period. =IF(AND(CA3="",CC3=""),"",CA3+CC3) $N_{Expected,Before} = N_{Expected,Before,MV} + N_{Expected,Before,SV}$
CF		Expected MV+SV Crashes After	Expected number of MV and SV crashes in the after period. =IF(AND(CB3="",CD3=""),"",CB3+CD3) $N_{Expected,After} = N_{Expected,After,MV} + N_{Expected,After,SV}$
CG		Variance of Expected MV Crashes (After)	Variance of the expected MV crashes in the after period (Hauer, 1997, pp. 212-213, Table 11.10 & Eq. 11.29). =IF(CA3="","",BK3^2*CA3*(1-BL3)) $V_{Expected,After,MV} = {r_{Predicted,MV}}^2 \times N_{Expected,After,MV} \times (1 - w_{MV})$
CH		Variance of Expected SV Crashes (After)	Variance of the expected SV crashes in the after period (Hauer, 1997, pp. 212-213, Table 11.10 & Eq. 11.29). =IF(CC3="","",BY3^2*CC3*(1-BZ3)) $V_{Expected,After,SV} = {r_{Predicted,SV}}^2 \times N_{Expected,After,SV} \times (1 - w_{SV})$
CI		Variance of Expected MV+SV Crashes (After) ($V_{Expected,After}$)	Variance of the expected MV and SV crashes in the after period (Hauer, 1997, pp. 212-213, Table 11.10 & Eq. 11.29). =IF(CC3="","",CG3+CH3) $V_{Expected,After} = V_{Expected,After,MV} + V_{Expected,After,SV}$
CJ	Safety Effectiveness of Single Projects	Safety Effectiveness Index (θ)	Index of safety effectiveness calculated using the empirical Bayes B/A methodology (Hauer, 1997, p. 213, Table 11.11, Eq. 6.3). =IF(D3="","",IF(AND(P3="",U3=""),"",IF(AND(G3="KABC",I3<>"",J3<>"",K3<>"",P3="",U3=""),"",IF(OR(CF3=0,AT3=0),"",IF(AT3="","",(AT3/CF3)/(1+(CI3)/CF3^2)))))) $\theta = \frac{N_{Observed,After}}{N_{Expected,After}} \times \frac{1}{\left(1 + \frac{V_{Expected,After}}{{N_{Expected,After}}^2}\right)}$

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
CK		Variance of θ (Var_θ)	Variance of theta (Hauer, 1997, p. 213, Table 11.11, Eq. 6.4). =IF(CJ3="","",(CJ3^2)*(AT3/AT3^2+CI3/CF3^2)/(1+CI3/CF3^2)^2) $Var_\theta = \theta^2 \times \left(\frac{N_{Observed,After}}{N_{Observed,After}{}^2} + \frac{V_{Expected,After}}{N_{Expected,After}{}^2}\right) \times \left(\frac{1}{\left(1 + \frac{V_{Expected,After}}{N_{Expected,After}{}^2}\right)}\right)^2$
CL		Standard Error of θ (SE_θ)	Standard error of theta (HSM, p. 9-37, Eq. 9A.1-12). =IF(CJ3="","",IF(CK3="","",SQRT(CK3))) $SE_\theta = \sqrt{Var_\theta}$
CM	Groups of Projects	WC(s) & All/Target Crashes & Crash Severity(-ies)	This field determines unique groups of similar projects by: - WCs. - All/target crashes. - Crash severity groups. =Naïve!R4
CN		Work Code(s)	TxDOT HSIP WCs of the group of similar types of projects to be evaluated. =Naïve!S4
CO		Work Code Description	Description of WCs. =Naïve!T4
CP		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =Naïve!U4
CQ		Crash Severity (-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =Naïve!V4
CR		Number of Projects	Number of projects included in each project group. =Naïve!W4

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
CS	Safety Effectiveness of Groups of Projects	Variance of Expected Crashes (After) ($V_{Expected,After,Total}$)	Variance of the expected crashes in the after period (HSM, p. 9-36, Eq. 9A.1-9). =IFERROR(IF(OR(SUMPRODUCT(($D$3:$D$499=CN4)*($F$3:$F$499=CP4)*($G$3:$G$499=CQ4),CI$3:CI$499)=0,CN4="",CP4="",CQ4=""),"",SUMPRODUCT(($D$3:$D$499=CN4)*($F$3:$F$499=CP4)*($G$3:$G$499=CQ4),CI$3:CI$499)),"") $Var_{Expected,Total} = \sum_{p=1}^{P} V_{Expected,After,p}$, where p is the total number of similar projects
CT		Crash Modification Factor	Safety effectiveness of a treatment (Hauer, 1997, p. 213, Table 11.11, Eq. 6.3; HSM, p. 9-36, Eq. 9A.1-8). A CMF greater than 1.0 indicates an expected increase in crashes, while a CMF less than 1.0 indicates an expected decrease in crashes. =IFERROR((IF(OR(CN4="",CP4="",CQ4="",SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4),AT$3:AT$499)=0,SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4),CF$3:CF$499)=0),"",(IFERROR((SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4),AT$3:AT$499)/SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4),CF$3:CF$499))/(1+CS4/(SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4),CF$3:CF$499))^2),"")))),"") $\text{CMF} = \frac{\sum_{p=1}^{n} N_{Observed,After,p}}{\sum_{p=1}^{n} N_{Expected,After,p}} \times \frac{1}{\left(1+\frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)}$, where n is the total number of similar projects
CU		Safety Effectiveness (as Percent Change in Crash Frequency)	Safety effectiveness of a treatment expressed as a percent change in crashes across all projects (HSM, p. 9-37, Eq. 9A.1-10). Positive values indicate an expected decrease in crashes, while negative values indicate an expected increase in crashes. =IF(OR(CT4="",CT4="Cannot Be Determined",CT4=0),"",100*(1-CT4)) $\text{Safety Effectiveness} = 100\% \times (1 - \text{CMF})$
CV		Variance of CMF (Var_{CMF})	Variance of the unbiased estimated safety effectiveness (HSM, p. 9-37, Eq. 9A.1-11). {=IF(OR(CT4="",CT4="",CT4="Cannot Be Determined",CT4=0),"",(CT4)^2*((1/SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4)*IF(AT$3:AT$499="",0,AT$3:AT$499)))+CS4/(SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4)*IF(CF$3:CF$499="",0,CF$3:CF$499)))^2)/(1+CS4/(SUMPRODUCT((D$3:D$499=CN4)*(F$3:F$499=CP4)*(G$3:G$499=CQ4)*IF(CF$3:CF$499="",0,CF$3:CF$499)))^2)^2)} $Var_{\text{CMF}} = \text{CMF}^2 \times \left(\frac{1}{\sum_{p=1}^{n} N_{Observed,After,p}} + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right) \Big/ \left(1 + \frac{Var_{Expected,After,Total}}{\left(\sum_{p=1}^{n} N_{Expected,After,p}\right)^2}\right)^2$, where n is the total number of similar projects

