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RESEARCH REPORT

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RP 257

Evaluating Performance of Highway Safety Projects

By

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16. Abstract

The purpose of this project was to investigate and document methods that the Idaho Transportation Department (ITD) and Local Highway Technical Assistance Council (LHTAC) can use to evaluate the performance of safety projects that have been implemented. The MAP-21 Act requires states to establish a safety project evaluation process and use the results for setting priorities for future safety projects. ITD and LHTAC currently lack formalized safety project evaluation processes.

A literature review was conducted to determine other states' current approaches to safety project evaluation, as well as state-of-the practice methods in this area. Based on this review, two evaluation methods contained in the Highway Safety Manual (HSM), the Empirical Bayes method and the Shifts-in-Collision-Type-Proportions method, were proposed for testing.

The Empirical Bayes method was applied for three safety-related highway segment improvement types – seal coats, rockfall mitigation, and inlaid centerline markings. The Shifts-in-Collision-Type-Proportions method was applied for the same improvement types, plus intersection turn lanes. The Empirical Bayes method indicated significant safety benefits associated with seal coat and rockfall mitigation improvements, and lesser benefits with the inlaid centerline markings. The Shifts-in-Collision-Type Proportions method resulted in average shifts in proportion for the fatal/injury crash type ranging from -0.07 to -0.25 for the highway segment improvements and 0.16 for intersection turn lanes.

This study demonstrated that these methods can be applied using currently available crash and roadway data. The number and type of safety projects that could be evaluated was limited by the lack of detailed construction history data on project location and type. Alternative approaches for future automation or semi-automation of the evaluation process include the development of custom software, implementation of commercial-off-the-shelf software, and enhancement of the spreadsheet-based approach used in this study.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4		mm
ft	feet	0.3048		m
yd	yards	0.914		m
mi	Miles (statute)	1.61		km
		AREA		
in^2	square inches	645.2	millimeters squared	cm^2
ft^2	square feet	0.0929	meters squared	m^2
yd^2	square yards	0.836	meters squared	m^2
mi^2	square miles	2.59	kilometers squared	km^2
ac	acres	0.4046	hectares	ha
		MASS (weight)		
oz	Ounces (avdp)	28.35	grams	g
lb	Pounds (avdp)	0.454	kilograms	kg
T	Short tons (2000 lb)	0.907	megagrams	mg
		VOLUME		
fl oz	fluid ounces (US)	29.57	milliliters	mL
gal	Gallons (liq)	3.785	liters	liters
ft^3	cubic feet	0.0283	meters cubed	m^3
yd^3	cubic yards	0.765	meters cubed	m^3

Note: Volumes greater than 1000 L shall be shown in m^3

Symbol	When You Know	Multiply By	To Find	Symbol
		TEMPERATURE (exact)		
^oF	Fahrenheit temperature	5/9 (^{o}F-32)	Celsius temperature	^oC
		ILLUMINATION		
fc	Foot-candles	10.76	lux	lx
fl	foot-lamberts	3.426	candela/m^2	cd/cm^2
		FORCE and PRESSURE or STRESS		
lbf	pound-force	4.45	newtons	N
psi	pound-force per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	Miles (statute)	mi
		AREA		
mm^2	millimeters squared	0.0016	square inches	in^2
m^2	meters squared	10.764	square feet	ft^2
km^2	kilometers squared	0.39	square miles	mi^2
ha	hectares (10,000 m^2)	2.471	acres	ac
		MASS (weight)		
g	grams	0.0353	Ounces (avdp)	oz
kg	kilograms	2.205	Pounds (avdp)	lb
mg	megagrams (1000 kg)	1.103	short tons	T
		VOLUME		
mL	milliliters	0.034	fluid ounces (US)	fl oz
liters	liters	0.264	Gallons (liq)	gal
m^3	meters cubed	35.315	cubic feet	ft^3
m^3	meters cubed	1.308	cubic yards	yd^3
		TEMPERATURE (exact)		
^oC	Celsius temperature	9/5 ^{o}C+32	Fahrenheit temperature	^oF
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/cm^2	candela/m^2	0.2919	foot-lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	pound-force	lbf
kPa	kilopascals	0.145	pound-force per square inch	psi

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The authors would like to acknowledge the Idaho Transportation Department's Office of Highway Safety and Office of Financial Planning and Analysis staff for their support in this study and for providing the data used in the analysis.

Technical Advisory Committee

Each research project has an advisory committee appointed jointly by the ITD Research Manager and ITD Project Manager. The Technical Advisory Committee (TAC) is responsible for assisting the ITD Research Manager and Project Manager in the development of acceptable research problem statements, requests for proposals, review of research proposals, and oversight of the approved research project. ITD's Research Manager appreciates the dedication of the following TAC members in guiding this research study.

Project Sponsor – John Tomlinson, ITD Office of Highway Safety

Project Manager – Kelly Campbell, ITD Office of Highway Safety

TAC Members

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Margaret Pridmore, ITD Roadway Data Section
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Sonna Lynn Fernandez, ITD Planning Section
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Laila Kral, Local Highway Technical Assistance Council

FHWA-Idaho Advisor - Lance Johnson, P.E.

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List of Acronyms

ITD – Idaho Department of Transportation
LHTAC – Local Highway Technical Assistance Council
HSM – Highway Safety Manual
TAC – Technical Advisory Committee
SPF – Safety performance function
FP&A – Office of Financial Planning and Analysis
COTS – Commercial-off-the-shelf software
FHWA – Federal Highway Administration
MAP-21 - Moving Ahead for Progress in the 21st Century Act
FAST - Fixing America's Surface Transportation Act
HSIP – Highway Safety Improvement Program
RTM – Regression-to-the-mean
CDOT – Colorado Department of Transportation
MoDOT – Missouri Department of Transportation
AADT – Average annual daily traffic
CMF – Crash modification factor
WebCARS – Web crash analysis reporting system
TAMS – Transportation asset management system
GIS – Geographic information system

Executive Summary

The purpose of this project was to investigate and document methods that the Idaho Transportation Department (ITD) and Local Highway Technical Assistance Council (LHTAC) can use to evaluate the performance of safety projects that have been implemented. The MAP-21 Act and FAST Act require states to establish a safety project evaluation process and use the results for setting priorities for future safety projects. ITD and LHTAC – like most other states – currently lack formalized safety project evaluation processes.

The goals of the research were to propose methods that ITD and LHTAC can use in the future for safety project evaluation, perform a test application of the methods to demonstrate their feasibility of use, and document the research results. The scope of the research was to apply the methods for a sample of previous safety projects within the limits of currently available data.

The first phase of the study was to conduct a literature review to determine other states' current approaches to safety project evaluation, as well as state-of-the practice methods. It was found that a majority of states do not have an evaluation process or are conducting evaluations based on simple before-after analysis. The review also included an investigation of state-of-the-practice evaluation methods. The findings indicated that the methods contained in the Highway Safety Manual (HSM) are widely-regarded as the most unbiased, versatile, and up-to-date tools available for this purpose.(1)

Two candidate evaluation methods contained in the HSM were identified from the literature review for testing in the second phase of the study. The Empirical Bayes method is used to estimate the change in crash frequency due to a safety improvement. The Shifts-in-Collision-Type-Proportions method quantifies the change in the proportion of total crashes for a target collision type, such as fatal and serious injury crashes, due to a safety improvement. Application of the methods involved the development of spreadsheet-based tools, review of ITD's construction history data to identify improvement sites for testing, collection of the required input data for the sample sites, and application of the tools with the input data to test the methods.

One component of the Empirical Bayes method is mathematical functions referred to as a safety performance functions (SPFs), which are used to estimate crash frequencies for the periods before and after a safety improvement is implemented. Generic SPFs contained in the HSM combined with local calibration factors can be used or, if available, SPFs developed for the local area can be applied. In this project, calibration factors and Idaho-specific SPFs were available for rural two-lane highway segments and two types of intersections. These Idaho-specific calibration factors and SPFs were developed in a study conducted by the University of Idaho and funded by ITD's Research Program.(2) Therefore, application of the Empirical Bayes method focused on these facility types. While the Empirical Bayes method can be used without local calibration factors or local SPFs, the resulting estimates of safety effectiveness may not be as accurate.

In addition, at least three years of crash data for the periods before and after the implementation of a safety improvement are required for the Empirical Bayes method. There were no LHTAC safety projects that met this criterion, because LHTAC only started receiving HSIP funding in 2014. As a result, the Empirical Bayes method was not applied for LHTAC safety projects.

Another limiting factor for the application of the Empirical Bayes method was the lack of traffic volume data for the minor road legs of rural intersections. A high percentage of intersections in rural areas have a non-state highway as the intersecting minor road. Because comprehensive volume data is not available for these roads, the Empirical Bayes method could not be applied to intersection safety improvements.

A significant finding of the identification of safety improvement sites for testing was that the number and type of safety projects that could be evaluated was limited by the lack of detailed construction history data on the project location and type. This data was not readily available from the Office of Financial Planning and Analysis (FP&A) or other units in ITD headquarters. Data for some of the projects was obtained from ITD's District offices, but this involved a much higher level of effort than anticipated. Certain analysis requirements, such as the minimum sample size, could be relaxed to compensate for these data deficiencies. However, this would reduce the statistical reliability of the evaluation results.

The Empirical Bayes method and Shifts-in-Proportions method were applied for samples of state highway segments where seal coat, rockfall mitigation, or inlaid centerline marking improvements had been implemented. The same samples were used for each method. The Shifts-in-Proportions method was also applied for a sample of state highway intersections where intersection turn bay improvements had been implemented.

The Empirical Bayes method was applied in two ways - using the local SPF developed in the University of Idaho study and the generic SPF contained in the HSM, together with a calibration factor developed in the study. Although the University of Idaho study determined that the local SPF produced more accurate crash frequency estimates, it was decided that applying the Empirical Bayes method in both ways in this project would be informative.

Statistically significant safety benefits were identified for all three project types when the Idaho-specific SPF was used. However, only the rockfall mitigation project type showed a statistically significant safety benefit when the HSM SPF was used with the local calibration factor. The results were mixed for the inlaid centerline marking project type, with the Idaho SPF application showing sizable benefits and a statistically significant result, while the HSM application showed moderate benefits with no statistical significance.

For the Shifts-in-Proportions method, fatal and injury crashes were selected as the target crash types because these crashes have the highest societal cost. The crashes within these categories were summed into a combined fatal-injury target crash type. Application of this method produced estimates of the average shift in proportion of fatal-injury type crashes ranging from -0.07 to -0.25. The average shift in proportion for the turn lane project type was 0.16. A negative value represents a reduction in the target crash type proportion and a positive value represents an increase in the proportion. None of the estimates were statistically significant, which may have been due to the small sample sizes.

To facilitate the evaluation of safety improvements, ITD and LHTAC should consider automation or semi-automation of the process. Three general automation approaches could be used:

- Development of custom software;
- Implementation of commercial off-the-shelf (COTS) software; or
- Enhancement of the spreadsheet application approach developed in this study.

