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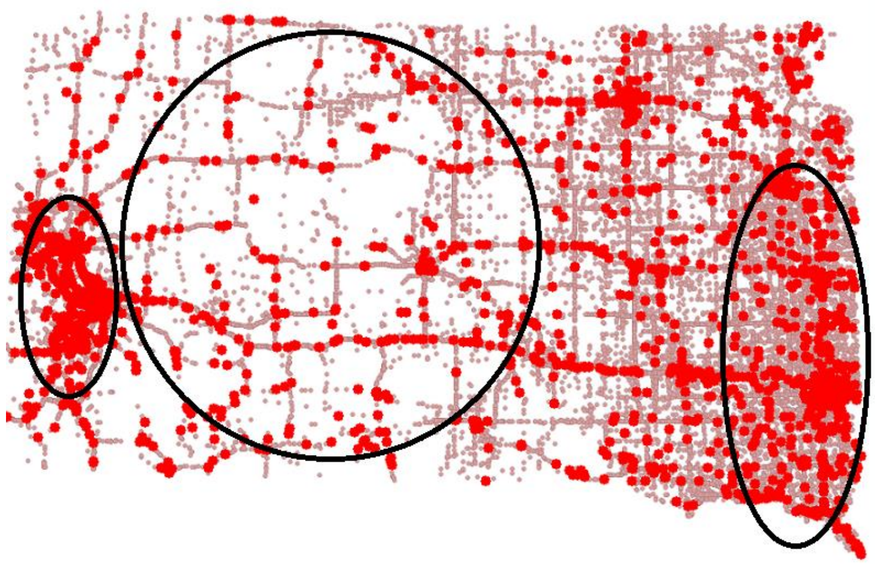

Review of State DOT Practices for Analyzing the Effectiveness of Completed Highway Safety Improvement Projects

Study SD2011-02
Final Report

Prepared by
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Pierre, SD

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DISCLAIMER

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16. Abstract

The South Dakota Department of Transportation (SDDOT) sought to enhance its safety program by investigating different methods of evaluating completed highway safety improvement projects. As a first step, the researcher completed a comprehensive literature review, using the results to develop a state survey. Upon approval of the state survey by the project's technical panel, thirteen states representing various geographic locations and population distributions were interviewed to determine which evaluation methods they are currently using or have used in the past, what data is needed to employ each method, time constraints, staffing requirements, and what modifications, if any, they have made to any of the available methods. Next, the researcher interviewed employees from various offices within SDDOT and the Department of Public Safety to determine what resources and data elements are available to the traffic safety engineers for safety analysis.

With the answers provided through the state surveys and interviews, the researcher recommended using the Empirical Bayes method of evaluating completed highway safety improvements when a particular safety improvement has been installed at multiple locations and simple before and after analysis for all other situations. The researcher also recommended making changes to the existing GIS database and roadway database, making advanced GIS training available to safety engineers, and developing a simple investigations database to make safety effectiveness evaluations more efficient regardless of the evaluation technique used.

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Acronym	Definition
AADT	Average Annual Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
CDOT	Colorado Department of Transportation
CMF	Crash Modification Factors
CM&P	Construction Measurement and Payment
DOT	Department of Transportation
DOT&PF	Alaska Department of Transportation and Public Facilities
DPS	Department of Public Safety
EB	Empirical Bayes
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
HDOT	Hawaii Department of Transportation
HSIP	Highway Safety Improvement Plan
HSM	Highway Safety Manual
IDOT	Iowa Department of Transportation
ISU	Iowa State University
LRS	Linear Referencing System
MaineDOT	Maine Department of Transportation
MAP-21	Moving Ahead for Progress in the 21st Century
MIRE	Model Inventory of Roadway Elements
MMUCC	Model Minimum Uniform Crash Criteria
MoDOT	Missouri Department of Transportation
MTD	Montana Transportation Department
NCDOT	North Carolina Department of Transportation
NCHRP	National Cooperative Highway Research Program
NDOR	Nebraska Department of Roads
NHI	National Highway Institute
ODOT	Oregon Department of Transportation
PDO	Property Damage Only
RCI	Railroad Crossing Improvement
RIS	Roadway Information System
RSI	Road Safety Improvement Program
RTM	Regression to the Mean
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act
SCDOT	South Carolina Department of Transportation
SDDOT	South Dakota Department of Transportation
SHSP	Strategic Highway Safety Plan
SPF	Safety Performance Function
STIP	Statewide Transportation Improvement Plan
TIM	Transportation Inventory Management
TraCS	Traffic and Criminal Software
TRB	Transportation Research Board
WSDOT	Washington State Department of Transportation
WYDOT	Wyoming Department of Transportation

1 EXECUTIVE SUMMARY

1.1 Problem Statement

The South Dakota Department of Transportation (SDDOT) Office of Project Development manages 10 to 15 safety improvement projects per year under the Road Safety Improvement Program (RSI) and 14 to 20 projects under the Railroad Crossing Improvement (RCI) program, in addition to providing traffic engineering services to local governments under the Federal 402 Safety Program. These federally funded programs must meet requirements established by the Federal Highway Administration (FHWA). Specifically, a highway safety program must employ "appropriate measures for reducing crashes and evaluating the effectiveness of safety improvements on a specific section of the road or street system."[1] In addition, the new surface transportation act Moving Ahead for Progress in the 21st Century (MAP-21) has made safety a top priority. MAP-21 requires improvements in the areas of data collection and safety analysis, an annually updated Strategic Highway Safety Plan (SHSP), an established evaluation process, and established measures to reduce serious injuries and fatalities on the highway system. The full effects of MAP-21 are not yet known, but it is important that SDDOT be prepared with proven screening and evaluation techniques that focus on reducing serious injuries and fatalities.

Although several methods are available to determine the effectiveness of safety improvements, SDDOT currently has no established method in place to evaluate projects because it is uncertain which method is most suitable for South Dakota. In the past, traffic safety engineers have used simple before and after analysis, but they question the accuracy of the method.

This project sought to determine which method of evaluating safety improvements is most appropriate for SDDOT, based on data availability, staffing requirements, and ease of use. Safety engineers from other state DOTs were interviewed to determine which methods they have used and what issues they have encountered while using those methods. This project will provide traffic safety engineers with the available options to evaluate completed hig hway safety improvements and recommend the actions needed to implement the methods.

Safety effectiveness evaluations help engineers determine which improvements have provided the most safety benefit and what improvements they should continue to use to mitigate crashes. A more accurate method of evaluation will help SDDOT continue to spend safety funds in an effective manner.

1.2 Research Objectives

This project had three objectives:

- Identify and evaluate methods to evaluate the effectiveness of highway safety improvements.
- Recommend the method(s) most applicable to SDDOT.
- Describe resources and procedures needed to implement these methods.

1.3 Task Descriptions

There were ten project tasks:

Task 1 – Review Project Scope and Work Plan

Meet with the project's technical panel to review the project scope and work plan.

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[1] National Highway Traffic Safety Administration. *Uniform Guidelines for State Highway Safety Programs.* November 2006 < http://www.nhtsa.gov/nhtsa/whatsup/tea21/tea21programs/402guide.html>

The researcher met with the project's technical panel on September 15, 2011 to review the project scope and work plan. During this meeting, panel members discussed their needs and perceptions. Their hope for this project was to find a method(s) that would be practical based on the current number of safety engineers employed at the DOT, educational background of current safety engineers, and amount of time needed to complete analysis.

Task 2 – Review and Summarize Literature

Review and summarize literature pertinent to methods of evaluating the effectiveness of safety improvements, including the Highway Safety Manual.

The researcher reviewed national literature, including the Highway Safety Manual, the final report for SD2009-07 *Methods to Identify Needed Highway Safety Improvements,* various Transportation Research Board (TRB) publications, the National Crash Modification Factor (CMF) Clearinghouse, and documents found on FHWA's website. The literature review provided baseline information that was used to develop a survey of other state practices.

Task 3 – Request Survey Participation

Using the Safety Engineers Listserv, send a request for survey participants. Contact participants recommended by the technical panel.

On January 10, 2012, the assistant safety engineer from SDDOT posted a brief description of the survey on the State Safety Engineers Listserv. Thirteen State Highway Safety engineers responded to the request for survey participants.

Task 4 – Identify Important Attributes for a Method & Identify Current Practices

Determine important attributes for a safety effectiveness evaluation method and identify current practices for choosing safety improvements. Important attributes will be used to develop a final survey.

The panel felt that it would be more efficient to combine task 4 and task 5, so the task 4 meeting was delayed until a draft survey was complete.

Task 5 – Develop Verbal Survey

Develop a verbal survey directed toward other state DOT's to determine which safety improvement evaluation methods they are currently using, whether they have made modifications to the methods, issues they have had employing the methods, whether they have documentation of their process, whether they use more than one process for different roadway types, what data is required for the method, and answers to other questions deemed relevant by the technical panel.

The researcher presented a memorandum to the technical panel on January 5, 2012. The memorandum included findings from the literature review and a draft survey. The survey was divided into six sections including, preliminary questions that covered prior experience in traffic safety engineering, general questions that covered the frequency and cost of safety projects, questions about the methods used, data needs, the state agency's definition of effectiveness, and documentation. The panel provided comments and the survey was finalized.

Task 6 – Conduct Interviews

***Upon approval of the technical panel, conduct interviews of all participating DOTs*.**

Safety engineers from thirteen state DOTs were interviewed. Participating states included Alaska, Colorado, Hawaii, Iowa, Maine, Montana, Missouri, North Carolina, Nebraska, Oregon, South Carolina, Washington, and Wyoming.

Task 7 – Evaluate Methods

***Evaluate all methods identified in the survey*.**

The researcher interviewed staff of SDDOT and the South Dakota Department of Public Safety to determine what data are available, the accuracy of available data, the time required to retrieve data in existing databases, and staffing availability and constraints. After the interviews were completed, the researcher assessed SDDOT resources relative to the needs identified in the state surveys to determine which methods of evaluating safety improvements are practical for SDDOT.

Task 8 – Summarize Findings

Summarize the findings of the interviews and present the summary to the technical panel for comment.

On September 6, 2012, the researcher presented a technical memorandum containing the research findings to the technical panel.

Task 9 – Prepare Final Report

Prepare a final report summarizing research methodology, findings, conclusions, and recommendations.

After meeting with the technical panel, the researcher prepared a draft final report.

Task 10 – Make Executive Presentation

Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

On April 16, 2013, the researcher presented project findings and recommendations to the Research Review Board.

1.4 Findings

The major findings from the tasks are summarized below. More detailed findings are presented in section 5.0 of the complete final report.

1.4.1 Training and Experience

Traffic safety authorities recognize that two skill sets are required to perform safety effectiveness evaluations, and weaknesses in either can affect the validity of safety effectiveness evaluations.

The first major skill set involves proficiency in investigative field work. Authorities recommend that engineers have knowledge of a wide variety of potential countermeasures and safety issues specific to the state. Appendix E of the complete final report contains a list of training opportunities and resources recommended by the traffic safety engineers interviewed.

The other major skill set involves proficiency in querying and using crash data in analysis. Knowledge of Geographic Information Systems (GIS) is important to performing safety effectiveness evaluations because they rely on crash data from SDDOT's crash and traffic databases. Being able to quickly access this information and make recommendations or changes to the database increases the efficiency and ability of safety engineers in performing effectiveness evaluations as well as other job duties.

The State maintains a central GIS database that contains data from multiple state government agencies, such as crash data from the Department of Public Safety, traffic data from SDDOT, or hydrologic data from the Department of Environments and Natural Resources. A team of staff of the Bureau of Information and Telecommunications provides hosting and other services to maintain the database. Any data can be added to the database as long as it has spatial reference. Data is accessed through a custom-built, user-friendly interface that contains prebuilt layer files that include specific data elements. This layer files are developed and maintained by the GIS professionals of TIM. The layer files provide valuable decision-making information to DOT offices, but some layer files, such as the 5 percent report, have a specific purpose.