Column	Data Type	Data Field	Data Field Description, Excel Formula, and Equation (if applicable)
CW		Standard Error of CMF (SE_{CMF})	SE of the safety effectiveness of the treatment (HSM, p. 9-37, Eq. 9A.1-12). =IF(OR(CT4="",CT4="Cannot Be Determined",CT4=0),"",SQRT(CV4)) $SE_{CMF} = \sqrt{Var_{CMF}}$
CX		Standard Error*100	SE of the safety effectiveness of the treatment expressed as a percent (HSM, p. 9-37, Eq. 9A.1-13). =IF(OR(CT4="",CT4="Cannot Be Determined",CT4=0),"",100*CW4)
CY		Statistical Significance	Statistical significance of the estimated safety effectiveness of the treatment (HSM, p. 9-37, Step 14). =IF(OR(CT4="",CT4="Cannot Be Determined",CT4=0),"",IF(ABS(CU4/CX4)<1.7,"Not significant at 90% confidence level",IF(AND(ABS(CU4/CX4)>=1.7,ABS(CU4/CX4)<2),"Significant at 90% confidence level",IF(ABS(CU4/CX4)>=2,"Significant at 95% confidence level"))))

APPENDIX K:
ECONOMIC ANALYSIS SHEET

This appendix presents the data fields in the “Economic Analysis” sheet of the segment evaluation tool. Similar fields are included in the “Economic Analysis” sheet of the intersection evaluation tool.

Table 41. Data Fields of "Economic Analysis" Sheet.

Column	Data Type	Data Field	Data Field Description and Excel Formula
A	Data for Individual Projects	District Name	Abbreviation of TxDOT district name (three letters). =IF(Input!A3="","",Input!A3)
B		CSJ	Control section job number. =IF(Input!B3="","",Input!B3)
C		Road Name	Name of the road where the project has been implemented. =IF(Input!C3="","",Input!C3)
D		Work Code(s)	TxDOT HSIP WCs that have been implemented at the project to be evaluated. =IF(OR(Input!F3="",ISERROR(Input!F3)),"",Input!F3)
E		Work Code Description	Description of selected WCs. This field is automatically populated. =IF(OR(Input!G3="",ISERROR(Input!G3)),"",Input!G3)
F		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =IF(Input!AG3="","",Input!AG3)
G		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =IF(Input!AH3="","",IF(Input!AH3="K (Fatal)","K",IF(Input!AH3="A (Suspected serious injury)","A",IF(Input!AH3="B (Nonincapacitating injury)","B",IF(Input!AH3="C (Possible injury)","C",IF(Input!AH3="O (Property damage only)","O",IF(Input!AH3="U (Unknown)","U",IF(Input!AH3="KA","KA",IF(Input!AH3="KAB","KAB",IF(Input!AH3="KABC","KABC",IF(Input!AH3="KABCO","KABCO",IF(Input!AH3="KABCOU","KABCOU",""))))))))))))
H		Actual Construction Cost	Total construction cost of a project. =IF(Input!AS3="","",Input!AS3)

Column	Data Type	Data Field	Data Field Description and Excel Formula
I		Annual Maintenance Cost	Annual maintenance cost of a project, if any. =IF(AND(Input!AT3="",H4<>""),0,IF(AND(Input!AT3="",H4=""),"",Input!AT3))
J		Project Service Life	Service life of a work code. =IF(Input!F3="","",INDEX('Menu Lists'!K$2:K$386,MATCH(Input!F3,'Menu Lists'!$H$2:$H$386,0)))
K		Number Years Before	Total number (decimal) of years in the before period. =IF(OR(Input!I3="",Input!J3=""),"",YEARFRAC(Input!I3,Input!J3))
L		Number Years After	Total number (decimal) of years in the after period. =IF(OR(Input!K3="",Input!L3=""),"",YEARFRAC(Input!K3,Input!L3))
M	Calculations for Individual Projects	Average Crash Cost	Average cost of a crash in the before period. The comprehensive crash unit cost comes from Page 2 of the following FHWA Guide: https://safety.fhwa.dot.gov/hsip/docs/fhwasa17071.pdf Crash severity proportions were estimated based on historical crash data in Texas. =IF(G4="K",'Menu Lists'!B$14*SUM(Input!AI3:AM3),IF(G4="A",'Menu Lists'!B$15*SUM(Input!AI3:AM3),IF(G4="B",'Menu Lists'!B$16*SUM(Input!AI3:AM3),IF(G4="C",'Menu Lists'!B$17*SUM(Input!AI3:AM3),IF(OR(G4="O",G4="U"),'Menu Lists'!B$18*SUM(Input!AI3:AM3),IF(G4="KA",('Menu Lists'!B$14*SUM(Input!AI3:AM3)*('Menu Lists'!$W$2)+'Menu Lists'!B$15*SUM(Input!AI3:AM3)*'Menu Lists'!$X$2),IF(G4="KAB",('Menu Lists'!B$14*SUM(Input!AI3:AM3)*('Menu Lists'!$Y$2)+'Menu Lists'!B$15*SUM(Input!AI3:AM3)*'Menu Lists'!$Z$2+'Menu Lists'!$AA$2*'Menu Lists'!B$16*SUM(Input!AI3:AM3)),(IF(G4="KABC",('Menu Lists'!B$14*SUM(Input!AI3:AM3)*('Menu Lists'!$AB$2)+'Menu Lists'!B$15*SUM(Input!AI3:AM3)*'Menu Lists'!$AC$2+'Menu Lists'!$AD$2*'Menu Lists'!B$16*SUM(Input!AI3:AM3)+'Menu Lists'!$AE$2*'Menu Lists'!B$17*SUM(Input!AI3:AM3)),(IF(OR(G4="KABCO",G4="KABCOU"),('Menu Lists'!B$14*SUM(Input!AI3:AM3)*('Menu Lists'!$AF$2)+'Menu Lists'!B$15*SUM(Input!AI3:AM3)*'Menu Lists'!$AG$2+'Menu Lists'!$AH$2*'Menu Lists'!B$16*SUM(Input!AI3:AM3)+'Menu Lists'!$AI$2*'Menu Lists'!B$17*SUM(Input!AI3:AM3)+'Menu Lists'!$AJ$2*'Menu Lists'!B$18*SUM(Input!AI3:AM3)),""))))))))))