Enhancement of the spreadsheet application approach is recommended, at least in near future. The advantages of this approach compared to the custom software or COTS software options are:

- Significantly lower implementation cost and risk;
- No recurring licensing fee;
- Additional tools could be tailored to ITD's and LHTAC's databases, practices, and evaluation needs;
- Users would have a better understanding of each step of the process through a more hands-on application; and
- Tools could be added incrementally rather than implementing a complete system.

In addition, the cost savings associated with this approach would allow resources to be focused on the higher-priority issues of establishing safety project databases, improving the record-keeping of construction history data, and developing the capabilities needed for the evaluation of a broader range of safety projects. In the future, the custom software or COTS software options should be considered.

Recommendations

The following recommendations are based on the findings of the study:

1. ITD should establish a safety project evaluation process to comply with federal requirements and provide improved information for future safety project investment decisions.
2. The Empirical Bayes method and Shifts-in-Crash-Type-Proportions method, as described in the HSM, should be the safety evaluation methods used in this process.
3. Once a sufficient number of local HSIP-funded safety projects have been implemented to provide minimum sample sizes for applying the evaluation methods, LHTAC should establish an evaluation process utilizing the methods recommended in this study.
4. The evaluation process should be applied, at a minimum, every three years.
5. Where feasible, ITD and LHTAC should consider developing calibration factors or local SPFs to help ensure evaluation of safety project performance is as accurate as possible.
6. ITD and LHTAC should consider establishing safety project databases to capture all of the project information required to apply the evaluation methods. ITD and LHTAC will need to determine where the data should be stored and who will be responsible for maintaining it.

7. The safety project databases should be updated continuously with information on newly constructed projects to improve the robustness of future evaluations.
8. ITD and LHTAC should consider options for collecting the comprehensive traffic volume data needed to apply the Empirical Bayes method for non-state highways.
9. Construction history recordkeeping should be improved to include detailed information on the specific location and type of safety improvements that have been implemented.
10. Construction history data should be stored in a standard format to be developed by ITD and LHTAC and included as a part of the standard project closeout procedure.
11. The tools developed in this study should be used in the short-term for application of the recommended evaluation methods.
12. Automation of the process should be considered to facilitate regular evaluation of safety projects. At least initially, this could be done through enhancements to the spreadsheet application approach developed in this study. In the future, the custom software or COTS software options should be considered.

Chapter 1
Introduction

The purpose of this project was to investigate and document methods that the Idaho Transportation Department (ITD) and Local Highway Technical Assistance Council (LHTAC) can use to evaluate the performance of safety projects that have been implemented. The MAP-21 Act and FAST Act require states to establish a safety project evaluation process and use the results for setting priorities for future safety projects. Section 1112(c)(1) of the MAP-21 Act states that: "To obligate funds apportioned under section 104(b)(3) to carry out this section, a State shall have in effect a State highway safety improvement program." Section 1112(c)(2)(F) of the Act further states that: "As part of the State highway safety program, a State shall (i) establish an evaluation process to analyze and assess results achieved by highway safety improvement projects carried out in accordance with the procedures and criteria established by this section; and (ii) use the information obtained under clause (i) in setting priorities for highway safety improvement projects." The legislation does not direct the states on the specific type of evaluation process to be used.

ITD and LHTAC – like most other states – currently lack formalized safety project evaluation processes. Over the past four years, ITD and DKS have developed the Highway Safety Corridor Analysis (HSCA) program that uses a data-driven analytical process to identify priority locations for safety improvements on the state-highway-system, but it does not have an evaluation component. This project addresses that gap.

This project was funded through ITD's Research Program. A technical advisory committee (TAC) was established to provide input throughout the project and review technical work products. The committee was comprised of staff from ITD's Office of Highway Safety, Transportation Systems Division, Roadway Data Section, and Planning Services Section, as well as staff from LHTAC and FHWA's Idaho Division Office.

The goals of the research were to propose methods that ITD and LHTAC can use in the future for safety project evaluation, perform a test application of the methods to demonstrate their feasibility of use, and document the research results. The scope of the research was to apply the methods for a sample of previous safety projects within the limits of currently available data.

The first step in the study was to conduct a literature review to determine other states' current approaches to safety project evaluation, as well as state-of-the practice methods. The results of the review were considered in identifying the recommended approaches for ITD and LHTAC to follow in the future. The review included an on-line search of currently used safety project performance evaluation methods, as well as correspondence with organizations involved in the development and implementation of these methods.

Two candidate evaluation methods were identified from the literature review for application in the second step of the study. Application of the methods involved the development of spreadsheet-based tools, review of ITD's construction history data to identify improvement sites for testing, collection of the required input data for the sample sites, and application of the tools with the input data to test the methods.

The third step of the study was to document the findings of the investigation in this final study report. The report is organized following the sequence of study tasks. Chapter 2 describes the results of the literature review, including other states' approaches to safety project evaluation and state-of-the-practice methods. Chapter 3 documents the study findings, including the proposed evaluation methods, application of the methods and the results, recommendations for future application of the methods, and an evaluation of alternative approaches for automation of the process. Chapter 4 presents conclusions from the research and recommendations for future implementation of a safety project evaluation process.

Chapter 2
Literature Review

An online literature review was conducted to determine other states' current approaches to safety project evaluation, as well as state-of-the practice methods. The results of the review were considered in the recommendation of approaches for ITD and LHTAC to follow in the future.

Other States' Approaches

The FHWA's Highway Safety Improvement Program (HSIP) is a core Federal-aid program. The goal of the program is to achieve a significant reduction in traffic fatalities and serious injuries on all public roads, including non-state-owned public roads and roads on tribal lands, by allocating funding for safety improvement projects. The HSIP requires a data-driven, strategic approach to improving highway safety that focuses on performance.

The HSIP publishes the Noteworthy Practice Series, which presents case studies of successful approaches by states and local agencies to HSIP planning, implementation, and evaluation. The individual case studies provide summaries of each practice, key accomplishments, and results. A 2011 report in this series found that the majority of states are conducting project evaluations based on simple before-after analysis, and a few are using evaluation results to develop state-specific crash modification factors (CMFs) for the Empirical Bayes method.[3] The report went on to state that while simple before-after evaluations are easy to perform and may provide a basic understanding of safety changes, they assume that any change is due solely to the safety improvement at the site and may misrepresent the true effectiveness of a project due to the effects of regression-to-the-mean (RTM). RTM bias describes a situation in which crash rates are artificially high (or low) during the before period and would have decreased (or increased) even without an improvement to the site.

Ideally, project evaluation should incorporate more advanced techniques, such as development of safety performance functions (SPFs) and application of the Empirical Bayes method. These techniques are used to account for natural fluctuations in crashes from year-to-year and other changes potentially impacting evaluation results. The Empirical Bayes method, specifically, can be incorporated into project evaluations to reduce the effects of RTM. The HSIP report indicated, however, that very few states have been able to use this method since it requires calibrated SPFs, and that many states do not have the training, resources, tools, manpower, or necessary data to calibrate SPFs.

The report provided two examples of states that have been able to utilize the Empirical Bayes method in safety project evaluation. The Colorado Department of Transportation (CDOT) developed SPFs for all roadway facility and intersection types in the state, which enabled them to institutionalize the Empirical Bayes method into all safety project evaluations and reduce the effects of RTM. The SPFs were originally developed for use in the network screening process. This started in the late 1990's, as a part of the development of the Level of Service of Safety concept, which is used to identify locations with the potential for safety improvement. By 2001, CDOT had calibrated SPFs for all public roadways (state and local) in Colorado, stratified by the number of lanes, terrain, environment, and functional classification. In 2009, SPFs were developed for all intersection types.

The development of SPFs has not only advanced CDOT's network screening process, but also allowed the Empirical Bayes method to be used as a standard procedure for safety evaluation analysis. CDOT has found that the Empirical Bayes method is particularly effective when it takes a long time for a few crashes to occur, as is often the case on Colorado's rural roads.

CDOT's application system gradually evolved over a ten-year period between the late 1990's and 2009. Initially, the process was developed in-house in a series of spreadsheets. In a telephone conversation on March 7th, 2016, David Swenka of CDOT indicated that one of the more time-intensive requirements was integrating the input data from several different sources inside and outside of CDOT. To reduce the labor requirements for input data preparation and data processing, the process was implemented within a custom application system, which included a database that can be queried by the user.

The HSIP report included a study by the Wisconsin DOT to investigate multiple project evaluation methods, resulting in the acquisition of the Safety Analyst software package, which allowed them to incorporate the Empirical Bayes method into project evaluations by using the SPFs contained in the software. Safety Analyst is a set of software tools distributed by AASHTO for use by state and local highway agencies in highway safety management. The SPFs in Safety Analyst were developed using national data and are intended to be calibrated to local conditions.

As a part of the study, a process was developed to extract the appropriate crashes by location, type, and year from the Wisconsin DOT's crash database based on the project location and the scheduled start and completion dates. HSIP projects were evaluated based a benefit-cost analysis using five years of before data and three years of after data. A comparison of the B/C ratios for a sample of projects calculated based on an Empirical Bayes analysis and a simple before-after analysis showed that the B/C ratios for the simple before-after analysis were overestimated by as much as 100 percent.

The literature search identified another example of use of the Empirical Bayes method for systemic safety project evaluation by the Missouri Department of Transportation (MoDOT).[(4)] Systemic safety projects involve widely implemented improvements based on high-risk roadway features correlated with specific severe crash types. This approach provides a more comprehensive method for safety planning and implementation that supplements traditional site analysis. Using this method, MoDOT evaluated their Smooth Roads Initiative, which improved 2,300 miles of roadways with resurfacing, improved markings, and centerline rumble strips or shoulder/edgeline rumble strips and combinations of these countermeasures. The evaluation computed a benefit-cost ratio for the improvements and the percent reduction in fatal crashes, fatal plus disabling injury crashes, and fatal plus all injury crashes. The analysis was structured so that each combination of countermeasures was analyzed for each facility type for which it was implemented.

Disaggregating the analysis to this level of detail allowed MoDOT to understand the degree to which individual countermeasures reduced crashes or the potential for crashes on each facility type. The study concluded that all of the 18 countermeasure combinations evaluated had statistically significant results with benefit-cost ratios substantially greater than 1.0.

To identify whether other states have made progress in implementing the Empirical Bayes method for safety project evaluation, Erin Kenley of FHWA's Office of Safety Programs Implementation and Evaluation was contacted on January 7, 2016. She indicated that a comprehensive source of information on this topic does not exist, but that the states' individual HSIP Annual Reports available from FHWA's website could be reviewed to identify the overall level of activity in this area and the safety project evaluation methods reported by the states. A summary of the review findings is provided in Appendix A.