Certain data elements needed to perform safety effectiveness evaluations were not readily available to traffic safety engineers in the State's GIS database until they were requested during this project. Most significantly, the database did not contain a list of locations where safety improvements have been made or the type of safety improvement that were installed. As changes occur in the field of safety engineering and in new laws, guidance, or rules, data needs will change; knowing the capabilities of GIS software to store and organize data would be beneficial to traffic safety engineers.

There are two types of GIS training available to SDDOT staff, but no SDDOT-specific training. Introductory, as well as advanced level courses are available online free and for a fee through ESRI, SDDOT's ArcGIS software vendor. There are currently three in-house training courses available to state employees. The courses are four hours long and training is provided by GIS specialists from the core GIS Support team from the Bureau of Information and Telecommunications. Training teaches users how to use ArcGIS tools such as Datahound, a custom-built ArcGIS add-on developed by the Bureau of Information and Telecommunications that contains a list of most of the State's GIS layers and makes searching for data quicker. DOT-specific training would be useful, but it should be tailored to the user's specific needs. There are many layer files and data elements important to safety staff, such as the five percent report and road safety improvement layers. Introductory training that captures the important aspects of the SDDOT crash data should be developed for newer traffic safety engineers, and advanced courses could build on that knowledge.

1.4.2 SDDOT Roadway Data

Roadway segment and intersection data are collected and maintained in a central database called the Roadway Information System (RIS). RIS has three main components: a roadway features component, an intersection inventory, and a traffic inventory. RIS uses linear referencing to show the location of roadway information along the state highway system and some county roads. This means that each data element in RIS is associated with a particular displacement from a Mileage Reference Marker.

The roadway features component of RIS contains many of the geometric data elements needed to perform safety effectiveness evaluations for roadway segments. The roadway features are updated annually, typically starting in November of each year. In 2011, Transportation Inventory Management began collecting additional geometric segment data elements that could be used in various safety analysis applications, as a part of the implementation plan for study SD2009-07 *Methods to Identify Needed Highway Safety Improvements*. The additional roadway segment elements collected in 2011 are listed in Table 2 of the complete final report.

The intersection inventory contains data elements needed to perform safety effectiveness evaluations for intersections, but it was not available until 2011, after the implementation plan for SD2009-07 was created. Table 3 of the complete final report identifies the geometric intersection data elements that were uploaded into RIS in 2011. Prior to 2011, only two of the required data elements for safety effectiveness evaluations at intersections are available through the Department of Public Safety's crash database at locations where a crash has occurred—type of traffic control, either minor road stop or signal stop, and presence or absence of intersection lighting.

The traffic inventory contains current and projected traffic information on the State highway system. Data elements that are important to safety effectiveness evaluations include the ADT, section type, and functional class. The ADT is updated annually, but historical ADT is not maintained in the inventory.

The RIS database contains the year in which major reconstruction has occurred, but RIS does not record any other historical changes. For instance, the user would be unable to determine whether the shoulders on a particular segment were widened from two feet to four feet during a year of major reconstruction. This information could only be found by looking at the historical values for roadway width in the Highway Needs Book. Historical data is useful to determine whether safety has been affected by factors other than an improvement.

Other documentation, such as SDDOTs Highway Needs and Project Analysis Reports dating from 1979 to the present year, saved feature files from 2005 to the present year, personal data files from 1999 to 2003, GIS maps from 2004 to the present year, and old plans, could be used to obtain all historical geometric segment and intersection data, but there is no single location where historical data features can be extracted.

1.4.3 Department of Public Safety Crash Data

The Department of Public Safety collects crash data and stores it in a central database based upon a GIS roadway database supported by SDDOT. The roadway database has not been updated since 2007, so if any changes such as changes in roadway naming conventions have occurred, the data may not be accurate at those locations.

The crash data maintained by the South Dakota Department of Public Safety is very good relative to peer states. Beginning in 2007, the South Dakota Highway Patrol (SDHP) began using Traffic and Criminal Software (TraCS). The software has greatly enhanced crash reporting by the SDHP and those local agencies that began using the software since it became available in 2010. Rather than inputting paper reports into the central database, data is entered electronically and automatically sent to the central database. The software performs automatic checks which greatly reduce reporting errors.

The data contained in the DPS crash database is not perfect though. There are still reporting errors, especially at agencies that have not had the funding to switch over to TraCS and still submit paper reports. Missing and unreported data are more frequent on reservations.

1.4.4 Investigations/Improvement Database

The final report for study SD2009-07 recommended that SDDOT develop a sitebysite investigations database recording the issues studied, treatments implemented, and results observed. At the time, SDDOT did not consider an investigations database essential because it is not needed to perform network screening using the method proposed by the study. If SDDOT is planning on adopting any method other than simple analysis, then safety engineers should have access to an investigations database.

Ideally, an investigations database would contain all the information needed to perform a before and after evaluation in one location. Essential data include the location and description of completed safety improvements, geometric segment or intersection data before and after the improvement was implemented, a minimum of three years before and after crash data, and historical traffic data.

Information that would be helpful includes site visit notes and notes regarding any major site changes at improvement sites. The database should be searchable by improvement type or project type.

In November 2012, staff of TIM began updating a layer in the central GIS database titled ‘accomplishments’ that identifies the type and location of projects implemented by SDDOT. Safety staff can search this layer by project code or improvement type code to generate a list of all of the locations where a particular improvement has been implemented and the date that the project was implemented. Data in the file dates back to the 70’s. The ‘accomplishments or projects completed’ layer is now available to department staff members using ArcGIS.

The accomplishments layer will be helpful in performing effectiveness evaluations on particular treatments, but there are some limitations. The data includes the project location, project and improvement description, and contract award date, but does not include any geometric or crash data. GIS layers can be combined, so geometric segment data and crash data recorded in RIS could be merged with the accomplishments layer. Second, region wide and county wide improvements, such as signing, delineation, or painting are not included in the layer because regions do not keep track of improvement locations.

A separate investigations database should be created to bring all information needed for safety effectiveness evaluations to one location. Safety engineers would record the locations of site visits, notes from site visits including the geometric conditions prior to any improvements being implemented, and provide the data to GIS professionals from TIM. Safety engineers should also identify locations where improvements have been implemented using HSIP funding. If locational data were provided for region wide improvements, that data could also be included. Crash data, geometric data, and data from the accomplishments layer could be merged into the investigations database. The database would provide a single location where the essential data elements needed to perform safety effectiveness evaluations could be located.

1.4.5 Methods Explored

Methods considered during this project include simple before and after analysis, Empirical Bayes analysis, comparison group analysis, full Bayesian analysis, the shift in proportion method, and the cross-sectional method. Based on the data availability, staff availability, resources available to perform various methods, accuracy and ease of use, the Empirical Bayes method is most appropriate when there are sufficient sample sites with a particular treatment. Simple analysis should be used for all other situations. The methods, including calculations, advantages and disadvantages, and applicability to SDDOT, are described in more detail in section 5.0 of the complete final report. Table 1 summarizes the criteria used to evaluate each of the methods. The executive summary is limited to a discussion of the two methods recommended for use at SDDOT.

1.4.5.1 Simple Analysis

Simple before and after analysis compares crash statistics at a site before an improvement was implemented to crash statistics at the site after an improvement was made. Three basic steps are needed to perform a simple evaluation. First, traffic and crash data are collected for treated sites before and after a safety improvement has been made. Next, the crash frequency at the site is calculated before and after the treatment was implemented. Crash frequency for a segment is calculated as the number of crashes per million vehicle-miles traveled. For intersections or point locations, the frequency is measured in crashes per million vehicles. After the crash frequency is determined for both before and after periods, the percent in crashes reduction can be determined as the change in crash frequency in the before and after periods over the crash frequency before the treatment was implemented. If the crash frequency decreases the improvement is deemed successful.

Table 1: Method Applicability and Limitations

Method	Practical at SDDOT	Data available	Criteria for Selecting a method: Disadvantages	Criteria for Selecting a method: Advantages
Simple Before/After	Yes	Yes	Least Accurate Experiences Regression to the Mean (RTM) bias Does not account for changes in traffic volume Performance measures vary from state to state	Only traffic and crash data needed Ability to evaluate a single site quickly Meets HSIP reporting requirements
Empirical Bayes	Yes	Yes	May be limited by lack of sample sites Safety Performance Functions (SPFs) needed Crash Modification Factors (CMFs) needed Data intensive May use method at a single location, but accuracy is unknown	Reduces RTM bias Accounts for changes in traffic volume Accounts for site to site variations CMFs and SPFs with local calibration procedures available in HSM Simple calculations relative to modeling methods
Comparison Group	Possibly	Maybe	Likely not able to find enough treatment and comparison sites SPFs needed Cannot use method at a single location, must have both a treatment group and a comparison group Data intensive	May reduce RTM bias Simple calculations relative to modeling methods More accurate than simple analysis
Shift in Proportion	Possibly	Yes	Method assumptions may be faulty Not used by other state highway agencies Not a lot of available literature May be limited by lack of sample sites May use method at a single location, but accuracy is equal to or less than simple analysis	Literature suggests the method is not affected by RTM bias at high-crash locations Only crash data needed
Full Bayesian	No	Yes	Extremely complex Cannot use method at a single location Data intensive Requires staff with extensive statistical background Time consuming and costly Resources currently not available to perform at SDDOT	Most accurate Reduces RTM bias Can define dependent variables relevant to SDDOT
Cross-sectional	No	Yes	Does not define a clear cause and effect relationship between the treatments and number of crashes Time consuming and costly Requires staff with statistical background Resources currently not available to perform at SDDOT	Only method that can be applied when no historical crash data is available
Other modeling methods	No	Yes	More accurate Work best for systematic improvements or improvements where there is sufficient sample size Extremely complex Requires staff with extensive statistical background May be limited by lack of historical data Time consuming and costly	More accurate than simple analysis

Most often crash frequency is used to determine the percent crash reduction and measure the effectiveness of treatments, but other performance measures can be used when data is limited. Some examples include comparing the total number of crashes in the before and after periods, comparing the total number of fatal crashes in the before and after periods, or measuring factors that are strongly linked to crashes, such as changes in average speed, changes in proportion of speeding vehicles, or changes in compliance with pedestrian signals.[2] If any of the defined performance measures decrease, the improvement is deemed successful.

Simple analysis cannot account for regression to the mean (RTM) bias, so when other methods such as the EB method are applicable and there are sufficient treatment sites, simple analysis should not be used. RTM bias is caused by random fluctuations in crashes over time. The number of crashes will naturally experience high and low periods, but after a high or low period, the number of crashes will regress toward an average number for that site. The effectiveness of a safety measure can be overestimated if a site had a randomly high crash rate in the before years. RTM bias can be reduced by using more years from the crash history but will still be present in the results.

Simple analysis is not data intensive. Because simple analysis requires only crash data and traffic data, it is useful when geometric or other data are limited. The Highway Safety Manual (HSM)[3] recommends 10 to 20 treatment sites for use of most methods, but simple analysis can be performed on one site or a group of sites. Performing a quantitative assessment of other factors that influence safety, such as an increase in traffic or changes in geometric characteristics or surrounding site conditions can help conclude whether results are reasonable. When there is limited before and after data or no comparable sites, simple analysis may be the only method available.

Simple evaluations can be completed quickly and do not require extensive training. The FHWA currently accepts simple analysis as a method to evaluate Highway Safety Improvement Program (HSIP) program effectiveness, and thus it is widely used among state DOTs, including SDDOT. Because single locations can be evaluated, simple analysis may be the only applicable method where a unique improvement type is installed at a few locations. In addition, if the geometrics of a site are unique, simple analysis may be preferred over types of analysis that require sites to have similar characteristics.

1.4.6 The Empirical Bayes Method

The Empirical Bayes method compares the number of crashes at a group of sites before a particular treatment was implemented to the number of crashes at a group of sites after a treatment was implemented. The EB method does not simply compare actual crash numbers; it uses both actual crash data and predicted values to account for RTM bias, changes in traffic, and site-to-site geometric variations.