Column	Data Type	Data Field	Data Field Description and Excel Formula
N		P/A	Uniform series present worth factor used to calculate the present worth from annual crash reduction benefits. NOTE: It assumes a discount rate of 1% (0.01), which users can replace with any other desired discount rate, if known. =IF(OR(J4=""),"",(1/0.01)*(1-1/(1+0.01)^J4))
O		Construction Cost + (Maintenance Cost*P/A)	Calculated as [Construction Cost]+[Maintenance Cost]*[P/A] =IF(H4="","",($H4+$I4*$N4))
P		Annual Benefits—Naïve	Annual benefits in dollars due to crash reduction estimated using the naïve method. It is the difference between the expected number of crashes and the observed crashes in the after period, divided by the number of years included in the after period and multiplied by the average crash cost. =IF(L4="","",((Naïve!M3-Naïve!L3)/L4)*M4)
Q		Annual Benefits—Naïve with Correction	Annual benefits in dollars due to crash reduction estimated using the naïve method with traffic volume correction. It is the difference between the expected crashes and the observed crashes in the after period, divided by the number of years (after period) and multiplied by the average crash cost. =IF(L4="","",(('Naïve with Volume Correction'!AK3-'Naïve with Volume Correction'!AJ3)/L4)*M4)
R		Annual Benefits—Comparison Group	Annual benefits in dollars due to crash reduction estimated using the comparison group method. It is the difference between the expected number of crashes and the observed crashes in the after period, divided by the number of years included in the after period and multiplied by the average crash cost. =IF(OR('Comparison Group'!N3="",L4=""),"",(('Comparison Group'!N3-'Comparison Group'!K3)/L4)*M4)
S		Annual Benefits—Empirical Bayes	Annual benefits in dollars due to crash reduction estimated using the EB method. It is the difference between the expected number of crashes and the observed crashes in the after period, divided by the number of years included in the after period and multiplied by the average crash cost. =IF(OR(L4="",'Empirical Bayes'!CF3="",'Empirical Bayes'!AT3=""),"",(('Empirical Bayes'!CF3-'Empirical Bayes'!AT3)/L4)*M4)

Column	Data Type	Data Field	Data Field Description and Excel Formula
T		B/C—Naïve	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the naïve method to the total construction and maintenance cost of a project. =IF(OR(D4="",P4="",P4=0),"",(P4*$N4)/($H4+$I4*$N4))
U		B/C—Naïve with Correction	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the naïve method with traffic volume correction to the total construction and maintenance cost of a project. =IF(OR(D4="",Q4="",Q4=0),"",(Q4*$N4)/($H4+$I4*$N4))
V		B/C—Comparison Group	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the comparison group method to the total construction and maintenance cost of a project. =IF(OR(D4="",R4="",R4=0),"",(R4*$N4)/($H4+$I4*$N4))
W		B/C—Empirical Bayes	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the EB method to the total construction and maintenance cost of a project. =IF(OR(D4="",S4="",S4=0),"",(S4*$N4)/($H4+$I4*$N4))
X	Groups of Projects	WC(s) & All/Target Crashes & Crash Severity(-ies)	This field determines unique groups of similar projects by: - WCs. - All/target crashes. - Crash severity groups. =Naïve!R4
Y		Work Code(s)	TxDOT HSIP WCs of the group of similar types of projects to be evaluated. =Naïve!S4
Z		Work Code Description	Description of WCs. =Naïve!T4
AA		All or Target Crashes	Type of crashes to be evaluated. Users can include all crashes or only the target crashes that each work code can theoretically prevent. The preventable crash criteria of each work code are provided in the TxDOT HSIP Work Codes Table. =Naïve!U4
AB		Crash Severity(-ies)	Severity levels of crashes to be evaluated. The user can evaluate the effect of a project or treatment on one, multiple, or all crash severities. Note that SPFs are available in Texas only for KABC crashes. =Naïve!V4

Column	Data Type	Data Field	Data Field Description and Excel Formula
AC		Number of Projects	Number of projects included in each project group. =Naïve!W4
AD	Calculations for Groups of Projects	B/C—Naïve	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the naïve method to the total construction and maintenance cost of a group of projects. =IF(OR($X5="",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$P$4:$P$500,$N$4:$N$500)=0,SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500)=0),"",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$P$4:$P$500,$N$4:$N$500)/SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500))
AE		B/C—Naïve with Correction	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the naïve method with traffic volume correction to the total construction and maintenance cost of a group of projects. =IF(OR($X5="",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$Q$4:$Q$500,$N$4:$N$500)=0,SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500)=0),"",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$Q$4:$Q$500,$N$4:$N$500)/SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500))
AF		B/C—Comparison Group	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the comparison group method to the total construction and maintenance cost of a group of projects. =IF(OR($X5="",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$R$4:$R$500,$N$4:$N$500)=0,SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500)=0),"",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$R$4:$R$500,$N$4:$N$500)/SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500))
AG		B/C—Empirical Bayes	B/C ratio compares the annual crash reduction benefits (in dollars) calculated using the EB method to the total construction and maintenance cost of a group of projects. =IF(OR($X5="",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$S$4:$S$500,$N$4:$N$500)=0,SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500)=0),"",SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$S$4:$S$500,$N$4:$N$500)/SUMPRODUCT(($D$4:$D$500=Y5)*($F$4:$F$500=AA5)*($G$4:$G$500=AB5),$O$4:$O$500))