The review indicated that some states have developed or have made progress in developing either state-specific SPFs or calibration factors for the HSM's SPFs. State-specific SPFs can be developed "from scratch" using local crash, traffic volume, and roadway characteristics data for a sample of sites. In lieu of state-specific SPFs, calibration factors can be developed for the HSM's SPFs to better fit the functions to local conditions. Some states are using SPFs for network screening and/or project identification. Interestingly, none of the states reported using the SPFs with the Empirical Bayes method for project evaluation. The only information found regarding project evaluation was for several states that indicated they are still using simple before-after analysis.

State-of-the-Practice Methods

In addition to other states' approaches, the literature search investigated state-of-the-practice methods for safety project evaluation. The findings indicated that the methods contained in the HSM are widely-regarded as the most unbiased, versatile, and up-to-date tools available.

These methods are also consistent with the requirements of the MAP-21 Act, FAST Act, and the HSIP. The general framework for the identification and analysis of highway safety problems and countermeasure opportunities under MAP-21 is defined in 23 U.S.C. 148(3)(2). This framework is consistent with the general safety management practices for states described in FHWA's HSIP MAP-21 Interim Eligibility Guidance, which include:

- Identification of safety problems either through a site analysis or systemic approach;
- Identification of countermeasures to address those problems;
- Prioritization of projects for implementation; and
- Evaluation of projects to determine their effectiveness.

Furthermore, the HSIP Manual specifically references the HSM as the source of tools to support the HSIP process.(5) The manual outlines procedures and tools to assist transportation professionals with the planning, implementation, and evaluation phases of the HSIP. With regard to the HSM, the HSIP Manual states that:

"The Highway Safety Manual (HSM) provides practitioners with the best factual information and tools to facilitate roadway design and operational decisions based on explicit consideration of the safety consequences. The HSM serves as a resource for information related to the fundamentals of road safety, road safety management processes, predictive methods, and CMFs. The road safety management process outlined in the HSM aligns very closely with the HSIP process. Related to the HSIP, the HSM guides safety practitioners in several applications, including: identifying sites with potential for safety improvement, identification of contributing factors and potential countermeasures; economic appraisals and prioritization of projects; and evaluation of implemented improvements."

Chapter 3
Findings

Evaluation Methods

The HSM defines safety effectiveness evaluation as the process of developing quantitative estimates of how a treatment, project, or a group of projects has affected crash frequencies or severities. It describes methods and procedures for:

- Evaluating a single project at a specific site;
- Evaluating a group of similar projects;
- Evaluating a group of projects for the purpose of quantifying a CMF for a countermeasure; and
- Assessing the overall safety effectiveness of specific types of projects or countermeasures in comparison to their costs.

Safety effectiveness evaluations may use several different types of performance measures, such as the percentage reduction in crashes, the shift in the proportion of crashes by collision type or severity level, the CMF for a treatment, or the comparison of the safety benefits achieved to the cost of a project or treatment.

The evaluation process is more complex than simply comparing before and after crash data at treatment sites, because consideration must also be given to what changes in crash frequency would have occurred at the evaluation sites even if the treatment had not been implemented. For this reason, most evaluations use data for both treatment and non-treatment sites. The non-treatment sites can be represented either by SPFs or actual crash and volume data.

The most common approach for safety effectiveness evaluation is before-after studies. All before-after studies use crash and traffic volume data for the time periods before and after improvement of the treatment sites. The sites do not need to be selected in a particular way, but if they were selected for improvement because of unusually high crash frequencies, then this may introduce selection bias, because they were not randomly selected. This could cause RTM bias, because periods of high crash frequency naturally tend to be followed by periods of comparatively low crash frequency, regardless of whether a safety improvement has been implemented.

Before-after evaluation conducted without any consideration of non-treatment sites are referred to as simple or "naïve" before-after evaluations. Such evaluations do not compensate for RTM bias or general time trends in the crash data. Therefore, this is not a preferred evaluation method.

Alternative Before-After Evaluation Methods

The HSM outlines four before-after evaluation methods:

- Before-after studies using SPFs – the Empirical Bayes method;
- Before-after studies using the comparison group method;
- Before-after studies to evaluate shifts in collision type proportions; and
- Observational cross-sectional studies

Two of these methods –the comparison group method and observational cross-sectional studies - have significant disadvantages, however.

With the comparison group method, the purpose of the comparison group is to estimate the change in crash frequency that would have occurred at the treatment sites if the treatment had not been made. Therefore, the selection of an appropriate comparison group is a key step in the evaluation. A significant disadvantage of this method is the amount of time required to select and prepare the data for the comparison group sites. A minimum of 650 sites must be included, and statistical testing must be applied to ensure adequate similarity to the treatment sites.

There are also disadvantages associated with observational cross-sectional studies, commonly referred to as "with and without studies." In these studies, crash data is compared for one set of sites with a specific treatment, such as a left-turn lane, to data for another set of sites without the treatment. There are two substantial drawbacks to this method. First, there is not an effective way to compensate for potential RTM bias introduced by site selection procedures. Second, it is difficult to assess cause and effect and, therefore, whether the observed differences between the treatment and non-treatment sites are due to the treatment or other unexplained factors.

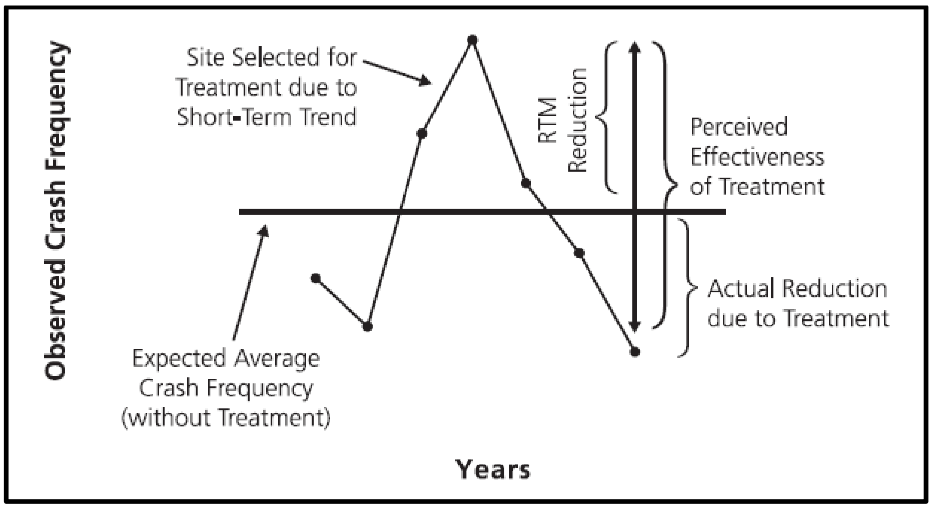
Recommended Evaluation Methods

Because of the disadvantages of the comparison group method and observational cross-sectional studies, the Empirical Bayes method and the Shifts-in-Collision-Type-Proportions method are recommended for use by ITD and LHTAC in the evaluating highway safety improvement project performance.

Empirical Bayes Method

The Empirical Bayes before-after safety evaluation method is used to compare crash frequencies at a group of sites before and after a treatment is implemented, while explicitly addressing the RTM issue. Crash fluctuation over time makes it difficult to determine whether changes in the observed crash frequency are due to changes in site conditions (e.g., a safety improvement project) or natural fluctuations. As described in the HSM, when a period of comparatively high crash frequency occurs, it is statistically probable that the following period will have a comparatively low crash frequency. This tendency is referred to as RTM and also applies to the high probability that a low crash frequency period will be followed by a period of high crash frequency.

Failure to account for the effects of RTM introduces the potential for RTM bias, or selection bias. Selection bias occurs when sites are selected for treatment based on short-term trends in observed crash frequency. As shown in Figure 1 below, RTM bias can result in the overestimation or underestimation of the effectiveness of a treatment (i.e., the change in expected average crash frequency). Without accounting for this bias, it is not possible to know if an observed reduction in crashes is due to a treatment or the natural reduction in crash frequency. Therefore, RTM bias can undermine any attempt to estimate the true performance or effectiveness of a safety improvement project.



Source: Highway Safety Manual

Figure 1. Regression-to-the-Mean (RTM) and RTM Bias

The Empirical Bayes method focuses on the use of expected average crash frequencies for both the before and after periods in order to address RTM bias. The expected crash frequencies reflect both observed crashes at the site, as well as crash information from other similar sites. The information from other sites is incorporated using an SPF to develop a predicted average crash frequency for the site. An example of an SPF from the HSM for rural two-lane highways is shown below.

$$N_{SPF\ rs} = (AADT) \times (L) \times (365) \times 10^{(-6)} \times e^{(-0.4865)}$$

Figure 2. HSM Safety Performance Function

Where:

$N_{SPF\ rs}$ = estimate of predicted average crash frequency for SPF base conditions for a rural two-lane, two-way roadway segment (crashes/year);

AADT = average annual daily traffic volume (vehicles per day) on roadway segment; and

L = length of roadway segment (miles).

In this equation, the predicted number of crashes per year is a function of AADT, segment length, and a constant, $e^{(-0.4865)}$, which is the number of crashes per million vehicle miles traveled.

In addition to the SPFs contained in the HSM, some highway agencies have performed statistically-sound studies to develop their own jurisdiction-specific SPFs derived from local conditions and crash experience.

The SPFs reflect a set of assumed base conditions for various geometric and traffic control features of the site. For example, the base condition for shoulder width in the HSM's rural two-lane highway SPF is six feet. In applying an SPF for a particular site, adjustments must be made to reflect the specific characteristics of the site. This is done using CMFs. CMF values for site characteristics that are equal to the base condition are 1.0. CMF values for site characteristics that increase the frequency of crashes compared to the base condition, such as a shoulder width of two feet, are greater than one. Conversely, CMF values for site characteristics that reduce the frequency of crashes, such as a shoulder width of 10 feet, are less than one.

CMF values for various site conditions are obtained from the HSM. They are presented in the form of a discrete value, formula, or graph. Only the specific CMFs associated with each SPF are applicable to that SPF, as these CMFs have base conditions which are identical to the base conditions of the SPF.

In addition to the CMFs, the predicted number of crashes per year estimated by the SPF must be adjusted to reflect local site conditions not accounted for by the CMFs. This is done using a calibration factor. Calibration factors are developed using a process based on observed crash data from many similar sites in the local area (statewide or non-statewide).

The SPF, together with the CMFs and calibration factor, form the basis of the predictive model for crash frequency. The general form of the HSM predictive model is shown below:

$$\mathrm{N}_{predicted} \quad = \quad N_{SPF\,x} \times (CMF_{1x} \times CMF_{2x} \times CMF_{yx}) \times \mathrm{C}_x$$

Figure 3: General Form of HSM Predictive Model

Where:

$\mathrm{N}_{predicted}$ = predictive model estimate of crash frequency for a specific year for site type *x* (crashes/year);

$N_{SPF\,x}$ = predicted average crash frequency determined for base condition with the SPF representing site type x (crashes/year);

CMF_{yx} = crash modification factors specific to site type *x*; and

C_x = calibration factor to adjust for local conditions for site type *x*.