The first step is to find out how many crashes are expected to occur in the before period. The expected number of crashes is a weighted average of the actual number of crashes observed at a site and the number of crashes predicted by a model. If the site is experiencing an unusually high or low number of crashes in that period, the model will adjust the crashes to a number that is closer to the norm for that site, reducing the potential for RTM bias. The significance of RTM bias depends on the number of crashes. For large samples with several hundred crashes, analysis will not be as susceptible to RTM bias. Small samples that exhibit fewer crashes are more problematic, and it is more difficult to determine

[2] Herbel, S., L. Laing, C. McGovern. Highway Safety Improvement Program (HSIP) Manual. Report No. FHWA-SA-09-029, Federal Highway Administration, Washington D.C., 2010.

[3] American Association of State Highway Transportation Officials (AASHTO) *Highway Safety Manual, 1st Edition*, Washington, D.C. 2010.

whether decreases in crashes simply represent random fluctuation. Because large sample sizes with many crashes are typically not available in South Dakota, the EB method would be preferable.

The next step is to determine how many crashes would be expected in the after period without any treatments. The purpose of this step is to account for changes in traffic volume when determining how many crashes are expected in the after period. A ratio of the predicted number of crashes in the before period to the predicted number of crashes in the after period is multiplied by the expected number of crashes in the before period.

The expected number of crashes in the after period is then compared to the actual number of crashes in the after period. The difference between the expected and actual crashes is the potential for improvement.

The models used to predict the number of crashes is called Safety Performance Functions (SPFs). The SPF predicts the crash frequency at a site in a normal period, not a high or low period. Safety performance functions are available in the HSM for the most popular facility types.

Crash modification Factors (CMFs) are used to account for differences in site geometry. SPFs in the HSM are developed using base conditions, so if a particular segment being analyzed differs from the base conditions, the analyst must use Crash Modification Factors (CMFs) to adjust the SPF to fit the site conditions. For instance, if an SPF is developed using a base roadway width of 12 feet, but a particular segment is only 10 feet, the SPF is multiplied by the CMF for a 10 foot roadway segment. The base conditions considered for roadway segments include lane width, shoulder width, shoulder type, roadside hazard rating, driveway density, grade, horizontal curvature, centerline rumble strips, presence of passing lanes, presence of lighting, and presence of automatic enforcement. The base conditions considered for intersections include intersection angle, left-turn lane, right-turn lane, and lighting. CMFs are available in the HSM and are developed using the same base conditions used to develop SPFs. The HSM fully describes the steps used to calculate the safety effectiveness using the Empirical Bayes method and includes several examples.

Data is the limiting factor when deciding whether to use the Empirical Bayes method. To use the EB method, the analyst will need a Safety Performance Function, Average Annual Daily Traffic (AADT) to predict the crash frequency for a roadway segment or intersection, and geometric intersection or segment data. SDDOT has most of the data elements needed to perform the EB method. Missing data elements could be estimated.

The number of sample sites where a particular improvement was installed is another limiting factor. A minimum of 10 sites is preferable. SDDOT only implements between 10 and 15 HSIP projects per year, so there will be instances where unique projects do not fit into a group that can be analyzed.

The 2012 – 2016 Statewide Transportation Improvement Program lists all the safety projects that will take place between 2012 and 2016. The STIP does not list project specific details, such as geometric site information or specific construction activities that will take place, so it is difficult to determine if sites are comparable. Based on the projects listed in the STIP, there should be enough sample sites with a common improvement type to perform Empirical Bayes analysis.

Of the states surveyed, the second most common method used was the Empirical Bayes method. Most states found that transitioning to the Empirical Bayes method is easier than using comparison sites or employing more complex analysis methods that require the development of models because the methodology is simple once the SPFs and CMFs have been developed. Many resources, including experienced peers from other states, are available to help make the transition to the EB method easier for SDDOT.

The EB method is data intensive and for it to be practical, analysts need the ability to query improvement locations by improvement type. There should be an investigations database documenting improvement types that have occurred, crashes at that site, and site visit notes. It would be desirable for the database to contain geometric site conditions. Analysts can look up past improvements in the accomplishments layer of the central GIS database maintained by SDDOT, but a specific investigations layer to the database would be most desirable.

1.5 Recommendations

1.5.1 Empirical Bayes Analysis for Multiple Site Evaluations

SDDOT should use the EB method to analyze the effectiveness of safety improvements where an improvement has been installed at 10 or more locations.

SDDOT currently uses simple analysis to evaluate safety improvements but should instead use the EB method when there is sufficient data. SDDOT has all the data and resources needed to implement the EB method, but in some instances, there are not enough sample sites where a particular treatment has been installed to use EB analysis. Available literature agrees that there should be a minimum of 10 sample sites with a particular treatment, for EB analysis to be accurate. Many treatment types are commonly used throughout the state to increase safety, such as lighting, ADA improvements, signing, and delineation projects. There should be sufficient sample sites to perform EB analysis on a variety of countermeasures used by the SDDOT. While historical data may be initially difficult to find, with the creation of an investigations database and some data improvements, all the needed data should be readily available for use. Traffic Safety engineers will need to determine which improvement types have been installed at 10 or more locations within the last five years or more, gather and group crash data, geometric data, and traffic data by improvement type, and use the procedures outlined in the HSM to analyze the effectiveness of implemented improvements.

Empirical Bayes analysis is more statistically sound than simple analysis, applies to South Dakota's low traffic locations, and can be verified by using other methods. It is common for highway agencies to perform a simple analysis parallel to EB analysis to be used as a reference. Simple analysis will typically show slightly higher reductions in crash rates, but the results should be similar. SDDOT should use simple analysis to validate the results of EB analysis.

1.5.2 Simple Analysis for Single Site Evaluations

SDDOT should use simple analysis to evaluate the effectiveness of improvements in situations where there are limited improvements of a particular type or there are unique site conditions.

Simple analysis is the quickest and easiest method available. When there is only one site that exhibits a particular treatment, the statistical significance cannot be determined, so it makes sense to use the simplest method. Also, when a particular site has unique features, such as added safety mechanisms that are not accounted for by available CMFs and SPFs, simple analysis is practical. The Safety Edge is an example of a fairly new safety feature that has been installed in limited locations in South Dakota. This safety feature currently has no CMF, but FHWA is in the process of conducting a study to determine a CMF value for the Safety Edge. At these sites simple analysis would be most practical.

1.5.3 Apply EB Method in Conjunction with other methods to Assess Performance of Crash Analysis Tool or Other Non-Traditional Site Screening Methods

SDDOT should use the EB method to assess the effectiveness of the excess proportion screening method applied using the Crash Analysis Tool during the two-year pilot period or other non-traditional site screening methods implemented at SDDOT.

The implementation plan for study SD2009-07 proposed the use of a new GIS-based network screening tool developed for SDDOT. Staff of SDDOT are in the process of deciding whether to use the tool or other site screening options, but they do plan on modifying the current black spot approach to screening sites for potential safety improvements. The EB method is statistically sound and should be used to evaluate the new Crash Analysis Tool or any non-traditional site screening methods used.

The Crash Analysis Tool (CAT) uses the excess proportion screening method to determine which sites exhibit an excess proportion of a specific crash type and can be used to find locations with a high proportion of fatal and injury crashes. If fatal and injury crashes are the focus of screening, as recommended in the new surface transportation act, the evaluation method should be able to determine whether site screening methods were successful in reducing serious injuries and fatalities. Both the shift in proportion method and EB method can be used to determine whether site screening methods reduced serious injuries and fatalities. The HSM contains default distributions that can be applied to SPFs to predict how many fatal and injury crashes will occur at a site. The predicted fatal and injury crashes can be applied in the EB method. The shift in proportion of specific crash type method of evaluation is similar to the proposed site screening method in that focus can be placed on the proportion of serious injury and fatal crashes and is simple enough that it can be used in conjunction with the EB method to assess the effectiveness of the CAT.

To apply the EB method, there should be a minimum of 10 sample sites with an improvement type. The CAT may or may not select locations that require similar treatments, so it may take several years of using the tool before the data can be analyzed for effectiveness.

1.5.4 Investigations Database

SDDOT should develop and maintain a site-by-site database that records the type of safety improvements installed at a location and identifies all locations where safety improvements have been implemented, with information included on systematic improvement types, the year of installation, geometric site characteristics, and before and after crash data.

This recommendation was contained in the final report for SD2009-07 *Methods to Identify Needed Highway Safety Improvements for SDDOT* but was not adopted in the implementation plan. The traffic safety engineers in the central office felt that an investigations database would be very helpful in performing future evaluations, but it was not needed for use in the network screening methods recommended by the project.

To perform analysis types that need multiple sample sites with a particular improvement, a central database is a necessity. There is a layer in the central GIS database maintained by SDDOT called accomplishments that was updated in November of 2012. This layer can be used to search for locations where specific project types or improvements were implemented, such as ADA improvements or lane and shoulder widening.

The accomplishments layer will be helpful in performing effectiveness evaluations on particular treatments, but there are some limitations. The data includes the project location, project and improvement description, and contract award date, but does not include any geometric or crash data. GIS layers can be combined, so geometric segment data and crash data should be merged with the accomplishments layer in the future. Second, region wide and county wide improvements, such as signing, delineation, or painting are not included in the layer because regions do not keep track of improvement locations. Third, no documentation of site visits is available in the layer.

A separate investigations database should be created to bring all information needed for safety effectiveness evaluations to one location, include site visit documentation, and keep track of improvement types that are not documented in the accomplishments layer. Essential data include the location and description of completed safety improvements, geometric segment or intersection data before and after the improvement was implemented, a minimum of three years before and after crash data, and historical traffic information. Site visit notes and notes regarding any major site changes should also be included. The database should be searchable by improvement type or project type. Safety engineers would need to record the locations of site visits, notes from site visits including the geometric conditions prior to any improvements being implemented, and provide the data to GIS professionals form TIM. Safety engineers should also identify locations where improvements have been implemented using HSIP funding and provide the data to TIM. If locational data were provided for region wide improvements, that data could also be included. The GIS specialists could merge existing crash data and geometric site data into the investigations database. The database would provide a single location where the essential data elements needed to perform safety effectiveness evaluations could be located. For evaluation methods to be practical, the ability to find information about completed safety projects and sort safety projects by category is needed.

1.5.5 Report Locations of Region Wide Improvements

SDDOT should report the location of region wide improvements and data should be stored in a new investigations database.

The location of region wide improvements should be reported annually to traffic safety engineers and entered into either a new investigations database or the existing accomplishments database. Each region office is given funding annually for certain region wide improvements, such as bridge painting, pavement markings, rumble strips, and signing projects, but the location of improvements is not reported. The MRM displacement, improvement type, and date of improvement for region wide improvements should be recorded by region engineers and the data sent to the traffic and safety engineers. This information could be recorded by crew members as work is being performed and entered into a file format that is acceptable to the traffic safety engineers and GIS specialists of SDDOT.

Without locational data, the effectiveness of region wide improvements cannot be evaluated and old and new construction methods cannot be compared. For example, SDDOT only uses rectangular shoulder rumble strips, but in the future SDDOT may consider using football shaped rumble strip. If region wide improvements were documented safety engineers would have the data needed to compare the effectiveness of both rumble strip types and determine which type to use in the future. Even simple design elements such as the rumble strip or pavement markings can improve over time, and SDDOT should maintain data so those elements can be evaluated against alternatives in the future.

1.5.6 Calibrate Safety Performance Functions

SDDOT should use the method outlined in the HSM to calibrate Safety Performance Functions to Local Conditions.

Safety Performance Functions are used to predict the number of crashes at a site based on the average annual daily traffic for that site. The number of crashes is affected by geometric site conditions, driver behavior, animal behavior, and weather conditions. National CMF values are available to adjust for geometric changes, such as the widening of a road, but there is no way to adjust SPFs based on the other factors, except to calibrate them to local data. SDDOT should calibrate the SPFs from the HSM to local conditions using the procedure outlined in the HSM.