APPENDIX L:
SAMPLE EVALUATION RESULTS

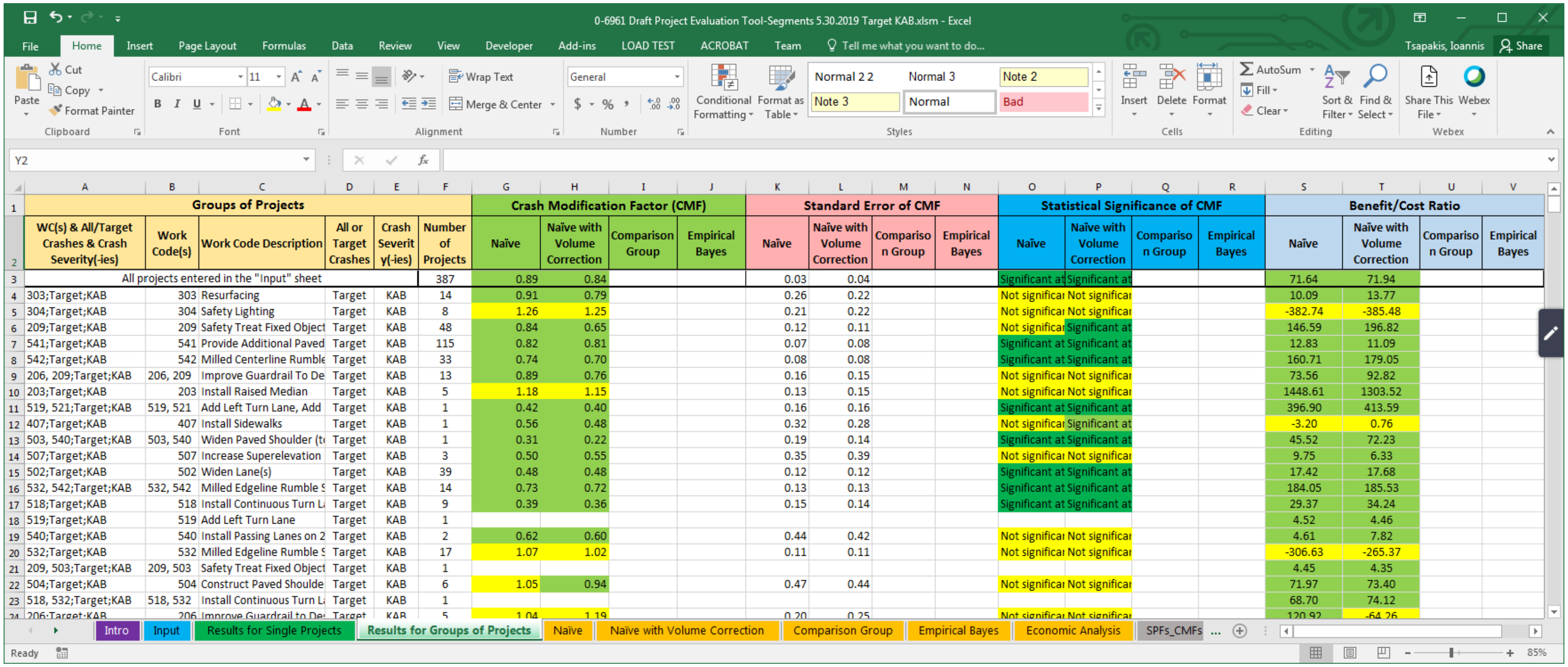
This appendix presents a sample of evaluation results for individual projects and groups of projects.