With the Empirical Bayes method, the observed crash frequency is combined with the predicted average crash frequency using a weight to obtain the expected average crash frequency. Introduction of the predicted average crash frequency accounts for the natural fluctuation in crashes and, therefore, the RTM bias.

The recommended frequency of updating safety performance functions and calibration factors was not identified in the literature search. However, in a telephone conversation on March 7th, 2016, David Swenka indicated that CDOT's goal for updating their safety performance functions is roughly once every five years.

Application of the Empirical Bayes method as described in the HSM is comprised of the following basic steps:

1. Estimation of the expected average crash frequency in the before period;
2. Estimation of the expected average crash frequency in the after period without the treatment;
3. Estimation of treatment effectiveness; and
4. Estimation of the precision of the treatment effectiveness.

Using the example of a safety improvement project for a group of rural two-lane road segments, an overview of these steps and the required input data is provided below.

Input Data

For each site, the required data are:

- Segment length;
- AADT by year for the before and after periods;
- Observed total crash frequency by year for the before and after periods;
- Crash modification factors (CMFs); and
- Calibration factor.

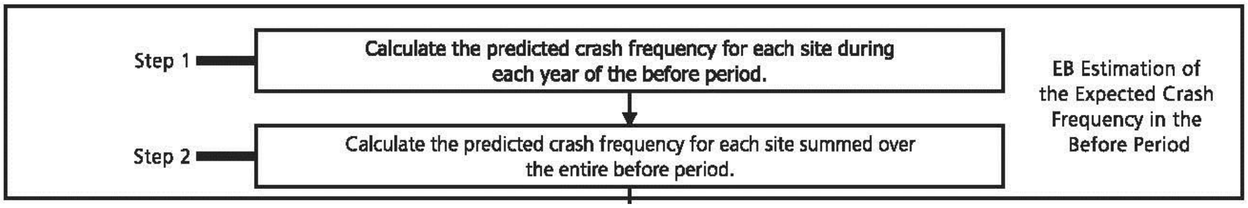
The before study period for a site must end before implementation of the treatment began. The after study period normally begins after treatment implementation is complete, and a buffer period of several months is usually allowed for traffic to adjust to the presence of the treatment. Evaluation periods that are even multiples of 12 months are used so there is no seasonal bias in the evaluation data.

The HSM recommends three to five years of crash and volume data for the before and after periods. CMF values are developed to reflect differences between the geometric characteristics of the site and those assumed as base conditions for the SPF. The calibration factor adjusts the estimate of average crash frequency produced by the SPF to reflect differences in local characteristics not accounted for in the CMFs.

Application of the Empirical Bayes method can be summarized in four basic parts. An example of the complete process is presented in Chapter 9 of the HSM starting on page 9-17.

Part 1: Estimation of Expected Average Crash Frequency in Before Period

In Part 1, the segment length and volume data are used as inputs to the predictive model to calculate the predicted average crash frequency for each site during each year of the before period. The predicted



Source: Highway Safety Manual

Figure 4. Part 1 of Empirical-Bayes Evaluation Method

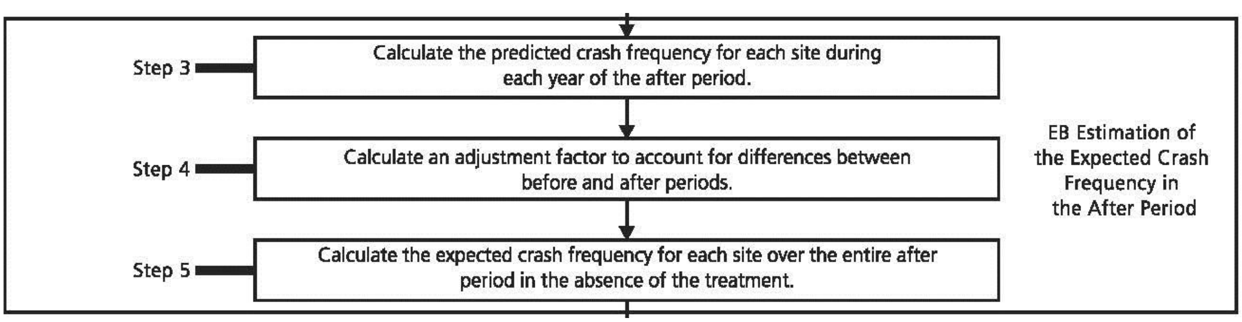
crashes are summed across the individual years to produce total predicted crashes for each site for the before period.

Following this, a weight is developed for use in estimating the expected average crash frequency in the before period for each site. The weight is specific to each site, and is calculated based on the site's total predicted crashes for the before period and a parameter referred to as the overdispersion parameter. The overdispersion parameter is calculated for each site as a function of the segment length and a constant provided in the HSM for the applicable SPF.

For each site, the weight is used to estimate the expected average crash frequency in the before period as a weighted combination of the predicted number of crashes and the observed number of crashes. Combining the predicted crash frequency with the observed crash frequency increases the statistical reliability of the estimate (the probability that the estimate is correct).

Part 2: Estimation of Expected Average Crash Frequency in After Period without Treatment

The expected average crash frequency in the after period without treatment is calculated in a similar way to the expected frequency in the before period. Predicted average crash frequencies for each site for each year of the after period are developed using the same SPF, CMFs, and calibration factor as in Part 1, together with the segment length and traffic volumes for the after period. These are summed over the entire after period.



Source: Highway Safety Manual

Figure 5. Part 2 of Empirical-Bayes Evaluation Method

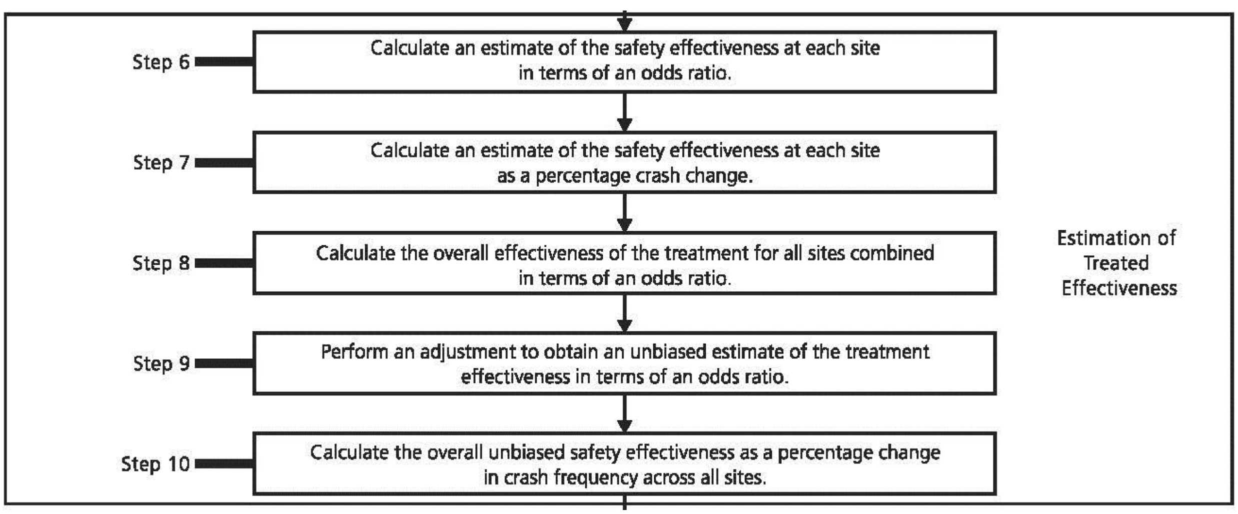
An adjustment factor to account for the differences in duration and traffic volume between the before and after periods at each site is calculated as the ratio of the total predicted average crash frequency for the after period to total predicted average crash frequency for the before period. This factor is multiplied by the expected average crash frequency for the before period to produce an estimate of the expected average crash frequency for the after period.

In some cases, there may be differences other than duration and traffic volume between the before and after periods for a site that limit the ability to attribute changes in the expected crash frequency to specific conditions. These differences may include changes in land use, weather, or geometric design. One way to address this limitation is to estimate the expected average crash frequency for the specific conditions for each year of the study period, as is done with the predictive method. This can account for the effect of changes in certain geometric features covered by the CMFs, but would not reflect changes in other geometric features or conditions such as the weather or the speed limit.

Another way to address this limitation is to shorten the number of years in the study to reduce the likelihood of other changes. However, this must be balanced against the improved estimation of crash frequency and the reduction in natural crash variability and RTM that occurs with longer study periods.

<u>Part 3: Estimation of Treatment Effectiveness</u>

The effectiveness of a given safety improvement for a group of sites is estimated in the form of an odds ratio. With the Empirical Bayes evaluation method, the odds ratio is calculated by dividing the observed crash frequency in the after period by the expected average crash frequency in the after period without the treatment. The safety effectiveness is also represented as the percentage crash change at each site. This is done by subtracting the odds ratio from one and multiplying the result by 100. For example, a project with an odds ratio of 0.185 would have a safety effectiveness value of 81.5%.



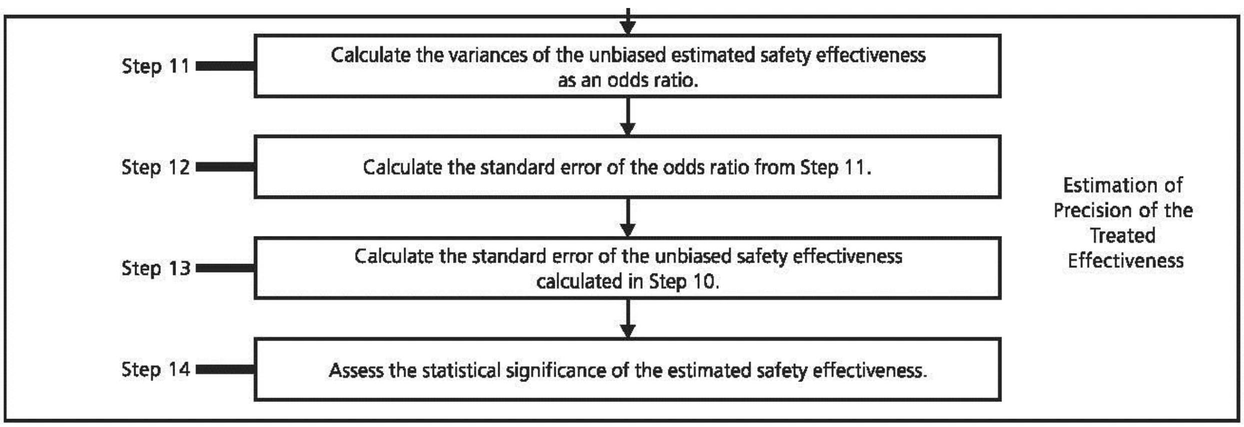
Source: Highway Safety Manual

Figure 6. Part 3 of Empirical-Bayes Evaluation Method

The overall effectiveness of the safety improvement is estimated by summing the observed and expected crash frequencies for the after period across all of the sites and then calculating a combined odds ratio. Because this estimate is potentially biased, an adjustment factor is developed and applied to obtain an unbiased estimate of the treatment in terms of an adjusted odds ratio. An adjusted odds ratio of less than one indicates a reduction in crash frequency due to the improvement; a ratio of more than one indicates that the treatment was counterproductive.