Calibration of SPFs will involve a considerable amount of data collection and analysis and should be accomplished as a contract research project. The first step in calibration involves collecting geometric and crash data from sample sites. Most of the required data elements are available in RIS and in the DPS crash database. There are 10 intersection types and eight segment types for which HSM SPFs are available and will need calibration. For each segment type, data from approximately 100 0.1-mile segments is needed, and for each intersection type, data from approximately 100 intersection locations is needed. The HSM recommends between 30 and 50 sites for calibration, but South Dakota has many low crash locations and will likely require 100 sample sites per calibration. The second step involves calculating the expected number of crashes at each site using SPFs and CMFs for the most recent year in which crash data is available. The expected number of crashes and actual number of crashes from the most recent year are used to determine the calibration factor.

1.5.7 Formal GIS Training for Traffic Safety Engineers

The traffic safety engineers in Project Development and other offices should have access to basic and advanced GIS training and GIS training specific to SDDOT's GIS crash database.

In order to perform safety effectiveness evaluations, traffic safety engineers must be able to navigate the GIS database to find the required data elements, such as the type of improvement, the number of crashes in the before and after period, and the site characteristics. The SDDOT GIS database is structured so that engineers can find some of the information quickly, but some changes will need to be made to the database to make other data elements readily available. If safety engineers have knowledge of the capabilities of GIS software, they will be prepared to either make the needed changes or recommend what changes should be made.

One example of an essential GIS layer file that was developed was the ability to find the top 5 locations exhibiting the most need for safety improvements, for the 5 percent report. Until Congress passed SAFETEA-LU, there was no need for engineers to find the top 5 percent of sites in South Dakota and without additions to the GIS database, engineers would have had to manually look through each crash location in the state and determine the number of crashes at each site. The layer file allows safety engineers to quickly find relevant crash data within the state's GIS database.

In addition, when there are staffing changes, it would be helpful to have SDDOT-specific GIS training that frames the uses of crash data and shows how each of those elements can be located in the database. For safety effectiveness evaluations, some important data needs include locating sites where safety improvements have been implemented, locating sites where a specific improvement has been implemented (a function that is not yet available), determining crash numbers at sites, determining roadway characteristics at sites, and determining site features and other notes from investigative reports (a function that is not yet available). Knowledge of GIS software will help safety engineers in the transition to a new safety effectiveness evaluation method and a new screening method and adapt to any other changes in the traffic safety field, such as new federal reporting requirements.

1.5.8 Ensure End-of-Year Features File Contain All Needed Geometric Data Elements

SDDOT should create an end-of-year feature file with all of the geometric segment and intersection data elements necessary to perform safety effectiveness evaluations.

The Model Inventory of Roadway Elements (MIRE) Version 1.0 recommends that States track the date of change for each MIRE element in the geometric data file or track the posting date.[4] Currently the SDDOT RIS file records the date that elements were last updated, but that date does not always correspond to the date a particular roadway feature changed. The RIS file was recently updated and all dates associated with data elements reflect the update, rather than the last date an actual change was

[4] Lefler, N. et al. *Model Inventory Roadway Elements* Report No. FHWA-SA-10-018, Federal Highway Administration. Washington D.C., October 2010.

made to the data. Feature files that contain geometric data elements from RIS are currently archived on the SDDOT shared drive each year from 2005 to the present in pdf files, but some of the data elements needed for safety effectiveness evaluations are not contained in the feature files. Missing data elements include horizontal and vertical alignment, grade, and lighting. Major changes would be required in the RIS database to record the date and type of each change that occurs in the state network. If possible, it would be ideal to record the date of change, instead of the date of last update for data elements in RIS, and ensure that all of the data elements used in safety effectiveness evaluations are contained in the feature files. Traffic safety engineers could determine what the roadway geometric conditions were at each site prior to any changes using the feature files, and they would know what year to look for changes.

1.5.9 Update the GIS Roadway Database Used by the Department of Public Safety

SDDOT should update the GIS Roadway Database used by the Department of Public Safety to store crash data.

The GIS database used by the Department of Public Safety should be updated to ensure accurate data is available for use in safety effectiveness evaluations. The GIS roadway database used by the Department of Public Safety to store crash data has not been updated since 2007. If any changes have occurred since 2007, such as changes in the naming of a particular road segment, the data will not be accurate or the location of reported crashes will not be accurately referenced.

2 PROBLEM DESCRIPTION

2.1 Problem Statement

The SDDOT Office of Project Development manages 10 to 15 safety improvement projects per year under the Road Safety Improvement Program (RSI) and 14 to 20 projects under the Railroad Crossing Improvement (RCI) program, in addition to providing traffic engineering services to local governments under the Federal 402 Safety Program. These federally funded programs must meet requirements established by the Federal Highway Administration (FHWA). Specifically, a highway safety program must employ "appropriate measures for reducing crashes and evaluating the effectiveness of safety improvements on a specific section of the road or street system."[5] In addition, the new surface transportation act Moving Ahead for Progress in the 21st Century (MAP-21) has made safety a top priority. MAP-21 will require improvements in the areas of data collection and safety analysis, an annually updated Strategic Highway Safety Plan (SHSP), an established evaluation process, and established measures to reduce serious injuries and fatalities on the highway system. The full effects of MAP-21 are not yet known, but it is important that SDDOT be prepared with proven screening and evaluation techniques that focus on reducing serious injuries and fatalities.

The predominant method used by other states to evaluate the effectiveness of implemented safety improvement projects is the simple before and after evaluation. Simple before and after analysis compares crash statistics at a site before and after a safety improvement is made. If the crash frequency or severity of crashes decreases, the improvement is deemed successful. Several issues are associated with simple analysis. One of the main concerns is the effect of regression to the mean (RTM) bias. RTM bias occurs because the frequency of crashes at sites tends to fluctuate naturally. Natural high and low periods may be mistaken for changes in crash frequency due to a safety improvement. Other problems associated with simple analysis make the results of evaluations questionable. For instance, variations in traffic are not accounted for, and the effect of other geometric conditions of the site is also not considered. SDDOT has used simple analysis to fulfill its annual FHWA reporting requirements, but there are concerns with the validity of this method.

Many states have yet to apply the newly published Highway Safety Manual because they are unsure of the practical aspects of applying the different methods. Although several methods are available to determine the effectiveness of safety improvements, SDDOT currently has no established method in place because it is uncertain which method is most suitable for South Dakota.

SDDOT has made recent efforts to improve its safety program. In 2009, SDDOT sponsored research project SD2009-07 *Methods to Identify Needed Safety Improvements in South Dakota.* Based on data availability and resources, the researcher recommended SDDOT use the excess proportion method to prioritize safety improvements in urban environments and a combination of the excess proportion method and the traditional ranking approach to identify safety improvements in rural environments. The excess proportion method prioritizes selected sites based on the excess proportion of a particular crash type or severity. This method does not rely on traffic volume data and is not affected by regression to the mean bias, which is a problem with the traditional site screening method. The researcher developed the Crash Analysis Tool (CAT), which is used to apply the excess proportion method to crash locations throughout the state.

In July of 2011, the technical panel for study SD2009-07 *Methods to Identify Needed Safety Improvements in South Dakota* created an implementation plan proposing a two-year pilot in which

[5] National Highway Traffic Safety Administration. *Uniform Guidelines for State Highway Safety Programs.* November 2006 < http://www.nhtsa.gov/nhtsa/whatsup/tea21/tea21programs/402guide.html>

SDDOT would use both traditional methods and the Crash Analysis Tool to identify needed safety improvements. Under the implementation plan, additional geometric segment and intersection data elements would be collected by Transportation Inventory Management (TIM). After the two-year pilot period, SDDOT will evaluate the effectiveness of the excess proportion method compared to traditional screening approach and determine whether TIM will continue to collect the additional HSM data elements. SDDOT has collected additional data elements but is still in the process of installing and implementing the Crash Analysis Tool. SDDOT needs a statistically sound method of evaluating completed safety improvements to compare the change in safety resulting from traditional and proposed site screening methods.

This project will need to explore evaluation methods used by other states, focusing on data requirements, staffing needs, ease of use, sample size required for each method, and the advantages and disadvantages to each evaluation method. Based on SDDOT's needs, the appropriate safety effectiveness evaluation method(s) will be recommended to determine if the new Crash Analysis Tool is an effective screening tool, which evaluation method(s) will best help SDDOT meet current federal requirements and new requirements established by MAP-21, and ensure SDDOT is spending safety funds in the most effective manner.

2.2 Background

A 2002 publication on the Federal Highway Administration website indicated that a majority of states were still using simple before and after analysis to evaluate safety improvement projects. Since then, resources regarding more rigorous methods have become available. The first version of the Highway Safety Manual (HSM), released in 2010, identifies and describes methods to identify needed safety improvement projects as well as methods to evaluate the effectiveness of safety improvements. The information in the Highway Safety Manual provides a good starting point in the identification of common methods to evaluate safety projects.

Several methods are available to evaluate the effectiveness of safety improvements:

- The most common—the simple before and after study—compares the crash statistics at a site before an improvement was implemented to crash statistics after the improvement was made. If the crash frequency or severity of crashes decreases, the improvement is deemed successful. This is the simplest type of analysis, but it does not account for natural changes in crash statistics.
- Crash modification factors (CMF) predict expected crash frequencies that can be compared to the actual crash frequencies experienced after a safety improvement was put in place.
- The Empirical Bayes method (EB) relies on calibrated safety performance functions (SPF) to obtain expected values for crash data after a treatment has been in place. The EB method accounts for some of the regression to the mean bias caused by natural fluctuations in traffic patterns and crash rates.
- Comparison groups compare control sites to treated sites before and after a treatment has been completed.

Some highway agencies have taken steps to adopt the HSM, but a majority of agencies, including SDDOT, continue to use simple before and after analysis to evaluate the effectiveness of safety improvements. This research will help SDDOT determine whether to continue using simple analysis or adopt a more rigorous method of evaluating completed highway safety improvements.

3 OBJECTIVES

The purpose of this research is to understand which methods of evaluating completed highway safety improvements can be applied to SDDOT. The research had three objectives:

3.1 Objective 1: Identify and evaluate methods of evaluating the effectiveness of completed highway safety improvements.

To identify and evaluate methods, a thorough literature review was conducted. The literature review included safety effectiveness evaluation methods described in Part B of the Highway Safety Manual, including the Empirical Bayes before and after evaluation method, observational cross-sectional studies, observational before and after evaluation studies to evaluate shifts in collision crash type proportions, and observational before and after evaluations using the comparison-group method. These methods, except for the cross-sectional method, are more readily applied and the HSM contains step-by-step calculations and sample problems. Additional literature was referenced to determine other methods that could be used to evaluate safety measures and current practices.

A summary of the literature review describing the strengths and weaknesses, calculations, notable practices, and data needs of each method was presented to the technical panel along with a draft survey. The literature summary was useful in identifying questions important to the state survey.

Upon approval of the final state survey, highway safety engineers from other state DOTs were interviewed to determine what effectiveness evaluation methods are being used, data requirements, staffing needs, in what situations the methods failed, and pros and cons of each method. A total of thirteen states participated in interviews.

3.2 Objective 2: Identify the methods applicable to SDDOT.

The researcher met with Traffic Safety Engineers and staff of Transportation Inventory Management and the Department of Public Safety to define the data availability, safety project sample pool, and other information needed to determine which methods are applicable to SDDOT. Based on the results of the surveys and discussions with stakeholders, the researcher prepared a final report.

3.3 Objective 3: Describe resources and procedures needed to implement these methods.

Report findings include a summary of the methods examined, a description of data and available resources, and findings from the interviews.

4 Task Descriptions

This section of the report presents the ten project tasks. Major tasks include a literature summary, state survey, SDDOT interviews, and an evaluation of the methods examined.

4.1 Task 1 – Review Project Scope and Work Plan

Meet with the project's technical panel to review the project scope and work plan.