	General Project Information						Target Crashes		Observed		Duration		Avg. Traffic		ety Effectiveness Index			Standard Error of ϑ			Benefit/Cost Ratio			
District Name	CSJ	Road Name	Work Code(s)	Work Code Description	Length (miles)	Actual Construction Cost	All or Target Crashes	Crash Severity (-ies)	Before	After	Before	After	Before	After	Naïve	Naïve with Volume Correction	Empirical Bayes	Naïve	Naïve with Volume Correction	Empirical Bayes	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes
AUS	1377-01-019	FM1327	303	Resurfacing	7.19051	$ 183,984	All	KABCO	23	65	2.09	4.19	8,699	11,379	1.35	1.02		0.31	0.27		-1533.95	-390.02		
ATL	0217-01-032	US0059	303	Resurfacing	3.90298	$ 2,459,009	All	KABCO	13	44	1.43	4.76	12,560	11,364	0.94	1.03		0.28	0.32		-2.03	-14.43		
ELP	0002-14-037	FM0258	304	Safety Lighting	1.46968	$ 1,705,111	All	KABCO	41	134	1.68	4.39	15,945	18,811	1.22	1.02		0.21	0.22		-582.20	-163.87		
PAR	0047-18-067	US0075	209	Safety Treat Fixed C	12.3998	$ 893,533	All	KABCO	96	326	1.53	4.68	49,510	51,285	1.10	1.04		0.13	0.17		-3709.73	-2460.37		
ATL	1388-02-021	FM1251	209	Safety Treat Fixed C	4.40684	$ 1,452,002	All	KABCO	1	2	1.77	4.34	730	373	0.41	0.77		0.25	0.47		0.37	-0.61		
CRP	1208-03-019	FM1944	541	Provide Additional F	4.9949	$ 1,662,400	All	KABCO	6	9	1.68	4.28	645	654	0.50	0.47		0.23	0.22		27.33	28.25		
TYL	0203-08-014	FM1253	541	Provide Additional F	1.14446	$ 1,259,321	All	KABCO	1	5	1.66	4.07	1,280	1,110	1.02	1.16		0.56	0.63		-2.57	-2.90		
TYL	0679-01-010	FM0757	541	Provide Additional F	2.13637	$ 2,482,886	All	KABCO	11	6	1.66	4.28	844	941	0.19	0.17		0.09	0.08		119.48	137.02		
HOU	0543-03-069	FM0762	542	Milled Centerline R	18.6774	$ 296,805	All	KABCO	32	72	1.63	4.03	14,807	17,225	0.88	0.74		0.18	0.18		529.80	1467.49		
ABL	0157-04-047	US0277	303	Resurfacing	2.99204	$ 519,648	All	KABCO	5	32	1.65	4.92	3,600	3,569	1.79	1.77		0.72	0.73		-90.40	-91.09		
AUS	0115-04-046	FM0020	206, 209	Improve Guardrail T	12.248	$ 1,237,071	All	KABCO	21	72	1.57	4.21	4,200	4,709	1.22	1.07		0.29	0.29		-325.14	-182.95		
AUS	0807-01-026	FM0535	206, 209	Improve Guardrail T	20.1865	$ 1,098,213	All	KABCO	21	62	2.03	4.34	1,276	1,580	1.32	1.03		0.32	0.30		-387.25	-144.45		
BRY	0114-10-093	BU0290F	303	Resurfacing	1.4337	$ 634,743	All	KABCO	33	124	1.65	4.86	8,639	8,055	1.24	1.30		0.23	0.30		-767.96	-958.57		
BRY	2399-01-059	FM2818	203	Install Raised Medi	1.92066	$ 650,717	All	KABCO	78	287	1.61	4.78	28,754	29,858	1.22	1.16		0.15	0.20		-7119.55	-5967.85		
DAL	0048-03-083	US0077	519, 521	Add Left Turn Lane,	0.41706	$ 1,102,724	All	KABCO	71	186	1.79	4.31	25,326	25,907	1.07	1.03		0.15	0.19		-617.34	-458.79		
SAT	2104-02-029	FM1957	303	Resurfacing	4.5511	$ 991,787	All	KABCO	70	255	1.68	4.56	26,811	29,920	1.32	1.17		0.18	0.21		-2734.73	-1812.50		
WAC	0320-05-014	SL0363	303	Resurfacing	6.56827	$ 447,301	All	KABCO	20	52	1.73	4.93	7,531	9,138	0.87	0.70		0.22	0.20		119.99	417.83		
HOU	0720-02-081	FM0149	303	Resurfacing	4.0942	$ 657,333	All	KABCO	21	58	1.42	4.14	8,659	10,906	0.90	0.70		0.22	0.19		69.13	400.92		
DAL	0697-04-016	FM0090	541	Provide Additional F	3.27684	$ 946,512	All	KABCO	4	22	1.79	4.32	1,783	1,857	1.82	1.71		0.79	0.76		-62.24	-60.22		
PAR	0765-03-022	FM0273	541	Provide Additional F	17.2987	$ 3,621,006	All	KABCO	12	30	1.66	4.60	2,020	2,261	0.83	0.73		0.26	0.25		11.86	26.55		
AUS	1533-01-019	FM1704	206, 209	Improve Guardrail T	10.109	$ 7,245,145	All	KABCO	27	41	1.69	4.44	3,418	3,622	0.56	0.52		0.13	0.14		128.77	147.08		
CRP	0738-03-028	FM3284	541	Provide Additional F	5.60389	$ 1,721,515	All	KABCO	6	9	1.70	4.33	1,274	1,472	0.51	0.43		0.23	0.20		25.94	35.81		
BRY	2673-02-010	FM2679	541	Provide Additional F	5.22816	$ 1,539,260	All	KABCO	2	4	2.04	4.22	1,050	984	0.64	0.67		0.37	0.39		0.22	-0.19		
CRP	0180-06-090	BS0035L	407	Install Sidewalks	1.34673	$ 233,264	All	KABCO	19	73	1.77	4.78	12,428	14,141	1.35	1.17		0.33	0.32		-1000.47	-674.81		
DAL	1017-01-014	FM0552	541	Provide Additional F	5.34913	$ 4,229,142	All	KABCO	12	36	2.01	4.80	5,501	5,966	1.16	1.05		0.36	0.35		-22.49	-15.11		
SAT	0291-06-043	SH0016	503, 540	Widen Paved Shoul	2.29148	$ 1,372,653	All	KABCO	9	30	1.93	4.71	7,800	10,506	1.23	0.90		0.42	0.32		-57.20	-2.38		
ATL	0946-03-022	FM0593	209	Safety Treat Fixed C	6.17548	$ 1,190,779	All	KABCO	2	14	1.97	4.36	771	675	2.11	2.33		1.06	1.18		-19.03	-20.13		
PAR	1494-01-023	FM1565	541	Provide Additional F	3.90395	$ 1,265,153	All	KABCO	13	5	1.79	4.67	1,200	1,892	0.14	0.08		0.07	0.04		326.95	548.18		
HOU	0367-02-078	SH0087	542	Milled Centerline R	6.40025	$ 54,201	All	KABCO	2	5	1.80	4.91	3,066	3,507	0.61	0.53		0.34	0.29		9.11	25.03		

Figure 62. Sample Results for Individual Segment Projects.