Part 4: Estimation of Precision of Treatment Effectiveness

To assess whether the estimate of an improvement's safety effectiveness is statistically significant, its precision must be determined. This is done by first calculating the precision of the odds ratio from Part 3, based on its variance. The precision of the odds ratio is expressed in terms of its standard error, which is the square root of the variance. This is then used to calculate the standard error of the safety effectiveness estimate as a measure of its precision.



Source: Highway Safety Manual

Figure 7. Part 4 of Empirical-Bayes Evaluation Method

The statistical significance of the safety effectiveness estimate can be determined by calculating the ratio of the estimate to the standard error of the estimate. If the ratio is less than 1.7, the treatment effect is not significant at the 90% confidence level. Ratios larger than 1.7 are significant at the 90% confidence level, and those larger than 2.0 are significant at the 95% confidence level.

For application of the Empirical Bayes method, the HSM recommends a minimum of 10 to 20 sites where the treatment has been implemented. Although an evaluation can be performed for fewer sites and shorter time periods than three to five years, statistically significant results are less likely.

In order to apply the Empirical Bayes method, the SPFs should reflect local (Idaho) conditions. This can be done in two ways:

- Use of SPFs developed for other areas, together with calibration factors reflecting local conditions; or
- Use of SPFs developed specifically for the local area using local observed data.

In Idaho, both of these options are available based on the results of a study conducted by the University of Idaho's National Institute for Advanced Transportation Technology. In this study, calibration factors were developed for state highways for the SPFs contained in the HSM for the following three rural facility types:

- Two-lane, two-way highways;
- Three-leg, stop-controlled intersections; and
- Four-leg, stop-controlled intersections

These facility types cover a high percentage of the facilities in Idaho's rural state highway network.

In addition, Idaho-specific SPFs were developed for the same facility types. A comparison in the study of the results using the HSM SPFs with the calibration factors to the Idaho-specific SPFs showed that the Idaho-specific SPFs performed better for two-lane, two-way highway segments and three-leg, stop-controlled intersections. For four-leg, stop-controlled intersections, the Idaho-specific SPFs did not produce significantly better results.

Shifts-in-Collision-Type-Proportions Method

The Shifts-in-Collision-Type-Proportions method is used to quantify and assess the statistical significance of a change in the frequency of a specific target collision type expressed as a proportion of total crashes between the periods before and after the implementation of a specific crash countermeasure or treatment. This method uses data only for treatment sites and does not require data for non-treatment or comparison sites. Target collision types (e.g., run-off-the-road, head-on, or rear-end) may include all crash severity levels or only specific crash severity levels (fatal-and-serious-injury crashes, fatal-and-injury-crashes, or property-damage-only crashes).

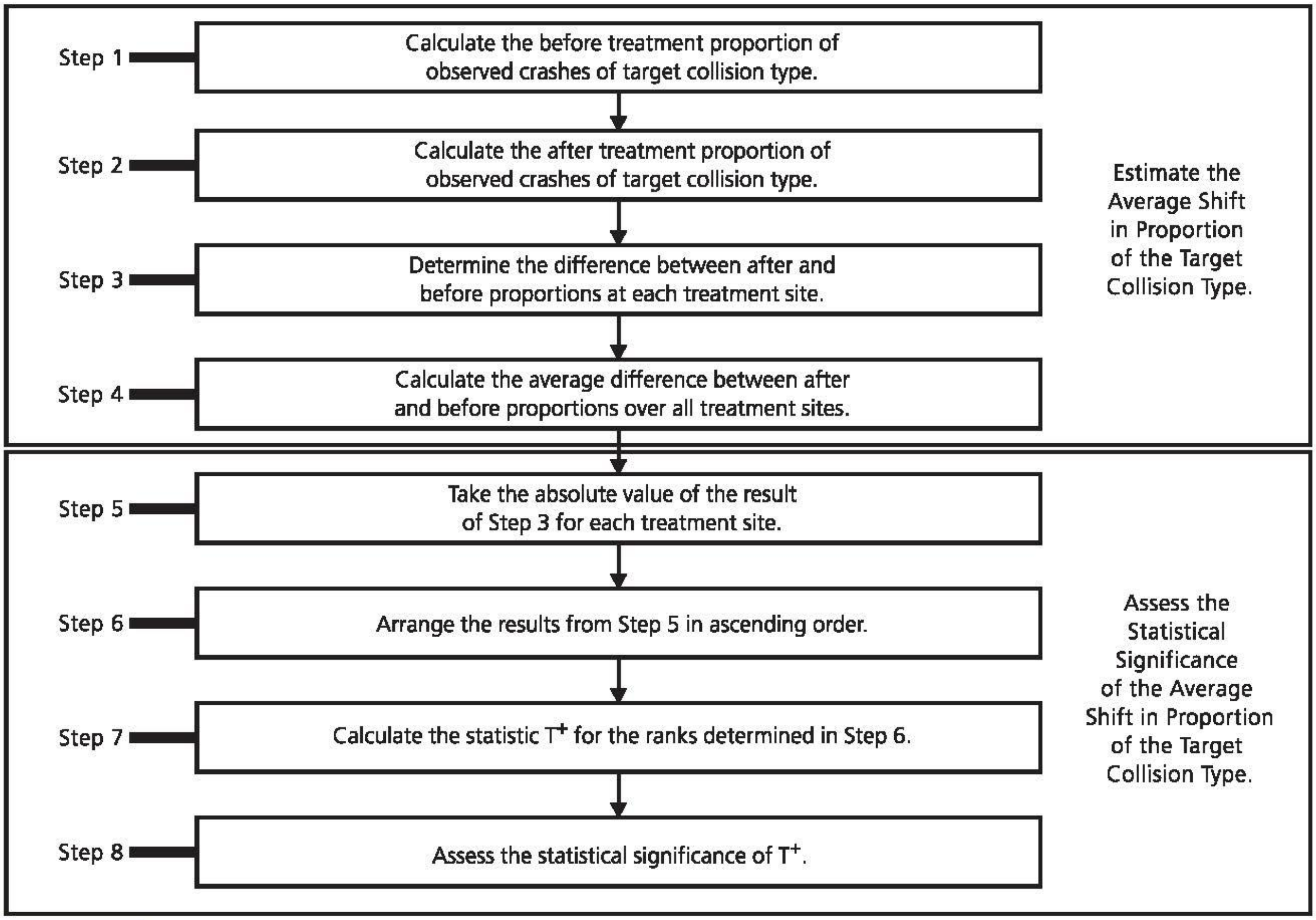
Because the measurement with this method is the shift in collision-type proportion rather than crash frequency, the RTM problem associated with crash frequency comparisons is not an issue.

Application of the Shifts-in-Proportions method as described in the HSM is comprised of two basic steps:

1. Estimation of the average shift in the proportion of the target collision type; and
2. Assessment of the statistical significance of the average shift in proportion of the target collision type

The only input data required for this method is observed crashes for the before and after periods for each site where the safety improvement has been implemented. Three to five years of crash data for the before and after periods is recommended in the HSM. As with the Empirical Bayes evaluation method, the before study period for a site must end before implementation of the treatment began. The after study period normally begins after treatment implementation is complete, and a buffer period of several months is usually allowed for traffic to adjust to the presence of the treatment. Evaluation periods that are even multiples of 12 months are used so there is no seasonal bias in the evaluation data.

An overview of the application steps for the Shifts-in-Proportions method is provided below. An example of the complete process is presented in Chapter 9 of the HSM starting on page 9-31.



Source: Highway Safety Manual

Figure 8. Overview of Shifts-in-Collision Type-Proportions Evaluation Method

<u>Part 1: Estimation of Average Shift in Proportion of Target Collision Type</u>

Part 1 consists of the following calculations to identify the average shift in the proportion of the target collision type among a sample of sites where a safety improvement has been implemented. For each site:

- Calculate the before treatment proportion of total crashes of the target collision type;
- Calculate the after treatment proportion of total crashes of the target collision type; and
- Determine the difference between the after and before proportions.

Following this, the differences in proportions for the individual sites are used to calculate the average difference in the proportions across all of the sites.

Part 2: Assessment of Statistical Significance of Average Shift in Proportion of Target Collision Type

In Part 2, a non-parametric statistical test referred to as the Wilcoxon signed rank test is used to determine the statistical significance of the shift in the proportion of the target collision type among the sample of sites identified in Part 1.

The test is applied by first determining the value of the T^+ statistic based on the results of Part 1:

- Obtain the absolute value of the difference in proportions for each site;
- Rank the sites in ascending order according to the absolute value of the difference in proportions;
- Calculate the sum of the ranks; this is the maximum total rank possible corresponding to the number of sites;
- For site ranks associated with a negative difference in proportions, replace the rank with a value of zero; and
- Calculate the sum of the adjusted ranks; this is the value of the T^+ statistic.

The statistical significance of T^+ is assessed using a two-sided significance test at the 90 percent confidence level. To do this, the value of T^+ is compared to t-values corresponding to the lower and upper limits of the 90 percent confidence interval. If the value falls between the limits, the average shift in proportion of the target collision type between the before and after periods is not statistically significant. If the T^+ value falls outside of either limit, the shift is considered statistically significant at the 90 percent confidence level.

Similar to the Empirical Bayes evaluation method, the HSM recommends a minimum sample size of 10 to 20 sites where the treatment has been implemented for application of the Shifts-in-Proportions method. Although an evaluation can be performed for fewer sites and shorter time periods than three to five years, statistically significant results are less likely.

Safety Project Performance Measures

The Empirical Bayes and Shifts-in-Proportions evaluation methods can be used to produce several different types of performance measures. These include the percentage reduction in crashes, the shift in the proportion of collisions by collision type or severity level, the CMF for a treatment, and the comparison of the safety benefits achieved to the cost of a project or treatment.

The Empirical Bayes method can be used to estimate the percentage change in average total crash frequency (i.e., all crash severities and collision types) or the change in average crash frequency by crash severity type or collision type. In the HSM, a table containing the default distribution of crashes by severity and collision type is provided for each SPF that is used to predict total crash frequency. The tables are applied sequentially to separate the total predicted crash frequency by crash severity level and collision type. Crash frequencies by severity level are estimated first, and then the second table is used to estimate crash frequencies by collision type for a particular severity level. In this way, separate performance measures for the percentage reduction in crashes can be developed for any combination of crash severity and collision type.