The researcher met with the project's technical panel on September 15, 2011 to review the project scope and work plan. During this meeting, panel members discussed their needs and perceptions. Their hope for this project was to find a method(s) that would be practical based on the current number of safety engineers employed at the DOT, educational background of current safety engineers, and amount of time needed to complete analysis.

4.2 Task 2 – Review and Summarize Literature

Review and summarize literature pertinent to methods of evaluating the effectiveness of safety improvements, including the Highway Safety Manual.

The researcher reviewed national literature, including the Highway Safety Manual and related documents, various Transportation Research Board (TRB) publications, Report 500, Volume 21, published by National Cooperative Highway Research Program (NCHRP) and the final report for SD2009-07 *Methods to Identify Needed Highway Safety Improvements*. Other documents were found on the FHWA website and the national CMF Clearinghouse website. The purpose of this this task was to identify methods to evaluate safety improvements and provide baseline information that could be used to develop a survey of other state practices. The researcher compiled the information into a brief memorandum listing the advantages, disadvantages, data requirements, and calculations of each method. The memo and a draft survey were presented to the Technical Panel on January 5, 2012.

4.3 Task 3 – Request Survey Participation

Using the Safety Engineers Listserv, send a request for survey participants. Contact participants recommended by the technical panel.

The assistant safety engineer, Josh Hinds, posted a request for survey participants on the State Safety Engineers Listserv on January 10, 2012. A total of thirteen states responded and expressed a willingness to participate.

4.4 Task 4 – Identify Important Attributes for a Method & Identify Current Practices

Determine important attributes for a safety effectiveness evaluation method and identify current practices for choosing safety improvements. Important attributes will be used to develop a final survey.

In lieu of having a separate meeting allocated for this task, the panel waited until after the draft survey was complete. At that time, they reviewed the draft survey to ensure that all of their questions would be addressed.

4.5 Task 5 – Develop Verbal Survey

Develop a verbal survey directed toward other state DOT's to determine which safety improvement evaluation methods they are currently using, whether they have made modifications to the methods, issues they have had employing the methods, whether they have documentation of their process,

whether they use more than one process for different roadway types, what data is required for the method, and other questions deemed relevant by the technical panel.

The literature review and a draft survey were presented to the Technical panel on January 5, 2012. The draft survey was broken into six sections: preliminary questions, including prior experience in traffic safety engineering; general questions that covered the frequency and cost of safety projects; and questions about the methods used, data needs, the state's definition of effectiveness, and documentation. The panel provided comments and the survey was finalized.

4.6 Task 6 – Conduct Interviews

Upon approval of the technical panel, conduct interviews of all participating DOTs.

Thirteen state DOTs were contacted for an interview, including Alaska, Colorado, Hawaii, Iowa, Maine, Montana, Missouri, North Carolina, Nebraska, Oregon, South Carolina, Washington, and Wyoming. The participants had varied educational backgrounds and different experiences to draw from based on their respective geographic location. The participants were interviewed 30 minutes to an hour each. When available, they were asked to provide documentation after the interviews. The researcher also contacted staff of FHWA to determine if any DOTs were using the shift in proportion method, but FHWA was unable to identify any safety engineers who had used the method.

4.7 Task 7 – Evaluate Methods

After the surveys were completed, the researcher interviewed SDDOT traffic and safety engineers, SDDOT GIS analysts, and staff of SDDOT TIM and the Department of Public Safety. The interviews focused on finding out what data are available, how accurate the data are, how easy it is to retrieve data in the existing databases, and staffing availability and constraints. After the interviews were completed, the researcher assessed SDDOT resources relative to the needs identified in the state surveys to determine which methods of evaluating safety improvements are practical for SDDOT.

4.8 Task 8 – Summarize Findings

Summarize the findings of the interviews and present the summary to the technical panel for comment.

The researcher met with technical panel members prior to fully evaluating the methods as described in Task 7. During the meeting, the panel was updated on progress of the implementation plan for an ongoing safety project SD2009-07, presented with a summary of the survey findings, and informed of the final tasks needed to complete SD2011-02.

4.9 Task 9 – Prepare Final Report

Prepare a final report summarizing research methodology, findings, conclusions, and recommendations.

This final report was developed using the SDDOT *Guidelines for Performing Research*. The report includes an executive summary, problem description, research objectives, research tasks, description of the project findings, and project recommendations. The project findings include a description of each method examined during this study and recommend which methods are most practical.

4.10 Task 10 – Make Executive Presentation

Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

The researcher presented the project results and recommendations to the SDDOT Research Review Board on April 16, 2013. The purpose of this task was to inform SDDOT's executive management of the findings from the research and the project recommendations.

5 FINDINGS AND CONCLUSIONS

This section of the report presents research findings by topic. The first subsection is an overview of the major survey findings. Subsequent subsections describe SDDOT's safety program, available data, and resources. The final subsections describe each method investigated and discuss the practicality of each method based on SDDOT's resources.

5.1 Overview of Survey Findings

Table 2 briefly summarizes the results of the state surveys. States currently use a variety of evaluation methods and measures of effectiveness. FHWA allows states to choose which safety effectiveness evaluation methods will be used to fulfill annual HSIP reporting requirements,but reporting requirements could change with the implementation of the new surface transportation act, MAP-21.

One of the major themes of MAP-21 is to establish a performance-based Federal program. Each state will be required to set targets for the number of serious injuries and fatalities and have an established evaluation process. Screening and evaluation techniques will need to effectively identify ways to reduce fatalities and serious injuries so that SDDOT can meet the targets established jointly by SDDOT and FHWA.

The summary of results also indicates that many of the states surveyed are moving toward or have already used the Empirical Bayes method to evaluate safety projects. As a result, there have been more published EB studies, more literature, and more improvements in the methodology.

The final major conclusion that can be drawn from Table 2 is that education and training is highly valued among safety engineers. Safety engineers have several skill sets that need to be developed, and it can take several years to become a well-rounded traffic safety engineer. During the state interviews, states were asked to provide a list of training and resources that they felt were valuable to traffic safety engineers. Those resources are listed in Appendix E of this final report.

5.2 Structure of the SDDOT's Safety Program

The traffic engineering positions at SDDOT are currently split between several offices. There are two traffic safety engineers in Project Development located in the central office, four region traffic engineers within the Division of Operations, and two traffic engineers within Road Design. The two traffic engineers within Project Development are mainly responsible for screening the state system for high-crash locations, performing safety effectiveness evaluations, performing field inspections, and funding and administrative activities. Administrative activities include reporting safety program expenditures and safety project effectiveness annually to FHWA. The duties performed by the engineers from Road Design and Operations involve performing site inspections and incorporating safety techniques into design. Region traffic engineers are also responsible for ensuring that safety projects are implemented according to the plans and specifications and performing field inspections.

5.3 Structure of Other DOT Safety Programs

Many of the traffic safety programs in other states have a headquarters location and several regional offices. The regional offices are typically responsible for screening and selecting projects, which they report to headquarters for approval. The regional offices are also responsible for site investigations, assisting with safety effectiveness evaluations, and other project activities. The headquarters is responsible for fulfilling annual FHWA reporting requirements, assisting with safety effectiveness evaluations, and providing support to regional offices. Typically, safety positions are not split between multiple offices outside of the traffic safety office.

Table 2: Agency Survey Responses

State	Training & Recommended Years of Experience	Average Annual Number of Projects (HSIP)	Evaluation Cycle	Minimum Years Before Data	Minimum Years After Data	Type of Analysis	Number of Support Staff[6]	Measure of Effectiveness
Alaska	5	40	Annual	5	3	Simple	9	B/C ratio 1.2:1
Colorado	Graduate Degree	$30 million annual safety budget	Continual	3-5	3-5	EB	Varies	B/C ratio 2:1 and Reduction in Crashes
Hawaii	2-3	4	Continual	3-5	3-5	Simple	1 FTE	Decline in Fatal & Serious Injury
Iowa	5	10	Simple – Annual, Other Analysis – Continual	3	3	Full Bayes, Simple	3	Reduction in Crashes
Maine	Ongoing Training Important	20-30	Annual	3-5	3	Simple, Modified Comparison Group	6	B/C ratio 2:1
Missouri	Ongoing Training Important	30-50	Annual	3	3	Simple, EB	8	Decline in Fatal & Serious Injury
Montana	3-5	50	Continual	3	3	Simple	1 FTE	Reduction in Crashes
Nebraska	Ongoing Training Important	10-15	Continual	3	3	Simple, Attempted Using Comparison Group Method	3	Statistically significant reduction in crash rate
North Carolina	2	150	Continual	3	3	Simple, Comparison Group, EB, Cross-sectional	6 in the Safety Evaluation Group	Decline in Fatal & Serious Injury
Oregon	2-3	30-60	Annual	3	3	Simple, Hope to use EB in future	1 FTE	Decline in Fatal & Serious Injury
South Carolina	Ongoing Training Important & 4	35-40	Annual	3	3	Simple, Contracted EB Study	1 FTE	Expect to see crash reduction follow CMFs
Washington	4	300[7]	Continual	3-7	3-7	EB, Cross-Sectional, Simple, Full Bayes, Mixed Logit	Varies, At least 1 month of 1FTE	Reduction in Crashes, Positive B/C ratio, Other
Wyoming	2	10-20	Continual	5	5	Simple, Modified Comparison Group	N/A	Reduction in Crashes

Traffic safety authorities recognize that multiple skill sets are required to perform safety effectiveness evaluations and other traffic engineering duties, so many traffic safety programs have multiple positions dedicated to specific tasks, such as performing data collection, putting together collision diagrams for safety effectiveness evaluations, and performing site inspections.

[6] Table 4 does not indicate what activities the support staff were involved in, such as data collection, data analysis, site inspection, etc. The definition of support staff varied among respondents.

[7] This number includes all safety projects.

5.4 Training and Experience

While SDDOT has some overlap in the duties required by each traffic safety position, only two central office employees are proficient in performing safety effectiveness evaluations, network screening, and fulfilling federal reporting requirements. With fewer employees, it is important to provide training opportunities and equip traffic safety engineers with resources to perform job duties.

Traffic safety authorities recognize that two skill sets are required to perform safety effectiveness evaluations, and weaknesses in either can affect the validity of safety effectiveness evaluations. The first major skill set involves proficiency in investigative field work. Authorities recommend that engineers have knowledge of a wide variety of potential countermeasures and safety issues specific to the state. Appendix E of this complete final report contains a list of training opportunities and resources recommended by the traffic safety engineers interviewed.

The other major skill set involves proficiency in querying and using crash data in analysis. Knowledge of Geographic Information Systems (GIS) is important to performing safety effectiveness evaluations because they rely on crash data from SDDOT's crash and traffic databases. Being able to quickly access this information and make recommendations or changes to the database increases the efficiency and ability of safety engineers in performing effectiveness evaluations as well as other job duties.

One example of an important change made to the GIS database came about after Congress passed the Safe, Accountable, Flexible, Efficient Transportation Equity Act (SAFETEA-LU). The law required engineers to submit a 5 percent report annually, describing 5 percent of the state's locations exhibiting the most severe highway safety needs. Until SAFETEA-LU, the existing crash database did not have any prebuilt layer files to make the task easy and traffic safety engineers would have needed to look at each crash location the state network individually to complete the report. The traffic safety engineer worked with staff of Transportation Inventory Management to build this functionality into the central GIS database. Knowledge of the software's capabilities improves the ability of safety staff to communicate their needs to GIS specialists employed in TIM.

The State maintains a central GIS database that contains data from multiple state government agencies, such as crash data from the Department of Public Safety, traffic data from SDDOT, or hydrologic data from the Department of Environments and Natural Resources. A team of staff of the Bureau of Information and Telecommunications provides hosting and other services to maintain the database. Any data can be added to the database if it is geographically referenced. Data is accessed through prebuilt layer files that contain specific data elements. Many of the layer files are developed by GIS professionals of TIM. Some of the layer files are useful to multiple DOT offices, but some layer files, such as the 5 percent report, have a specific purpose. Staff of TIM build and maintain the layer files.