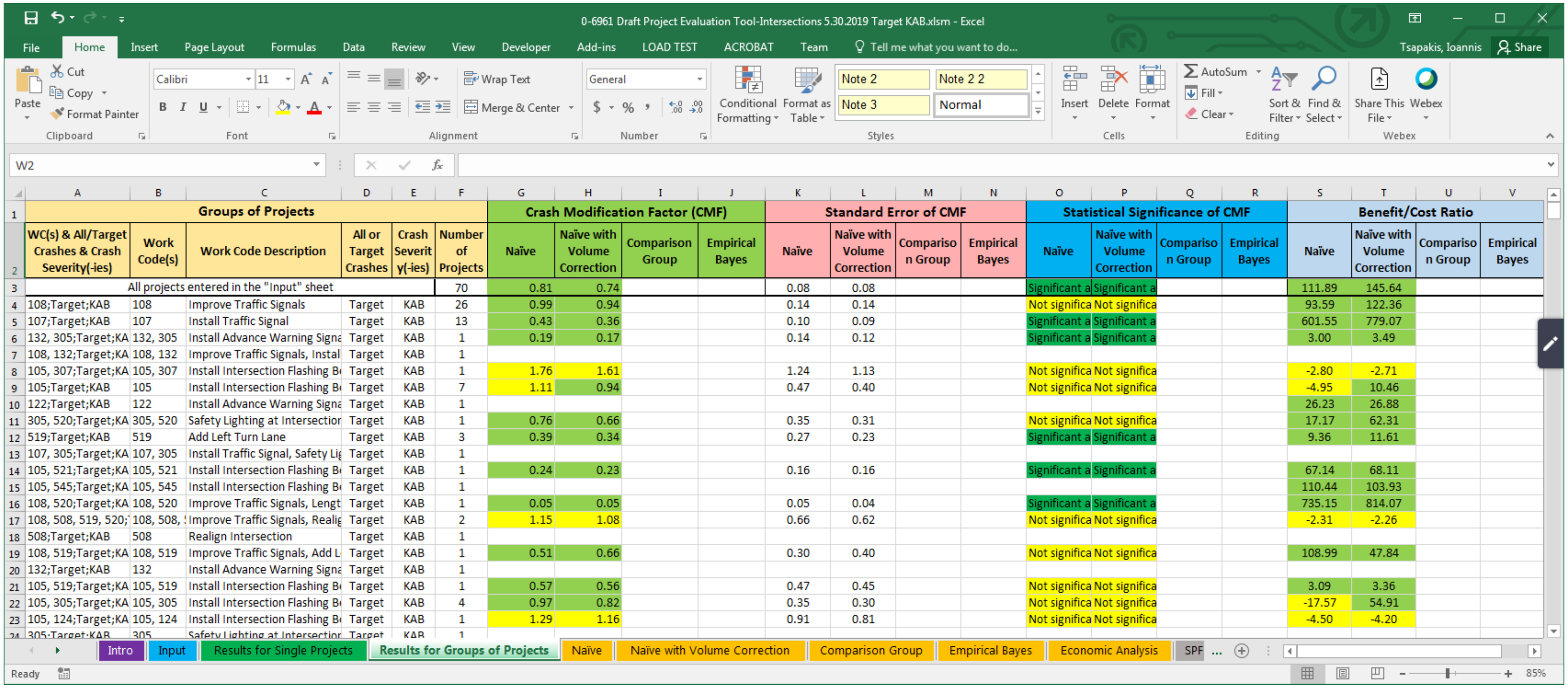
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	S	T	U	W	X	Y	AA
1	General Project Information							Target Crashes		Observed		Duration		Avg. Traffic		Safety Effectiveness Index (ϑ			Standard Error of ϑ			Benefit/Cost Ratio		
2	District Name	CSJ	Major Road Name	Minor Road Name	Work Code(s)	Work Code Description	Actual Construction Cost	All or Target Crashes	Crash Severity (-ies)	Before	After	Before	After	Before	After	Naïve	Naïve with Volume Correction	Empirical Bayes	Naïve	Naïve with Volume Correction	Empirical Bayes	Naïve	Naïve with Volume Correction	Empirical Bayes
3	ELP	0167-02-048	SL0478	Mobile Aver	108	Improve Traffic Signal	$ 643,749	All	KABCO	7	22	1.91	4.58	7,830	7,311	1.14	1.20		0.43	0.47		-33.14	-40.30	
4	LFK	0176-06-012	BU0059J	SH0146	107	Install Traffic Signal	$ 243,877	All	KABCO	5	14	1.86	4.42	5,846	6,416	0.98	0.88		0.43	0.39		-26.36	-11.78	
5	ABL	0688-01-016	FM0700	Wasson Roa	107	Install Traffic Signal	$ 81,347	All	KABCO	5	14	1.71	4.72	16,142	16,275	0.85	0.83		0.37	0.37		-8.17	-4.16	
6	AUS	0337-01-034	SH0029	Park Place	107	Install Traffic Signal	$ 466,648	All	KABCO	0	4	1.94	4.02	15,264	17,953									
7	BWD	0231-01-050	US0190	FM2313	107	Install Traffic Signal	$ 120,816	All	KABCO	3	2	1.75	4.61	12,271	13,059	0.19	0.18		0.13	0.12		85.82	93.20	
8	FTW	0171-05-087	SH0199	Ohio Garde	107	Install Traffic Signal	$ 110,216	All	KABCO	12	51	1.79	4.65	31,423	35,326	1.51	1.33		0.45	0.42		-1259.65	-1014.58	
9	SJT	0069-07-102	US0087	SH0208	108	Improve Traffic Signal	$ 208,209	All	KABCO	40	76	2.37	4.11	28,481	32,151	1.07	0.93		0.20	0.21		-847.10	283.35	
10	WAC	0231-10-015	BU0190F	FM3219	107	Install Traffic Signal	$ 171,155	All	KABCO	22	42	1.70	4.75	14,694	16,723	0.65	0.56		0.16	0.16		1425.37	2046.80	
11	AUS	0683-02-053	RM0620	N Quinlan P	132, 305	Install Advance Warni	$1,519,736	All	KABCO	8	31	1.60	4.18	46,712	51,364	1.32	1.18		0.47	0.43		-34.52	-27.44	
12	TYL	0138-03-139	US0259	SH0322	108	Improve Traffic Signal	$ 148,116	All	KABCO	6	11	1.75	4.69	18,845	18,910	0.59	0.58		0.26	0.26		118.04	119.33	
13	ATL	0062-06-051	US0059	SH0049	108, 132	Improve Traffic Signal	$1,997,854	All	KABCO	18	58	2.05	4.52	19,266	20,070	1.38	1.31		0.35	0.37		-98.69	-89.74	
14	PHR	0039-12-052	BU0077X	Lovett Rd	107	Install Traffic Signal	$ 930,097	All	KABCO	3	10	1.97	2.79	25,271	23,549	1.76	1.87		0.87	0.93		-17.98	-18.88	