These default distributions can benefit from being updated based on local data as part of the SPF calibration process. In the calibration study conducted by University of Idaho's National Institute for Advanced Transportation Technology, this was not done because the crash site sample sizes were too small to support this level of disaggregation.

Procedures for developing replacement default distribution values are contained in the HSM. Each replacement value for a given facility type should be derived from data for a set of sites that, as a group, includes at least 100 crashes and preferably more. For some distribution elements, at least 200 crashes are required. The duration of the study period for a given set of sites must be as long as necessary to include at least 100 crashes.

The Empirical Bayes method can also be used to quantify the value of a CMF for a countermeasure by examining multiple sites where the countermeasure has been evaluated. CMFs are calculated as the ratio of the estimated average crash frequency with condition "b" (with the improvement) to the estimated crash frequency with condition "a" (without the improvement). CMFs serve as an estimate of effectiveness of a particular treatment. The relationship between a CMF and safety effectiveness is given as: CMF = (100 ‐ Safety Effectiveness/100). CMFs can be applied in an economic analysis to compare the safety benefits of projects, in monetary terms, to the costs. To obtain statistically significant results, the HSM recommends a minimum of 10 to 20 sites.

The Shifts-in-Proportions method provides another performance measure. As described above, this method is used to estimate the shift in proportion of total crashes for a specific crash severity level or crash type resulting from the implementation of a particular safety improvement type at multiple sites.

Application of Recommended Evaluation Methods

In Task 3 of the study, the recommended evaluation methods were applied to various types of safety projects that have been implemented by ITD to assess their effectiveness. The application approach and application tools used are outlined below.

Application Approach

The specific way in which each method was applied was determined by the amount of available input data and the number of sample sites for each improvement type. To do this, a comparison was made between the required input data and sample size, as described in the HSM, and the available input data and sample size. Based on this comparison, modifications to the standard application approaches were made due to data gaps and inadequate sample sizes.

Empirical Bayes Method

Application of the Empirical Bayes method for highway segments focused on rural two-lane, two-way highways because these are the facility types for which calibration factors or local SPFs are available. For rural two-lane, two-way highway segments, the basic required data are:

- AADT by year for the before and after periods;
- Three years of observed total crash frequency data by year for the before and after periods;
- Crash modification factors; and
- Segment length.

In addition, if the SPFs contained in the HSM are to be applied rather than local SPFs, calibration factors are should be considered. Other than the calibration factor, these data are required for each site in the sample of sites for a particular safety improvement type. Calibration factors and local SPFs for rural, two-lane, two-way highway segments are available from a study conducted by the University of Idaho's National Institute for Advanced Transportation Technology.

The AADT and observed crash frequency data are needed for a period of at least three years before and after a project has been implemented to ensure statistical reliability of the results. For ITD safety projects, this meant that the project must have been constructed by 2011 or earlier, because the most recent crash data available were for 2014. There were no LHTAC safety projects that met this criterion, because LHTAC only started receiving HSIP funding in 2014. As a result, the Empirical Bayes method could not be applied for LHTAC safety projects. For ITD projects, the source of AADT data was TAMS and source of crash data was WebCARS.

Information on roadway characteristics for each project site is needed to calculate crash modification factor values. For rural two-lane, two-way highway segments, the crash modification factors are:

1. Lane width
2. Shoulder width
3. Shoulder type
4. Horizontal curves (various features)
5. Grade
6. Driveway density
7. Presence/absence of centerline rumble strips
8. Presence/absence of passing lane
9. Presence/absence of short four-lane section
10. Roadside hazard rating
11. Presence/absence of roadside segment lighting
12. Presence/absence of automated speed enforcement

Most of this information was derived from a combination of TAMS data, ITD video logs, and Google Earth.

Segment length is defined by the limits of the project. The general source of information on project limits was construction history data. The FP&A maintains a list of safety projects for which HSIP funding has been used. This list was obtained for projects dating back to 2001.[(6)]

An examination of this list indicated that while some projects were defined for discrete highway locations, others were defined over extended highway segments, across entire ITD Districts, or even as statewide projects. For example, a metal guardrail project could be defined over a 50-mile long segment. This does not mean, of course, that guardrail was installed continuously along the entire segment, but at specific locations within the segment. To apply the Empirical Bayes method for this example, however, the specific locations of guardrail installation would need to be known. Unfortunately, the FP&A does not maintain this level of detailed information for this project type. The only potential source of this information was the Districts' construction history files.

Another difficulty with the FP&A construction history file was that some projects were too vaguely described to determine the specific project type - for example, "safety improvement" or "intersection improvement". As with the project location, more detailed information on the project type was needed from the Districts' construction history files for these projects.

Other factors contributing to the lack of safety projects from the construction history file that could be analyzed were:

- Project was too recent (newer than 2011);
- Project was not located on a rural, two-lane, two-way highway (e.g., many projects were located on freeways);
- Project was located in urban area; and
- Project was not a segment or intersection-type improvement (e.g., fence repair).

Therefore, to increase the range of projects that could be evaluated, the Districts were contacted for more information on actual project locations and the specific types of improvements that were constructed. Several of the Districts were able to provide this information. In addition, a list of pavement projects constructed since 2001 was obtained from the FP&A. Although these projects were not funded through the HSIP program, some pavement improvements are known to have safety benefits, such as seal coats and resurfacing. Projects within several pavement project categories were identified from this list.

From the combination of safety project information from the FP&A construction history file and the Districts and the pavement project file, the following project types for highway segments were selected to test the Empirical Bayes and Shifts-in-Proportions evaluation methods:

- Rockfall mitigation
- Seal coats
- Inlaid centerline markings

To ensure statistically reliable results, the HSM recommends that at least 10-20 treatment sites should be included in the sample of projects. This requirement was met for all of the project types except seal coats.

For rural three-leg and four-leg stop-controlled intersections, the basic required data are:

- AADT by year for the before and after periods for the major intersection leg;
- AADT by year for the before and after periods for the minor intersection leg;
- Three years of observed total crash frequency data by year for the before and after periods; and
- Crash modification factor.

As for highway segments, if the SPFs contained in the HSM are to be applied, a calibration factor is recommended.

The intersection crash modification factors are:

1. Intersection skew angle
2. Intersection left-turn lanes
3. Intersection right-turn lanes
4. Presence/absence of lighting

Calibration factors and local SPFs for three-leg and four-leg stop controlled intersections were available from the 2015 calibration study conducted by the University of Idaho's National Institute for Advanced Transportation Technology. However, for the intersections that could potentially be evaluated with the Empirical Bayes method, AADT data was not available for the minor intersection leg. This was because the minor roads for these intersections were non-state highway facilities, for which comprehensive, historical traffic volume data is not available. Therefore, the Empirical Bayes method could not be applied for intersections.

Shifts-in-Collision-Type-Proportions Method

The required input data for the Shifts-in-Proportions method are observed crashes by collision type and severity level for the before and after periods for each project site. Three to five years of crash data for the before and after periods is recommended in the HSM. As with the Empirical Bayes method, this limited the application of the Shifts-in-Proportions method to ITD projects only, because LHTAC only started receiving HSIP funding in 2014. The same project types and treatment sites selected for application of the Empirical Bayes method were used for the Shifts-in-Proportions method.

Application Tools

Four Excel workbooks were developed to apply the Empirical Bayes and Shifts-in-Proportions methods. For each method, separate workbooks were developed for evaluating rural two-lane, two-way highways and four-leg, stop-controlled intersections. Each workbook contained a series of worksheets corresponding to the analysis steps described above. The worksheets follow the same format of the example applications provided in the HSM.

Empirical Bayes Method

The Empirical Bayes method workbook comprises the worksheets described below.

Sheet 1: Expected Crash Frequency - Before – Contains the data and algorithms required to calculate the expected crash frequency at each treatment site for the before period. For each site, the data includes AADT volumes and crash frequencies for each year of the before period, CMF values for roadway features, and the calibration factor. The algorithms are used to calculate, for each site, the predicted crash frequency for the before period, overdispersion parameter (*k*), weighted adjustment factor (*w*), and expected crash frequency for the before period.

Sheet 2: Expected Crash Frequency – After – Contains the same site data for the after period included in Sheet 1, plus a description of the improvement location and type. The algorithms are used to calculate the predicted crash frequency for the after period, adjustment factor (*r*), and expected crash frequency for each site for the after period.

Sheet 3: Safety Effectiveness – Sites – For each site, calculates the odds ratio and safety effectiveness of the improvement based on the observed and expected crash frequencies, and the variance term based on the before and after expected crash frequencies.

Sheet 4: Overall Effectiveness – All Sites – Calculates the overall safety effectiveness of the project type across all of the treatment sites based on the overall odds ratio and final adjusted odds ratio.

Sheet 5: Effectiveness Precision – Calculates the statistical significance of the overall safety effectiveness of the project type for the 90 percent and 95 percent confidence intervals.

In addition, the workbook contains a sheet for each treatment site containing the raw input data for the analysis.

The workbook was validated by applying it using the same data contained in the example application in the HSM. This involved comparing the calculations in each sheet to those in the example to ensure that the results were the same.

Shifts-in-Collision-Type-Proportions Method

A similar approach was taken in developing the workbook for the Shifts-in-Collision-Type-Proportions method. The contents of the two sheets comprising this workbook are described below.

Sheet 1: Average Shift in Proportion – Contains the data and algorithms required to calculate the average difference in the target crash type proportions between the before and after periods for each treatment site. For each site, the data includes the total crash frequency and target crash type frequency for the before and after periods. Based on this data, the proportion of crashes for the target crash type are calculated for the before and after periods for each site and then compared, yielding the difference in proportions. An average difference in proportions is calculated across all of the sites having non-zero differences.

Sheet 2: Statistical Significance – Calculates the T^+ statistic based on the ranks of the absolute differences in proportions of all the treatment sites and applies the Wilcoxon signed rank test to assess the statistical significance of the differences at the $\alpha = 0.10$ level of significance (i.e., 0.90 confidence level).

Similar to the Empirical Bayes method workbook, the workbook for the Shifts-in-Collision Type Proportions method was validated by applying it using the same data as in the HSM example and comparing the results to ensure that they were the same.

Application Results

The Empirical Bayes method and Shifts-in-Proportions method were applied for samples of state highway segments where seal coat, rockfall mitigation, and inlaid centerline marking improvements had been implemented. The same samples of sites were used for each method. The Shifts-in-Proportions method was also applied for a sample of state highway intersections where intersection turn bay improvements had been implemented, because volume data is not required for this method.

Empirical Bayes Method

The Empirical Bayes method was applied in two ways - using the local SPF developed in the 2015 University of Idaho calibration study, and using the SPF contained in the HSM together with the calibration factor developed in the same study. Although the study found that use of the local SPF produced more accurate crash frequency estimates, it was decided that applying the Empirical Bayes method in both ways would be beneficial. The results of the applications are shown in Table 1.