There are two types of GIS training available to SDDOT staff, but no SDDOT-specific training. Introductory courses are available online free through ESRI, SDDOT's ArcGIS software vendor. There are currently three in-house training courses available to state employees. The courses are four hours long and training is provided by GIS specialists from Transportation Inventory Management (TIM). Training teaches users how to use ArcGIS tools such as Datahound, an ArcGIS add-on developed by the Bureau of Information and Telecommunications that contains a list of most of the State's GIS layers and makes searching for data quicker. DOT-specific training would be useful, but it should be tailored to the user's specific needs. There are many layer files and data elements important to safety staff, such as the five percent report and road safety improvement layers. Introductory training that captures the important aspects of the SDDOT crash data should be developed for newer traffic safety engineers and advanced courses could build on that knowledge.

5.5 Roadway, Traffic, and Crash Data

The following section summarizes the roadway, traffic, and crash data available within SDDOT.

5.5.1 SDDOT Roadway Data

Roadway segment and intersection data are collected and maintained in a central database called the Roadway Information System (RIS). RIS uses linear referencing to show the location of roadway information along the state highway system and some county roads. This means that each piece of data in RIS is attributed to a particular displacement to and from a mile reference marker. There are three main components in RIS; a roadway features component, an intersection inventory, and a traffic inventory.

The roadway features component of RIS contains many of the geometric data needed to perform safety effectiveness evaluations for roadway segments. The roadway features are typically updated in November of each year. In 2011, Transportation Inventory Management began collecting additional geometric segment data elements that could be used in various safety analysis applications, as a part of the implementation plan for study SD2009-07. Table 3 lists the data elements needed to perform safety effectiveness evaluations and indicates whether the data elements are available. Table 3 specifies when the data became available. Some data elements are not contained in RIS but can be found in the Department of Public Safety's crash database at locations where a crash has been observed.

Table 3: Geometric Segment Data Elements

Data Need (HSM data element)	SDDOT Data Available	Please note any recent changes in data collection procedures.	If not, can data be derived?	Department of Public Safety data available?
Area type (urban/rural)	Yes			Yes
Number of lanes	Yes			Yes
Segment length	Yes			
Segment volume (AADT)	ADT			
Shoulder type and width	Yes			
Lane width	No		Surface width/#lanes	
Median Type (divided/undivided)	Yes[8]			Yes
Number of driveways	No			
Presence or absence of centerline rumble-strips	N/A			
Passing lane presence	No		# lanes	
Vertical curvature[9]				
Design Speed	Yes			
Grade	Yes			
k-value	Yes			
Horizontal curvature[10]				
Curve Degree	Yes			
Speed	No			Yes
Super-elevation	No			
Roadside hazard data/rating	No			
On-street parking	Yes[11]			
Lighting	Yes	2011[12]		Yes
Presence of a short four-lane section	Yes[13]			
Presence of a two-way left-turn lane	Yes	2011		
Presence of automated speed enforcement	N/A			
Culvert locations	No			

The intersection inventory contains data elements needed to perform safety effectiveness evaluations for intersections, but it was not available until 2011, after the implementation plan for SD2009-07 was created. Table 4 lists the geometric intersection data elements that were uploaded into RIS in 2011. Prior to 2011, only two of the required data elements for performing safety effectiveness evaluations at intersections are available through the Department of Public Safety's crash database at locations where a crash has occurred – the type of traffic control, either minor road stop or signal stop, and presence or absence of intersection lighting.

The traffic inventory contains current and projected traffic information on the State highway system. Data elements that are important to safety effectiveness evaluations include ADT, section type, and functional class. ADT is updated annually, but historical ADT is not maintained.

[8] Median type is only provided for the state highway system. County data does not include this roadway characteristic.

[9] Vertical curvature is only provided for the state highway system.

[10] Horizontal curvature data is only provided for the state highway system.

[11] Parking is only provided for county data.

[12] In 2011, additional geometric segment and intersection data elements were collected as a part of the implementation plan for SD2009-07.

[13] Data is available for sections greater than 500 feet.

Table 4: Geometric Intersection Data Elements

Data Need	SDDOT Data Available	Is there a date associated with the following data element?	Please note any recent changes in data collection procedures.	Department of Public Safety data available?
Area type (urban/rural)	Yes	Yes[14]	2011	
Intersection volume (AADT)	ADT	Yes	2011	
Number of intersection legs (3 or 4)	Yes	Yes	2011	
Type of traffic control (minor road stop or signal control)	Yes	Yes	2011	Yes
Intersection skew angle (degrees departure from 90 degrees	Yes	Yes	2011	
Number of approaches with intersection left-turn lanes (0,1,2,3, or 4)	Yes	Yes	2011	
Number of approaches with intersection right-turn lanes (0,1,2,3, or 4)	Yes	Yes	2011	
Presence or absence of intersection lighting	Yes	Yes	2011	Yes

The RIS database contains the year in which major reconstruction has occurred, but a user would not be able to determine whether particular features have changed over time. For instance, the user might know that a major reconstruction project occurred five years ago, but the user would not be able to tell how wide the segment shoulders were during that year. Only the current dimensions for each segment are recorded in RIS and the year that the particular feature was last updated. The Model of Inventory Roadway Requirements (MIRE)[15] recommends that when it is not feasible to capture the date of change for each data element, "an alternative is to make changes as they occur, and then capture and retain an 'end-of year' file for each year." In the RIS file the year that data elements were last updated is recorded in the database, but this date may not correspond to an actual change at the site.

There are different forms of documentation that could be used to determine all HSM historical geometric segment and intersection data, such as SDDOTs Highway Needs and Project Analysis Reports dating from 1979 to the present year, saved feature files from 2005 to the present year, personal data files from 1999 to 2003, GIS maps from 2004 to the present year, and old plans. The saved feature files come close to fulfilling the MIRE recommendation to retain an end-of-year file, but some of the data elements are missing. There is no single location where historical data features can be determined. For the purpose of safety effectiveness evaluations, it would be sufficient to check the earliest year for which data is being used in analysis against the most recent year of data to ensure that there have not been major changes in the roadway segment.

5.5.2 Department of Public Safety Crash Data

The Department of Public Safety collects crash data and stores it in a central database based upon the GIS roadway database supported by SDDOT. The roadway database has not been updated since 2007,

[14] In 2011, geometric intersection data elements were collected as a part of the implementation plan for SD2009-07.

[15] Lefler, N., R. Council, D. Harkey, D. Carter, H. McGee, and M. Daul. *Model Inventory of Roadway Elements – MIRE, Version 1.0*. Report No. FHWA-HRT-10-048, Federal Highway Administration, Washington D.C., 2010.

so if any changes, such as changes in roadway naming conventions, have occurred, the data may not be accurate at those locations.

The crash data maintained by the South Dakota Department of Public Safety is very good relative to peer states. First, the data is over 80 percent Model Minimum Uniform Crash Criteria (MMUCC) compliant. While each state can determine which data elements it would like to collect, following the MMUCC guidelines has several advantages. The data elements are clearly defined, reducing misreporting caused by ambiguity. The data elements that are required are more than sufficient for use in safety analysis. Table 5 lists all of the crash elements used in Highway Safety Manual applications and indicates whether the data elements are available:

Table 5: Available HSM Crash Data Elements

Highway Safety Manual Data Need	Department of Public Safety Data Available
Intersection/Segment Location	Yes
Fatal	Yes
Injury	Yes
PDO	Yes
Rear End	Yes
Sideswipe (Overtaking/opposite direction)	Yes
Angle (Intersection/ no intersection)	Yes
Angle (Left/right)	Yes
Pedestrian	Yes
Bike	Yes
Motorcycle	Yes
Head-on	Yes
Fixed Object (On road/ off road)	Yes
Parked Vehicle	Yes
Construction	Yes
Animal Collision	Yes
Deer	Yes
Roll-over (On road/ off road)	Yes

Beginning in 2007, the South Dakota Highway Patrol began using Traffic and Criminal Software (TraCS). The software has greatly enhanced the quality of data recorded by SDHP and local agencies that began using the software since it became available in 2010. Rather than inputting paper reports into the central database, data is entered electronically and automatically sent to the central database. The software performs automatic checks which greatly reduce reporting errors.

The data contained in the DPS crash database is not perfect though. There are still reporting errors, more so at the local level, where agencies have not had the funding to switch over to TraCS. Local agencies that do not have TraCS are required to submit paper reports to the South Dakota Department of Public Safety. Staff from DPS reviews the paper reports for errors or missing fields and input the data into the central database. Sometimes the paper reports are forgotten and never make it to DPS. Missing and unreported data are more frequent on reservations. The TraCS system implemented by South Dakota Highway Patrol in 2007 has greatly increased and enhanced the crash data collected by the Department of Public Safety.

5.6 Investigations/Improvement Database

The final report for study SD2009-07 recommended SDDOT develop a site-by-site investigations database recording the issues studied, treatments implemented, and results observed. At the time, an investigations database was not considered essential because it is not needed to perform network screening using the method proposed by the previous study. If SDDOT is planning on adopting any method other than simple analysis, the safety engineers should have access to an investigations database.

Ideally, an investigations database would contain all the information needed to perform a before and after evaluation in one location. Essential data include the location and description of completed safety improvements, geometric segment or intersection data before and after the improvement was implemented, a minimum of three years before and after crash data, and historical traffic information. Information that would be helpful includes site visit notes and notes regarding any major site changes at improvement sites. The database should be searchable by improvement type or project type.

In November 2012, staff of TIM began updating a layer in the central GIS database titled "accomplishments" that identifies the type and location of projects implemented by SDDOT. Safety staff can search this layer by project code or improvement type code to generate a list of all of the locations where a particular improvement has been implemented and the date that the project was implemented. Data in the file dates back to the 70's. The updated layer will soon be available to department staff members.

The accomplishments layer will be helpful in performing effectiveness evaluations on particular treatments, but there are some limitations. The data includes the project location, project and improvement description, and contract award date, but does not include any geometric or crash data. GIS layers can be combined, so geometric segment data and crash data could be merged with the accomplishments layer. Second, region wide and county wide improvements, such as signing, delineation, or painting are not included in the layer because regions do not keep track of improvement locations.

A separate investigations database should be created to bring all information needed for safety effectiveness evaluations to one location. Safety engineers would record the locations of site visits, notes from site visits including the geometric conditions prior to any improvements being implemented, and provide the data to GIS professionals from TIM. Safety engineers should also identify locations where improvements have been implemented using HSIP funding. If locational data were provided for region wide improvements, that data could also be included. Crash data could be merged into the investigations database. The database would provide a single location where the essential data elements needed to perform safety effectiveness evaluations could be located.

The current traffic safety engineers have noted that previous documentation procedures have not been efficient, and an investigations database would ensure that current and future traffic safety engineers are not visiting locations that have been previously investigated. An investigations database would make methods that evaluate multiple sites much more practical and efficient.

5.7 SDDOT Site Screening Methods

Historically, South Dakota has identified crash-prone locations by looking at all locations that experience five or more crashes within a three-year period using ArcGIS. Traffic safety engineers within the central office do a more thorough investigation of the crash types and site conditions to determine whether safety treatments might decrease crash numbers. Sites where animal or behavioral factors, such as drunk drivers, were the main cause of crashes would be eliminated. The sites are narrowed down to approximately 25 locations in each of SDDOT's four regions. Engineers from the central office and region office, law enforcement officials, city representatives, and a member of SDDOT Road Design visit the 25 locations, in addition to sites recommended by South Dakota's class 1 cities, to perform a road safety inspection. The sites with a benefit/cost ratio greater than one are selected and programmed into the STIP. This prioritization method may neglect low-volume crash sites, where fewer but more serious crashes are occurring. Also, the method does not account for Regression to the Mean (RTM) bias caused by random fluctuations in crash numbers.