15	BRY	3138-01-023	FM2347	FM2818	108	Improve Traffic Signal	$ 151,999	All	KABCO	23	45	2.04	4.42	49,574	58,032	0.87	0.73		0.21	0.20		447.00	1234.87	
16	CRP	1069-01-031	SH0357	Patti Drive	107	Install Traffic Signal	$ 147,765	All	KABCO	11	22	2.13	4.01	26,323	33,406	0.97	0.75		0.33	0.27		-62.09	218.38	
17	CRP	1557-01-039	FM0043	Yorktown Bl	107	Install Traffic Signal	$ 132,988	All	KABCO	18	23	2.13	4.87	24,440	25,553	0.53	0.50		0.16	0.16		1372.10	1513.33	
18	HOU	0389-07-035	SH0146	FM1765	108	Improve Traffic Signal	$ 160,772	All	KABCO	24	103	1.75	4.45	31,028	30,637	1.62	1.62		0.35	0.40		-3823.54	-3893.25	
19	HOU	0598-01-093	SH0288	Almeda Ger	108	Improve Traffic Signal	$ 321,071	All	KABCO	57	136	2.02	4.27	######	######	1.11	1.07		0.17	0.21		-1761.36	-1481.73	
20	HOU	1685-05-101	SH0006	Piping Rock	108	Improve Traffic Signal	$ 287,144	All	KABCO	14	81	1.04	4.65	61,268	70,708	1.21	1.04		0.33	0.30		-529.58	-257.17	
21	DAL	0081-06-037	US0377	FM0428	108	Improve Traffic Signal	$ 941,710	All	KABCO	5	3	4.77	1.64	16,095	19,902	1.46	1.16		0.89	0.71		-11.27	-7.71	
22	SAT	0215-07-025	SH0046	Blanco Road	105, 307	Install Intersection Fla	$2,151,052	All	KABCO	1	1	4.95	1.41	6,823	7,373	1.76	1.61		1.24	1.13		-0.64	-0.62	
23	AUS	0015-11-061	SL0275	Rundberg La	108	Improve Traffic Signal	$ 509,398	All	KABCO	114	25	4.91	1.06	57,664	56,636	1.01	1.01		0.22	0.25		-293.42	-543.84	
24	ATL	0096-08-053	US0080	SL0390	108	Improve Traffic Signal	$ 398,880	All	KABCO	54	23	4.39	1.74	16,268	16,163	1.06	1.05		0.26	0.28		-348.65	-377.62	
25	FTW	0747-04-069	FM0157	SS0303	108	Improve Traffic Signal	$ 251,941	All	KABCO	120	59	4.70	1.94	67,758	73,859	1.18	1.07		0.19	0.21		-6291.58	-3327.86	
26	AUS	0700-01-040	SH0071	Shovel Mou	105	Install Intersection Fla	$ 115,302	All	KABCO	3	2	4.91	1.29	9,637	12,712	1.89	1.42		1.30	0.97		-65.71	-51.97	
27	YKM	0432-02-088	SH0185	FM1432	107	Install Traffic Signal	$ 189,017	All	KABCO	8	2	4.14	1.27	16,102	13,575	0.73	0.85		0.51	0.59		40.67	5.92	
28	LFK	0176-05-179	US0059	FM0350	122	Install Advance Warni	$ 91,455	All	KABCO	9	2	4.94	1.53	18,946	19,416	0.65	0.62		0.45	0.44		136.71	148.74	
29	ABL	0011-06-045	US0180	US0283	105	Install Intersection Fla	$ 482,565	All	KABCO	1	0	4.02	0.41	5,776	5,100							1.39	1.23	
30	PAR	0173-07-051	SH0034	FM1564	105	Install Intersection Fla	$ 21,894	All	KABCO	1	13	1.16	4.40	8,900	10,141	1.71	1.49		0.89	0.77		-258.63	-243.75	