Table 1. Empirical Bayes Method Application Results

Project Type	Idaho SPF		HSM SPF with Calibration Factor	
	Safety Effectiveness*	Statistically Significant?	Safety Effectiveness	Statistically Significant?
Seal Coats	27.6%	Yes	17.5%	No
Rockfall Mitigation	51.2%	Yes	45.3%	Yes
Inlaid Centerline Markings	51.2%	Yes	19.9%	No

* Safety effectiveness is the relative difference between the observed crash frequency in the period after implementation of an improvement and the expected crash frequency for the after period without the improvement.

Positive safety effectiveness values indicate a safety benefit resulting from the improvement, while negative values indicate a safety disbenefit. The statistical significance of the safety effectiveness was measured using a 95% confidence interval.

When applying the Empirical Bayes method with the Idaho-specific SPF, statistically significant safety benefits were found for the seal coat, rockfall mitigation, and inlaid centerline marking project types. The Idaho SPF application showed somewhat higher benefits and statistically significant estimates than did the use of the HSM's SPF with the calibration factor. Only the rockfall mitigation project type showed a statistically significant safety benefit when the HSM SPF was applied with the local calibration factor. For the inlaid centerline markings project type, the Idaho SPF application resulted in a much higher safety benefit estimate than the HSM application, with a statistically significant result. This difference is related to differences in the predicted crash frequencies produced by the SPFs. For the inlaid centerline markings project type, the effects of the differences in the SPFs are likely amplified by the relatively low crash frequencies in the before and after periods across the sample sites.

Shifts-in-Collision-Type-Proportions Method

Fatal and injury crashes were selected as the target crash types for application of the Shifts-in-Collision-Type-Proportions method, because these crashes have the highest societal cost. The crashes within these categories were summed into a combined fatal-injury target crash type. This method could be applied for the intersection turn lane project type in addition to the seal coat, rockfall mitigation, and centerline marking highway segment project types, because unlike the Empirical Bayes method, traffic volume data is not required. The results of the application are shown in Table 2.

Table 2. Shifts-in-Proportions Method Application Results

Project Type	**Local SPF**	
	Avg. Difference in Proportions	**Statistically Significant?**
Seal Coats	-0.0685	N/A*
Rockfall Mitigation	-0.1118	N/A
Inlaid Centerline Markings	-0.2500	N/A
Turn lanes	0.1550	N/A

* The statistical significance of the results could not be determined because the minimum sample size requirement of 10 sites was not met for any of the project types.

The average shift in proportion represents the average change in the proportion of the target crash type between the before and after periods across all of the sample sites. The seal coat, rockfall mitigation, and inlaid centerline marking project types all have negative values, indicating a drop in the proportion of fatal-injury crashes. The turn lane project type has a positive value, indicating an actual increase in the proportion of these crashes. The minimum sample size requirement of four for determining statistical significance was not met for any of the project types, because only sites with a non-zero difference in proportions are included. Many sites had a zero difference in proportions because there were no fatal or injury type crashes either before or after implementation of the improvement.

Recommendations for Future Application

To facilitate regular evaluation of safety project performance, ITD and LHTAC should consider several changes to allow the required data to be more easily obtained and the evaluation to be performed for a wider range of safety projects.

In this study, the greatest difficulty in applying the recommended evaluation methods was the lack of readily available construction history information for safety projects with regard to the actual location of the safety improvements, as well as the specific types of improvements that were implemented. While the District offices were able to provide some of this information, there were still many projects that could not be evaluated because of this issue.

Therefore, it is recommended that ITD and LHTAC establish safety project databases that contain the following information for each improvement comprising the projects:

- Specific type of improvement;
- Location of improvement (route, segment number, beginning milepost number, ending milepost number); and
- Date of completion

ITD and LHTAC must decide where the databases should reside, but they should be easily accessible by staff or consultants conducting safety project performance evaluations.

To ensure that the databases are kept up-to-date, these data should be entered immediately following completion of a safety project. Entry of the data should be a required step in the project close-out process, so that a project would not be considered completed until this is done. Ideally, ITD District staff or local agency staff would be able to enter the data directly; otherwise, it could be provided to the units where the databases will reside for updating.

The evaluation should be broadened to include safety projects for all facility types in both rural and urban areas. To help ensure evaluation efforts are as accurate as possible, ITD should work to develop calibration factors and/or Idaho-specific SPFs for the facility types not covered in the University of Idaho study where feasible. Cost will be a consideration for this effort. For example, the cost of developing the calibration factors and local SPFs for the four facility types in the University of Idaho study was $62,000. In addition, the calibration factors and/or SPFs for all facility types should be periodically updated using new crash data, similar to CDOT's practice.

The same safety project evaluation capabilities available for state highways should also be available for the non-state highways administered by LHTAC. This will require the development of the same resources needed for state highways; i.e., a safety project database, calibration factors or local SPFs for applying the Empirical Bayes method, and a mechanism for keeping the safety project database up-to-date. It is possible that the same calibration factors and local SPFs used for state highways could be applied for non-state highways. This would need to be determined once data are available for a sufficient number of non-state highway projects to apply the methods.

An additional need for the evaluation of projects for non-state highways segments using the Empirical Bayes method is comprehensive traffic volume data. These data are currently available for all state highways through ITD's TAMS database, but only a portion of non-state highways. Additional traffic volume data for non-state highways would also expand the range of intersection improvement projects that could be evaluated, because a high percentage of the intersections in Idaho are comprised of at least one non-state highway facility.

Automation of Evaluation Process

Another factor to be considered if ITD and LHTAC incorporate safety project evaluation as a standard part of their safety programs is automation or semi-automation of the evaluation process. There are several potential benefits of this compared to manual methods:

- Increased accuracy of results;
- Greater consistency of application;
- Better documentation of safety benefits; and
- More routine evaluation of safety projects

There are three general automation approaches that could be followed:

- Development of custom software;
- Implementation of commercial off-the-shelf (COTS) software; and
- Enhancement of the spreadsheet application approach developed in this study

Development of Custom Software

Custom software would have all of the advantages listed above and could be tailored to specific ITD datasets, practices, and evaluation needs. The primary disadvantages of this approach are the potential high-cost and risk of developing new software "from scratch" and the length of time required before the system would be fully operational. Another disadvantage is users not having a sufficient understanding of the internal processes of the software. This lack of understanding could lead to misapplication of the software and a lack of confidence in the results.

Implementation of Commercial Off-the-Shelf (COTS) Software

COTS software would realize the advantages described above, plus the system implementation would likely have a lower cost, risk, and time requirement compared to the development of custom software.

An example of this type of software is Safety Analyst. This software package can be used by state and local highway agencies for highway safety management, including the evaluation of safety improvement projects. It was developed in a pooled-fund effort managed by the FHWA and sponsored jointly by 27 state highway agencies and interested local organizations, and is compatible with the HSIP. It is distributed through the AASHTOWare program, which is responsible for technical support, maintenance, and enhancements. As of 2014, the list of state/provincial highway agencies with Safety Analyst licenses included:

- Arizona
- Illinois
- Kansas
- Kentucky
- Michigan
- Missouri
- Nevada
- New Hampshire
- Ohio
- Pennsylvania
- Washington
- Ontario (Canada)

For evaluating the performance of safety projects, Safety Analyst automates the approaches described in Part B – Roadway Safety Management Process of the HSM, including the Empirical Bayes and Shifts-in-Proportions evaluation methods. The user is provided a series of dialog boxes corresponding to each application step of the process:

- Enter countermeasure construction information;
- Specify scope and type of evaluation;
- Select implemented countermeasures to evaluate;
- Specify history and crash periods;
- Select crash severity; and
- Specify crash category

Two types of output reports are generated during the evaluation, in accordance with the two types of before-after evaluation. One output report describes the countermeasure effectiveness as the percent change in crash frequency, while the other output report describes the countermeasure effectiveness as the change in proportion of the target crash type. The primary output table presents the overall effectiveness estimates and statistical precision estimates and tests. Several secondary tables provide effectiveness estimates for each of the individual locations in the study.

Also, if an economic analysis is specified, another output section provides results on the economic efficiency of the countermeasure(s). A benefit-cost ratio is calculated as the present value of the crash reduction benefits to the construction costs. This is done for individual sites as well as the overall average.

Another feature of Safety Analyst is that as safety performance evaluations are conducted, the results can be used to update the CMFs within the Safety Analyst database.

The disadvantages of COTS software such as Safety Analyst are the recurring licensing cost and the potential lack of flexibility needed to “fit” the package to ITD’s and LHTAC’s databases, practices, and evaluation needs. Similar to custom software, it may also be difficult for users to develop an adequate understanding of the internal processes of the software.

Enhancement of Spreadsheet Application Approach

The third option would be enhancement of the spreadsheet application approach developed for this project. This would involve the development of complementary tools to automate or semi-automate the most labor-intensive tasks of the evaluation process related to identification of the safety projects to be evaluated and collection of the required data to apply the methods, such as crash data and roadway inventory data. Other enhancements could include the development of GIS-based tools for the display and reporting of the evaluation results.

The advantages of this approach compared to the custom software or COTS software options are:

- Significantly lower implementation cost and risk;
- No recurring licensing fee;
- Additional tools could be tailored to ITD’s and LHTAC’s databases, practices, and evaluation needs;
- Through more hands-on application, users would have a better understanding of each step of the process; and
- Tools could be added incrementally rather than having to implement a complete system

The disadvantages of this approach are that the application process may still be more labor-intensive than with the other options and the possibility of more user error for the steps that would be automated with the other options.

It is recommended that the enhancement of the spreadsheet application approach should be followed, at least in near future, because of the advantages of this approach compared to the other two options and the relatively few disadvantages. In addition, the lower cost of this approach would allow resources to be focused on the higher-priority issues of establishing safety project databases, improving the record-keeping of the construction history data, and developing the capabilities needed for the evaluation of a broader range of safety projects. In the longer-term, the custom software or COTS software options could be reconsidered.

Chapter 4
Conclusions and Recommendations

Conclusions

A literature review revealed that the MAP-21 Act and FAST Act require states to establish a safety project evaluation process and use the results for setting priorities for future safety projects. ITD and LHTAC currently lack formalized safety project evaluation processes. Most other states also do not have established safety project evaluation processes. Of the states that do have evaluation processes, most perform simple before-after comparisons, while a few others use more rigorous methods. The literature review also found that the HSM is widely recognized as the definitive source of information on highway safety analysis procedures, including safety project evaluation.

Two evaluation methods contained in the HSM, the Empirical Bayes method and Shifts-in-Collision-Type-Proportions method, can be implemented by ITD. All of the required input data for these methods are available for rural state highway segments. These methods cannot currently be implemented by LHTAC because of the lack of previous local HSIP-funded safety projects. This is because LHTAC only started receiving HSIP funding in 2014, and a minimum of three years of before and after crash data is required to apply the methods.