SDDOT has also implemented certain systematic improvements, such as guardrail replacements and repairs statewide by region, durable pavement markings statewide by region, county signing and delineation projects, and rumble strip installations statewide by region. By 2013, SDDOT expects to have all highways covered with shoulder rumble strips that meet design standards (shoulder width and location to houses and businesses) and are selected by the region as location for installation. Other locations will have rumble strips installed as roadway construction is completed in the future. The selection of systematic improvements is based on what is allowed by FHWA and what has the greatest benefit per cost ratio.

In 2009, SDDOT initiated study SD2009-07 *Methods to Identify Needed Highway Safety Improvements in South Dakota*. The study looked at different methods of prioritizing sites based on crash history and other factors, such as data availability, the ability of the method to account for crashes in low-volume sites, and the ability of the method to account for fatal and injury crashes. Based on available data, the researchers recommended that SDDOT should use the Excess Proportion Method, which compares the ratio of one crash type to overall crash frequency for a location against the prevailing trend for areas similar to that location. The Crash Analysis Tool was developed as a deliverable to apply the excess proportion method.

In July 2011, the project panel met to develop an implementation plan based on the project recommendations. The implementation plan included 15 tasks to be completed by members from Project Development, Transportation Inventory Management, Research, and other offices. One of the main goals of the plan is to establish a two-year pilot study to test and evaluate the Excess Proportion Method. In addition, traffic safety engineers will need to evaluate the use of only injury and fatal crashes during screening versus using all crash types. The Office of Project Development has not committed to testing the CAT because other new software and methods continue to become available.

5.8 Evaluation Methods

A variety of analytical methods are available to evaluate the effectiveness of safety improvements, and the selection of a method is based on a variety of factors, such as the available data, the process used to select safety improvement projects, the accuracy desired in the analysis, the time available to perform analysis, and the quality of the sites used for analysis and comparison. The following sections describe each method examined by this study, including the calculations, advantages, disadvantages, and whether SDDOT has the resources needed to perform the method.

5.8.1 Simple Analysis

Simple before and after analysis compares crash statistics at a site before an improvement was implemented to crash statistics at the site after an improvement was made.

5.8.1.1 Calculation

There are three basic steps to perform a simple evaluation. First, traffic and crash data are collected for a site before and after a safety improvement has been made. Next, the crash frequency at the site is calculated before and after the treatment was implemented. Crash frequency for a segment is calculated as the number of crashes per million vehicle-miles traveled. For an intersection or point location, the frequency is measured in crashes per million vehicles. After the crash frequency is determined for both before and after periods, the percent in crash reduction can be calculated as the change in crash frequency in the before and after periods divided by the crash frequency before the treatment was implemented. If the crash frequency decreases, the improvement is deemed successful.

Most often crash frequency is used to determine the percent crash reduction and measure the effectiveness of treatments, but other performance measures can be used when data is limited. Some examples include comparing the total number of crashes in the before and after periods, comparing the total number of fatal crashes in the before and after periods, or measuring factors that are strongly linked to crashes, such as changes in average speed, changes in proportion of speeding vehicles, or changes in compliance with pedestrian signals.[16] If any of the defined performance measures decrease, the improvement is deemed successful.

The term decrease is not well-defined by DOTs. Some DOTs consider any reduction in the number of crashes a success, while other DOTs do not consider a treatment effective unless a specific benefit-cost ratio is reached. The measure of effectiveness for each of the states interviewed is included in Table 2 of this final report. SDDOT considers treatments with a benefit/cost ratio greater than one effective. Figure 1 illustrates the steps.

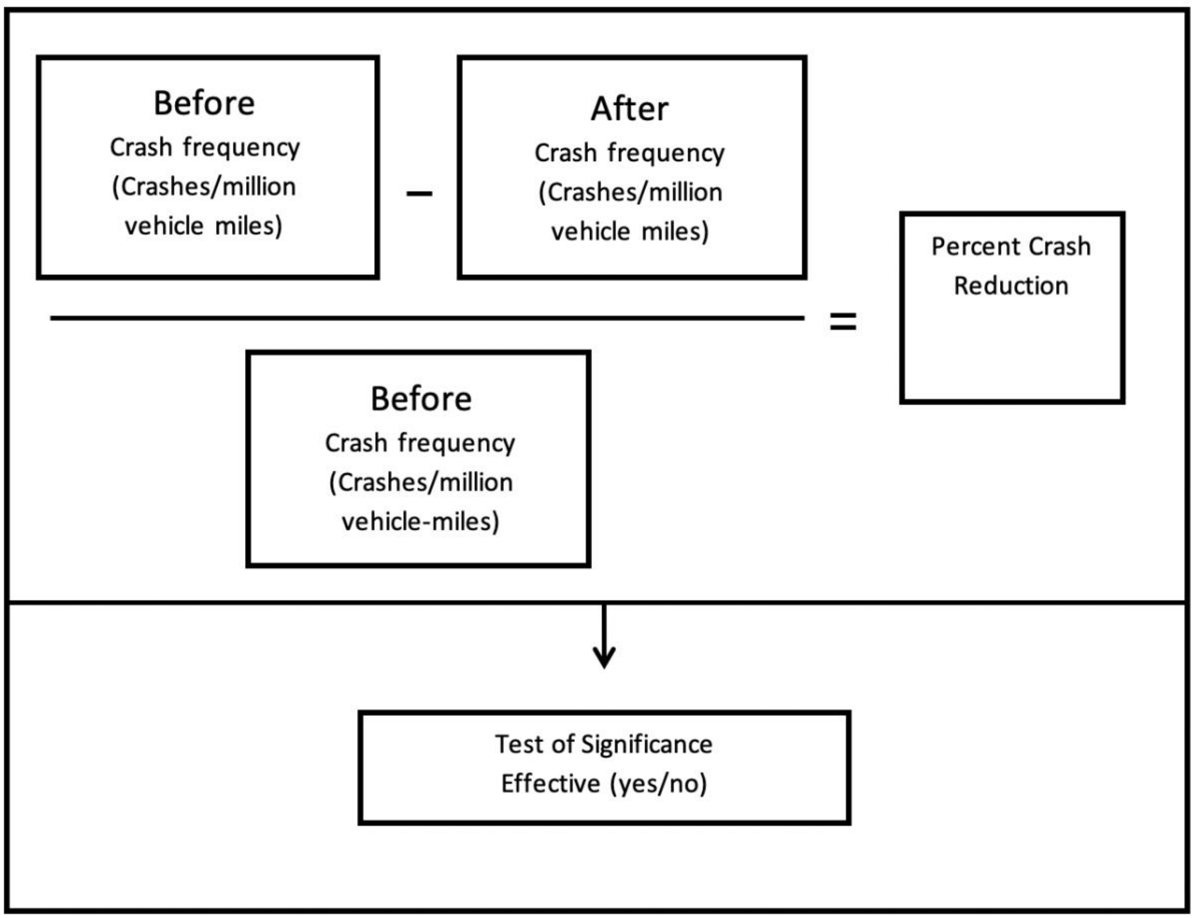

Figure 1: Simple Before and After Analysis

[16] Herbel, S., L. Laing, C. McGovern. *Highway Safety Improvement Program (HSIP) Manual.* Report No. FHWA-SA-09-029. Federal Highway Administration, Washington D.C., 2010.

A significance test can be used to determine whether RTM bias was a likely cause of higher crashes at the location. The Alaska DOT created an excel-based spreadsheet that calculates the reduction in crash rate based on the number of crashes in the before and after period. The worksheet also performs a Poisson test of significance to determine whether crashes in the before period are likely caused by RTM bias. The Poisson test of significance compares changes between the crash rate of the first and second year, second and third years, and the first and second versus the third year to determine if there was a statistically significant change in crashes at the location even though no modifications were made. If there were statistically significant fluctuations in crashes in the period before an improvement was implemented, RTM bias was likely a factor.

5.8.1.2 Advantages and Disadvantages

Simple analysis is the least analytical and least accurate of all methods. Most methods have a baseline to compare actual before and after crash numbers to expected crash numbers, but simple analysis does not. The only two options for verifying the results of a simple analysis are to use CMFs to compare the expected crash reduction to actual crash reduction and to perform a significance test. The first option is only a quantitative assessment and does not provide any information about the statistical significance of the results. The issue with the significance test is that when sites have very low crash numbers to begin with, like the majority of crash locations in South Dakota, it is difficult to tell whether results are significant. Also, the significance test only indicates whether RTM bias is likely an issue, it does not account for RTM bias. The likelihood of RTM bias can be reduced by using more years from the crash history, but it will still be present in the results.

A recent study compared the RTM affect for high-crash locations in Detroit and Grand Rapids, Michigan, using simple before and after analysis, two forms of the empirical Bayes method, and before and after analysis using a control/comparison group. The study assumed that "with the selection of proper control sites, the RTM effect can be eliminated." (4) A minimum of three years of crash data was collected at all locations before and after the treatments were implemented. At both test locations, simple before and after analysis and the empirical Bayes methods showed that there was a significant reduction in crashes at the same number of locations. The empirical Bayes methods showed a "lessor reduction in crashes compared with the other before and after methods for a majority of sites," (4) which would indicate that RTM bias is not fully addressed by simple before and after analysis, even when three full years of before and after data is used.

Also, this method does not account for increases or decreases in crash numbers due changes in traffic volume. Analysts may try to predict what the crash rate would be in future years based on the traffic and compare this number to actual crashes, but SPF models show that the relationship between traffic and crashes is not linear. The EB method or methods that use SPFs should be used if the analyst wants to account for traffic growth.

Simple analysis does not account for site-to-site variations, such as differences in geometric characteristics, which have been found to affect safety. Extraneous factors, such as changes in speed limit, should also be a consideration in safety effectiveness evaluations because they can affect site safety. Simple analysis cannot quantitatively assess the effects of extraneous factors, but a qualitative assessment can give the safety analyst a good idea of the validity of the study. Some important factors to consider include major changes to the segment or intersection beyond the safety improvement, the addition of new businesses, changes in speed limits, changes in roadway conditions caused by deterioration, changes in driver demographics, and other nearby improvements.

5.8.1.3 Applicability to SDDOT

Simple evaluations can be completed quickly and do not require extensive training. The FHWA currently accepts simple analysis as a method to evaluate HSIP program effectiveness, and thus it is widely used among state DOTs, including SDDOT. Because single locations can be evaluated, simple analysis may be the only applicable method where a unique improvement type is installed at a limited number of locations. For instance, within the 2012 – 2016 STIP, there is one project planned within five years to convert a divided highway to a 5-lane segment. Simple analysis is a practical solution for unique projects, such as the 5-lane conversion. Table 6 lists the safety projects programmed in the 2012 – 2016 STIP. There are several safety improvements that will be performed on a limited basis. Other methods can be used to evaluate single sites, but simple analysis is often most practical. The Highway Safety manual notes that the Empirical Bayes method, the comparison group method, the method of evaluating shifts in proportion of target crash types, or simple before and after analysis can be used to evaluate a single site, but simple analysis can be completed quickly and requires the least amount of effort. Some agencies felt that simple analysis is most accurate for analyzing a single improvement because there is no chance of incorrectly comparing the treatment site to other similar sites. In addition, if the geometrics of a site are unique or there is limited geometric data, simple analysis may be favorable over types of analysis that require sites to have similar characteristics. When crash data is unavailable, other data types can be assessed. For instance, average speed data may be used to evaluate the effectiveness of school zone crossing improvements.

Small improvements that have been grouped into larger STIP projects may be difficult to evaluate because larger projects can involve many design changes that would affect the safety of a site. The safety of combined changes can be assessed, but it is very difficult to separate the effects of various factors. States note that often these improvements simply cannot be evaluated.

5.8.2 Empirical Bayes Method

The Empirical Bayes method compares the number of crashes at a group of sites before a particular treatment was implemented to the number of crashes at a group of sites after a treatment was implemented. The Empirical Bayes method addresses the problem of natural variability by using a weighted average of actual observed crash frequency and the crash frequency predicted by a Safety Performance Function (SPF) at a site where an improvement has been installed. If the site is in a natural high period of crashes, the predicted number of crashes is weighted closer to the number of crashes expected in a normal period.