Figure 63. Sample Results for Individual Intersection Projects.



	Groups of Projects						Crash Modification Factor (CMF)				Standard Error of CMF				Statistical Significance of CMF				Benefit/Cost Ratio			
2	WC(s) & All/Target Crashes & Crash Severity(-ies)	Work Code(s)	Work Code Description	All or Target Crashes	Crash Severit y(-ies)	Number of Projects	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Compariso n Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Compariso n Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Compariso n Group	Empirical Bayes
3	All projects entered in the "Input" sheet					387	0.89	0.84			0.03	0.04			Significant at	Significant at			71.64	71.94		
4	303;Target;KAB	303	Resurfacing	Target	KAB	14	0.91	0.79			0.26	0.22			Not significar	Not significar			10.09	13.77		
5	304;Target;KAB	304	Safety Lighting	Target	KAB	8	1.26	1.25			0.21	0.22			Not significar	Not significar			-382.74	-385.48		
6	209;Target;KAB	209	Safety Treat Fixed Object	Target	KAB	48	0.84	0.65			0.12	0.11			Not significar	Significant at			146.59	196.82		
7	541;Target;KAB	541	Provide Additional Paved	Target	KAB	115	0.82	0.81			0.07	0.08			Significant at	Significant at			12.83	11.09		
8	542;Target;KAB	542	Milled Centerline Rumble	Target	KAB	33	0.74	0.70			0.08	0.08			Significant at	Significant at			160.71	179.05		
9	206, 209;Target;KAB	206, 209	Improve Guardrail To De	Target	KAB	13	0.89	0.76			0.16	0.15			Not significar	Not significar			73.56	92.82		
10	203;Target;KAB	203	Install Raised Median	Target	KAB	5	1.18	1.15			0.13	0.15			Not significar	Not significar			1448.61	1303.52		
11	519, 521;Target;KAB	519, 521	Add Left Turn Lane, Add	Target	KAB	1	0.42	0.40			0.16	0.16			Significant at	Significant at			396.90	413.59		
12	407;Target;KAB	407	Install Sidewalks	Target	KAB	1	0.56	0.48			0.32	0.28			Not significar	Significant at			-3.20	0.76		
13	503, 540;Target;KAB	503, 540	Widen Paved Shoulder (t	Target	KAB	1	0.31	0.22			0.19	0.14			Significant at	Significant at			45.52	72.23		
14	507;Target;KAB	507	Increase Superelevation	Target	KAB	3	0.50	0.55			0.35	0.39			Not significar	Not significar			9.75	6.33		
15	502;Target;KAB	502	Widen Lane(s)	Target	KAB	39	0.48	0.48			0.12	0.12			Significant at	Significant at			17.42	17.68		
16	532, 542;Target;KAB	532, 542	Milled Edgeline Rumble S	Target	KAB	14	0.73	0.72			0.13	0.13			Significant at	Significant at			184.05	185.53		
17	518;Target;KAB	518	Install Continuous Turn La	Target	KAB	9	0.39	0.36			0.15	0.14			Significant at	Significant at			29.37	34.24		
18	519;Target;KAB	519	Add Left Turn Lane	Target	KAB	1													4.52	4.46		
19	540;Target;KAB	540	Install Passing Lanes on 2	Target	KAB	2	0.62	0.60			0.44	0.42			Not significar	Not significar			4.61	7.82		
20	532;Target;KAB	532	Milled Edgeline Rumble S	Target	KAB	17	1.07	1.02			0.11	0.11			Not significar	Not significar			-306.63	-265.37		
21	209, 503;Target;KAB	209, 503	Safety Treat Fixed Object	Target	KAB	1													4.45	4.35		
22	504;Target;KAB	504	Construct Paved Shoulde	Target	KAB	6	1.05	0.94			0.47	0.44			Not significar	Not significar			71.97	73.40		
23	518, 532;Target;KAB	518, 532	Install Continuous Turn La	Target	KAB	1													68.70	74.12		
24	206;Target;KAB	206	Improve Guardrail to De	Target	KAB	5	1.04	1.19			0.20	0.25			Not significar	Not significar			120.92	-64.26		

Figure 64. Sample Results for Groups of Segment Projects.



Groups of Projects						Crash Modification Factor (CMF)				Standard Error of CMF				Statistical Significance of CMF				Benefit/Cost Ratio			
WC(s) & All/Target Crashes & Crash Severity(-ies)	Work Code(s)	Work Code Description	All or Target Crashes	Crash Severit y(-ies)	Number of Projects	Naïve	Naïve with Volume Correction	Comparison Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Compariso n Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Compariso n Group	Empirical Bayes	Naïve	Naïve with Volume Correction	Compariso n Group	Empirical Bayes
All projects entered in the "Input" sheet					70	0.81	0.74			0.08	0.08			Significant a	Significant a			111.89	145.64		
108;Target;KAB	108	Improve Traffic Signals	Target	KAB	26	0.99	0.94			0.14	0.14			Not significa	Not significa			93.59	122.36		
107;Target;KAB	107	Install Traffic Signal	Target	KAB	13	0.43	0.36			0.10	0.09			Significant a	Significant a			601.55	779.07		
132, 305;Target;KA	132, 305	Install Advance Warning Signa	Target	KAB	1	0.19	0.17			0.14	0.12			Significant a	Significant a			3.00	3.49		
108, 132;Target;KA	108, 132	Improve Traffic Signals, Instal	Target	KAB	1																
105, 307;Target;KA	105, 307	Install Intersection Flashing Be	Target	KAB	1	1.76	1.61			1.24	1.13			Not significa	Not significa			-2.80	-2.71		
105;Target;KAB	105	Install Intersection Flashing Be	Target	KAB	7	1.11	0.94			0.47	0.40			Not significa	Not significa			-4.95	10.46		
122;Target;KAB	122	Install Advance Warning Signa	Target	KAB	1													26.23	26.88		
305, 520;Target;KA	305, 520	Safety Lighting at Intersection	Target	KAB	1	0.76	0.66			0.35	0.31			Not significa	Not significa			17.17	62.31		
519;Target;KAB	519	Add Left Turn Lane	Target	KAB	3	0.39	0.34			0.27	0.23			Significant a	Significant a			9.36	11.61		
107, 305;Target;KA	107, 305	Install Traffic Signal, Safety Lig	Target	KAB	1																
105, 521;Target;KA	105, 521	Install Intersection Flashing Be	Target	KAB	1	0.24	0.23			0.16	0.16			Significant a	Significant a			67.14	68.11		
105, 545;Target;KA	105, 545	Install Intersection Flashing Be	Target	KAB	1													110.44	103.93		
108, 520;Target;KA	108, 520	Improve Traffic Signals, Lengt	Target	KAB	1	0.05	0.05			0.05	0.04			Significant a	Significant a			735.15	814.07		
108, 508, 519, 520;	108, 508,	Improve Traffic Signals, Realig	Target	KAB	2	1.15	1.08			0.66	0.62			Not significa	Not significa			-2.31	-2.26		
508;Target;KAB	508	Realign Intersection	Target	KAB	1																
108, 519;Target;KA	108, 519	Improve Traffic Signals, Add L	Target	KAB	1	0.51	0.66			0.30	0.40			Not significa	Not significa			108.99	47.84		
132;Target;KAB	132	Install Advance Warning Signa	Target	KAB	1																
105, 519;Target;KA	105, 519	Install Intersection Flashing Be	Target	KAB	1	0.57	0.56			0.47	0.45			Not significa	Not significa			3.09	3.36		
105, 305;Target;KA	105, 305	Install Intersection Flashing Be	Target	KAB	4	0.97	0.82			0.35	0.30			Not significa	Not significa			-17.57	54.91		
105, 124;Target;KA	105, 124	Install Intersection Flashing Be	Target	KAB	1	1.29	1.16			0.91	0.81			Not significa	Not significa			-4.50	-4.20		
305;Target;KAB	305	Safety Lighting at Intersection	Target	KAB	1																

Figure 65. Sample Results for Groups of Intersection Projects.