The number and type of safety projects that could be evaluated using these methods was limited by the lack of detailed construction history data on project location and type. This data was not readily available in a centralized database. Additional data was obtained for some of the projects from ITD's District offices, but this involved a much higher level of effort than anticipated. Certain analysis requirements, such as the minimum sample size, can be relaxed to compensate for these data deficiencies. However, this reduces the statistical reliability of the evaluation results.

The standard Empirical Bayes method was applied for rural state highways only, because calibration factors or SPFs were not available for urban facilities. Alternatively, this method could be applied for urban facilities if calibration factors were not used. This study demonstrated that both the Empirical Bayes method and the Shifts-in-Proportions method can be applied using Microsoft Excel spreadsheets.

The Empirical Bayes method was applied using Idaho-specific SPFs and the HSM's SPFs with local calibration factors for samples of sealcoats, rockfall mitigation, and inlaid centerline marking projects. Statistically significant safety effectiveness benefits were identified for the rockfall mitigation project type with both applications. The results were mixed for the seal coat and inlaid centerline marking project types, with the Idaho SPF application indicating safety benefits and a statistically significant result, while the HSM application showed moderate benefits with no statistical significance. The Empirical Bayes method could not be applied for the intersection project sample, because traffic volume data were not available for the minor (non-state highway) intersection legs.

Application of the Shifts-in-Proportions method for these project types produced estimates of the average shift in proportion of fatal-injury type crashes ranging from -0.07 to -0.25. The average shift in proportion for the turn lane project type was 0.16. None of the estimates were statistically significant, which may be due to the small sample sizes.

Several alternative approaches can be considered for automation or semi-automation of the safety project evaluation process. These are the development of custom software, implementation of COTS software, such as Safety Analyst, and enhancement of the spreadsheet-based application approach developed for this study.

Recommendations

The following recommendations are based on the findings of the study:

1. ITD should establish a safety project evaluation process to comply with federal requirements and provide improved information for future safety project investment decisions.
2. The Empirical Bayes method and Shifts-in-Collision-Type-Proportions method, as described in the HSM, should be the safety evaluation methods used in this process.
3. Once a sufficient number of local HSIP-funded safety projects have been implemented to provide minimum sample sizes for applying the evaluation methods, LHTAC should establish an evaluation process utilizing the methods recommended in this study.
4. This evaluation process should be applied, at a minimum, every three years.
5. Where feasible, ITD and LHTAC should consider developing calibration factors or local SPFs to help ensure evaluation of safety project performance is as accurate as possible.
6. ITD and LHTAC should consider establishing safety project databases to capture all of the project information required to apply the evaluation methods. ITD and LHTAC will need to determine where the data should be stored and who will be responsible for maintaining it.
7. The safety project databases should be updated continuously with information on newly constructed projects to improve the robustness of future evaluations.
8. ITD and LHTAC should consider options for collecting the comprehensive traffic volume data needed to apply the Empirical Bayes method for non-state highways.
9. Construction history recordkeeping should be improved to include detailed information on the specific location and type of safety improvements that have been implemented.
10. Construction history data should be stored in a standard format to be developed by ITD and LHTAC and included as a part of the standard project closeout procedure.
11. The tools developed in this study should be used in the short-term for application of the recommended evaluation methods.

12. Automation of the process should be considered to facilitate regular evaluation of safety projects. At least initially, this could be done through enhancements to the spreadsheet application approach developed in this study. In the future, the custom software or COTS software options should be considered.

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Appendix A
Other States' Safety Project Performance Evaluation-Related Activities

State DOT	Activities	Description
1. Alabama	Development of calibration factors	Developed calibration factors for two-lane, two-way rural highways and four-lane divided highways for Alabama.
2. Arkansas	SPF research	
3. California	1. SPF development 2. Safety Analyst implementation 3. Current project evaluation using simple before-after comparisons	1. Currently undertaking a research project to develop safety performance functions for highways, intersections and ramps to be used in Safety Analyst system. 2. A comprehensive set of performance functions for various road types, intersections and ramps are being developed that will impact the identification of locations with high collisions concentrations. 3. The effectiveness of the State HSIP was measured by comparing collision data before and after safety improvements were implemented at project sites.
4. Colorado	Project evaluation using Empirical Bayes method	1. Developed SPFs for all roadway facility and intersection types in the state. 2. Institutionalized the use of the Empirical Bayes method as a standard procedure for safety evaluation analysis to reduce effects of regression-to-the-mean. 3. Recalibration of SPFs and LOSS metrics using latest available state crash data. 4. Use of Empirical Bayes method and/or SPFs for project identification.
5. Florida	SPF development	Developed state-specific SPFs for 3- and 4-leg stop controlled intersections.
6. Illinois	1. Project identification using Empirical Bayes method 2. Development of calibration factors 3. Locally-derived crash type tables	1. Use of Empirical Bayes method and/or SPFs for project identification. 2. The Illinois HSM Crash Prediction Tool includes the HSM locally calibrated factors and locally derived crash default tables. The HSM tools are using in project identification and selection. 3. The use of HSM and quantitative decision making is becoming more

State DOT	Activities	Description
		prevalent in project programming decisions related to freeways and interchanges.
7. Indiana	Development of crash loss index	Most rural local roads lack recent volume data so a crash loss index was developed under a joint transportation research project with Purdue University. Socioeconomic data and road characteristics are used to develop a local expected road crash loss and crash loss density that is compared to existing crash history to determine relative safety need at a site or road segment.
8. Kansas	Development of calibration factors	Developed calibration factors for rural stop controlled intersections along with rural highway segments.
9. Kentucky	Project identification using Empirical Bayes method	Use of Empirical Bayes method and/or SPFs for project identification.
10. Maine	Development of calibration factors	SPF calibration factors have been developed for segments and intersections.
11. Missouri	Systemic safety improvement evaluation using Empirical Bayes	1. Using the Empirical Bayes evaluation methodology with safety performance functions, the Missouri Department of Transportation (MoDOT) evaluated their Smooth Roads Initiative (SRI), which improved 2,300 miles of roadways with resurfacing, improved markings, and centerline rumble strips or shoulder/edgeline rumble strips. 2. The countermeasure effectiveness is based on a comparison of the expected number of crashes with and without the edgeline treatment for the two years before the installation and the two years after the installation of the edgelines in 2009. 3. MoDOT used their Countermeasure Evaluation Tool to perform a "Before vs. After" evaluation. The Countermeasure Evaluation Tool is a customized spreadsheet that incorporates Empirical Bayes methodology to estimate the effectiveness of the implemented countermeasure. 4. Developed calibrated HSM SPF for rural two-lane, two-way highways.
12. Montana	SPF development	SPFs for roadway departure crashes are being developed.
13. New Hampshire	1. Network screening using Safety Analyst	1. Network screening is done using Safety Analyst. Input data are updated

State DOT	Activities	Description
	2. Project identification using Empirical Bayes method	to 10 most recent years. 2. Use of Empirical Bayes method and/or SPFs for project identification. 3. Plan to develop a system that is capable of regularly evaluating the effectiveness of its implemented countermeasures. 4. Information showing the overall effectiveness of the current programs will guide review of funding allocations for projects.
14. New York	Project evaluation using simple before-after analysis	The Post-Implementation Evaluation System (PIES) allows for actual before and after project evaluations. The system allows for verification that projected accident reductions reported as part of the Department's safety goal are reasonable and accurate; quantitative measurements of the effectiveness of the Department's overall capital program in improving highway safety (reducing accidents and safety benefit cost ratio); continued development of new accident reduction factors for accident countermeasures (shoulder rumble strips, roundabouts, and pavement surface treatments); and ensures that the mandated requirements are met.
15. North Carolina	1. SPF development 2. Development of calibration factors 3. Current project evaluation using simple before-after analysis	1. NCDOT is continuing to develop safety performance functions and will utilize the ISDM application on future STIP projects. 2. The Safety Evaluation Group of the Traffic Safety Systems Management Section has evaluated hundreds of countermeasure projects. The methodologies used in these evaluations offer various philosophies and ideas, in an effort to provide objective countermeasure crash reduction results. This information is provided so the benefit or lack of benefit for this type of project can be recognized and utilized for future projects. As the Safety Evaluation Group completes additional reviews for these types of countermeasures, they will be able to provide objective and definite information regarding actual crash reduction factors. 3. Naïve before and after analysis method is used to assess safety project performance. 4. Developed state-specific SPFs. Calibration factors were found for many facility types including rural 3- and 4-leg intersections.
16. Ohio	1. Project identification using Empirical	1. Each year, ODOT staff reviews the top safety locations in Ohio. Ohio is

State DOT	Activities	Description
	Bayes method and/or SPFs 2. Full implementation of Safety Analyst	one of the first states in the country to fully implement Safety Analyst and use it to prioritize safety locations across Ohio. 2. Use of Empirical Bayes method and/or SPFs for project identification.
17. Oklahoma	Segment project identification using Bayesian methods	1. Bayesian methods are used for segment project identification. 2. Roadway data is not available for most local roads, making it impossible to use the same analytical methods on these roads. 3. Improved site ranking methodologies include using only injury/fatal crash history (to better concentrate on reducing these crash types).
18. Oregon	Development of calibration factors	Developed calibration factors for HSM SPFs for rural two-lane, two-way highway, rural multi-lane highway, and urban and suburban arterial facilities.
19. Pennsylvania	SPF development	Have developed Pennsylvania-specific Safety Performance Functions (SPFs).
20. Rhode Island	Data collection for SPF and CMF development	RIDOT's wants to fully incorporate the HSM predictive methods in their entire HSIP process. Currently, RIDOT is undertaking data collection and integration effort to allow for predictive network screening and state-specific SPF and CMF development.
21. South Carolina	Project identification using Empirical Bayes method	Use of Empirical Bayes method and/or SPFs for project identification.
22. South Dakota	1. SPF development 2. Development of calibration factors	1. Developed jurisdiction-specific SPFs. 2. Calibrated HSM SPF for rural two-lane, two-way highway segments.
23. Utah	SPF development	1. Developing statewide crash model capable of identifying systemic trends, locations where certain crash types are over-represented, and HSM calibration factors. 2. Developed state-specific SPF for rural two-lane two-way roadways.
24. Virginia	1. Project identification using Empirical Bayes method and/or SPFs 2. Use of Safety Analyst 3. SPF development	1. Use of Empirical Bayes method and/or SPFs for project identification. 2. Developed several state-specific SPFs for use with Safety Analyst.
25. Washington	Project identification using Empirical Bayes	Use of Empirical Bayes method and/or SPFs for project identification.

State DOT	Activities	Description
	method and/or SPFs	
26. Wisconsin	Project evaluation using Empirical Bayes	1. Developed a project evaluation process incorporating Empirical Bayes analysis into all HSIP project evaluations. 2. Demonstrated the importance of using statistical evaluations to reduce the overestimation of safety benefits due to regression-to-the-mean bias.