The HSM describes the steps used to calculate the safety effectiveness using the Empirical Bayes method and also includes several examples. The method described in the Highway Safety Manual is referred to as the Hauer method and is described in more detail in the following section.

5.8.2.1 Calculation

A Safety Performance Function (SPF) is a mathematical model used to predict the average crash frequency of a given roadway segment based on the AADT. SPFs are developed for individual segment and intersection types, using base conditions. For instance, the Colorado DOT has developed an SPF for an urban four-lane signalized intersection with four legs and an SPF for an urban four-lane unsignalized intersection with four legs. The conditions at each site, such as Annual Average Daily Traffic (AADT), terrain, number of lanes, length of roadway segment, facility type, and shoulder width may vary from the base conditions.

The predicted average crash frequency at each site must be adjusted to base conditions by multiplying crash modification factors (CMFs) by the SPF equation. For instance, if an SPF is developed using a base roadway width of 12 feet, but a particular segment is only 10 feet wide, the SPF will need to be multiplied by the CMF for a 10 foot roadway segment. The base conditions considered for roadway segments include lane width, shoulder width, shoulder type, roadside hazard rating, driveway density, grade, horizontal curvature, centerline rumble strips, presence of passing lanes, presence of lighting, and presence of automatic enforcement. The base conditions considered for intersections include intersection angle, left-turn lane, right-turn lane, and lighting. CMFs are available in the HSM and are developed using the same base conditions used to develop SPFs. The National Highway Institute offers several courses that instruct engineers on the application of CMFs.

SPFs are used to determine the predicted crash frequency in the before and after periods. Figure 2 highlights the major steps in the EB method:

One of the distinctive features of the EB method is the use of SPF models to predict crash frequency and the weighting of both predicted crash numbers and observed crash numbers to derive an expected crash frequency. The weights given to predicted and observed values are determined using an overdispersion parameter.

The overdispersion parameter quantifies how well the SPF predicts the number of crashes by determining the spread of data around the mean. The data may be extremely spread out with a lot of variation, meaning there may be other factors that have been overlooked in the analysis. The overdispersion parameter is used to determine the appropriate weight given to the SPF model. Less weight will be given to an SPF with a lot of variation.

Once predicted crash frequencies are calculated for each year in the before period and each year in the after period, an adjustment factor can be determined. The adjustment factor accounts for changes in traffic volume between the before and after periods. It is the ratio of the sum of predicted crash frequencies in the after period to the sum of the predicted crash frequencies in the before period in the absence of a treatment.

The expected crash frequency calculated for the after period is the expected crash frequency without the treatment in place. It is a product of the adjustment factor and the expected crash frequency in the before period.

An odds ratio compares the expected number of crashes in the after period without the treatment to the observed number of crashes in the after period with the treatment. The odds ratio can be calculated for each individual site or for all combined sites. An odds ratio of less than one indicates a reduction in crashes.

In the final step of determining whether a safety improvement was effective, the absolute value of the ratio of the safety effectiveness and the standard error of safety effectiveness are determined. The safety effectiveness represents the percent reduction in crash frequency, and the standard error is calculated as the square root of the variance of the odds ratio found in the previous step. The HSM concludes that a ratio of less than 1.7 determines that a treatment was not effective. A ratio greater than 1.7 determines that a treatment was effective with 90 percent confidence and a ratio greater than 2.0 determines that a treatment was effective with 95 percent confidence.

Programs such as SafetyAnalyst can help traffic safety engineers perform effectiveness evaluations, but the steps are simple enough that specialized software is not necessary. Especially with the availability of published SPFs, traffic safety engineers can easily implement this method.

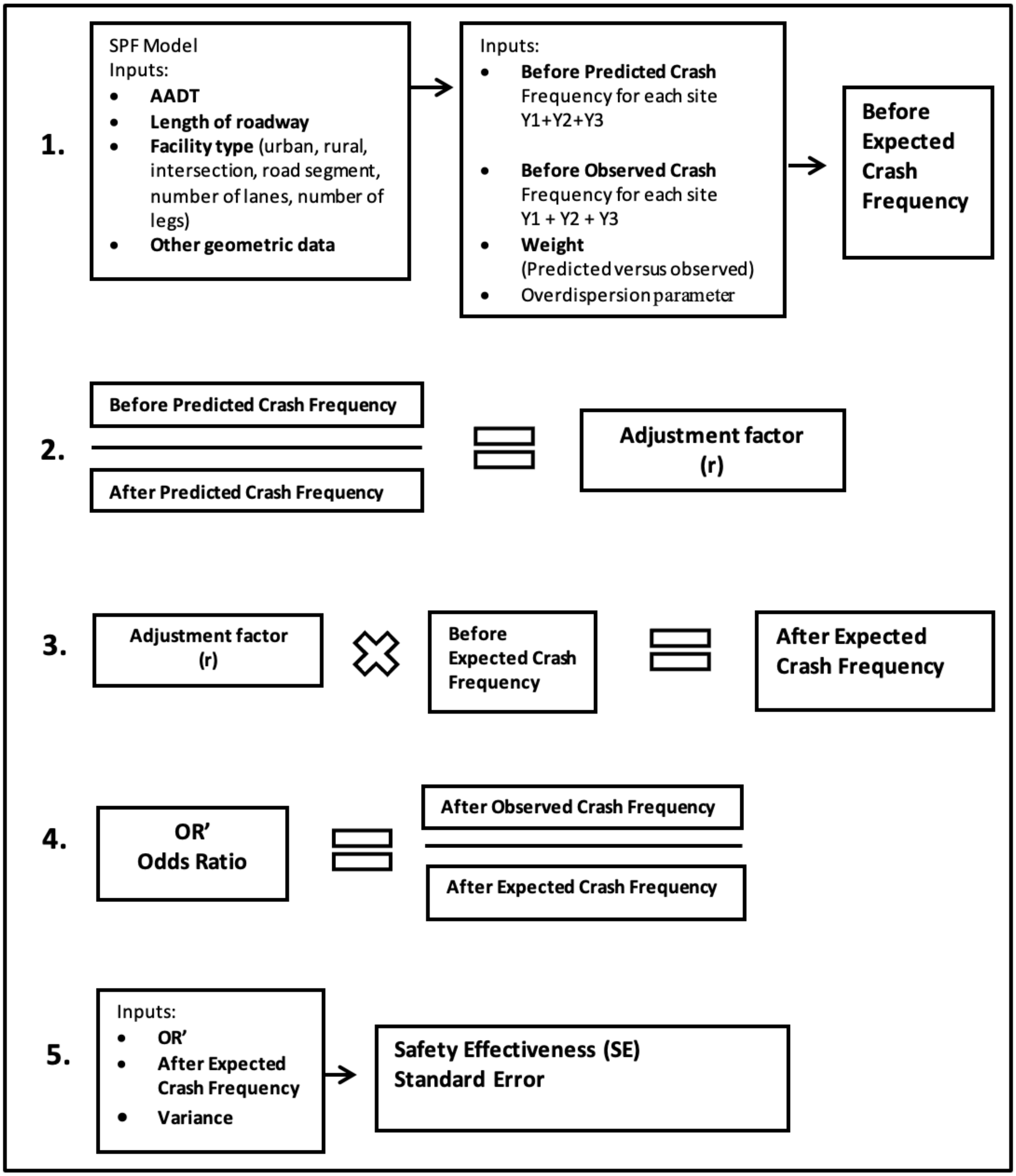

Figure 2: Empirical Bayes Analysis

5.8.2.2 Advantages and Disadvantages

Analysts like the EB method because it addresses RTM bias by using SPFs to predict the number of crashes at a site. The significance of RTM bias depends on the number of crashes. For larger samples with several hundred crashes, analysis will not be as susceptible to RTM bias. Smaller samples that exhibit fewer crashes are more problematic, and it is more difficult to determine whether decreases in crashes simply represent random fluctuation. Larger sample sizes with many crashes are typically not available in South Dakota and the EB method would be preferable.

SPFs listed in the HSM are national values, which can be calibrated to local conditions using the instructions in the appendix of the HSM. Unfortunately, SPFs may not be available for all types of facilities, so analysis may not be feasible for all types of improvements, unless SPFs are developed, found in alternative sources, or calibrated to the specific conditions for that facility type. A safety performance function is only as good as the analysis used to develop the SPF model, so attention must be given to how the SPF was developed.

The HSM also has default distribution tables that contain values that can be applied to SPFs to predict the number of total or fatal and injury crashes. Because fatal and injury crashes are currently emphasized in the surface transportation act, it may be useful to have a way to predict and compare just fatal and injury crashes. If safety engineers select countermeasures that are meant to decrease severe crash types, the default distributions should be used.

Data is the limiting factor when deciding whether to use the Empirical Bayes method. To use the EB method, the analyst will need a Safety Performance Function, Average Annual Daily Traffic (AADT) to predict the crash frequency for a roadway segment or intersection, and geometric intersection or segment data. SDDOT has most of the data elements needed to perform the EB method. Missing data elements could be estimated.

5.8.2.3 Applicability to SDDOT

Most of the historical data elements needed to implement the EB method are now being collected and maintained in the state's roadway database. Historical geometric segment and intersection data are available at SDDOT for all base conditions except driveway density and roadside hazard rating from 1999 to the present year. Driveway density could be estimated from aerial maps from 2004 to the present. Lighting data, which is currently being collected, is available historically in crash reports. Some of the base conditions, such as the type of shoulder, have a minimal effect on the site safety. SDDOT has the data necessary to perform these evaluations.

According to the 2012 – 2016 STIP, there are enough sample sites with a particular countermeasure to apply the EB method to a variety of countermeasures. The EB method requires a minimum of 10 sample sites where a particular improvement type has been installed. Some DOTs preferred a minimum of 20 sample sites. In studies conducted by other states, it did not matter whether a treatment type was implemented in the same year at the various sites or during different years, as long as there were three years of before crash and traffic data and three years of after crash and traffic data. At SDDOT, projects implemented between 2002 and 2009 should have three years of before and after data necessary to perform EB analysis.

The 2012 – 2016 Statewide Transportation Improvement Program lists all the safety projects that will take place between 2012 and 2016. The STIP does not list project specific details, such as geometric site information or specific construction activities that will take place, so it is difficult to determine if the project sites are comparable, but a majority of the project categories are performed at 15 or more locations. Table 6 lists the project types.

Table 6: Safety Project Types and Frequency

Project Category	Number of Projects
Rumble strip installations	Region wide
Guardrail replacements	Region wide
Durable pavement markings	Aberdeen, Mitchell, and Pierre Region
Cold plastics durable pavement markings	Rapid City Region
Sprayable durable pavement markings	Rapid City Region
Signing and delineation	30 or more county locations
Slope/Inslope flattening projects	10 or fewer projects
Lighting	25 or more locations
Signal replacements/upgrades	40 or more locations
Railroad crossing improvements	15 or more projects
Shoulder widening	15 or more projects
Crossbuck sign replacements	40 or more locations
Convert divided section to 3-lane	1 location
Convert divided section to 5-lane	1 location
Drainage improvements	Less than 5 locations
Correct horizontal and vertical alignment	Less than 5 locations
Permanent speed monitoring	2 locations

Many states noted that in the case where only a few sites are available, EB analysis can be performed, but the analyst needs to recognize that the results will exhibit a lower statistical significance. In the event that a single site is analyzed the statistical significance of the analysis will be diminished.

> "Any of the study designs and evaluation methods presented in Sections 9.3 and 9.4 (Empirical Bayes, comparison group method, and before and after studies to evaluate shifts in collision crash), can be applied to such an evaluation (observational before and after study). The results from the evaluation of a single site will not be very accurate and, with only one site available, the precision and statistical significance of the evaluation results cannot be assessed."[17]

The SPF models provided in the Highway Safety Manual are not calibrated to South Dakota's specific conditions. For instance, South Dakota has icy, snowy conditions during a certain timeframe throughout the year, whereas some states do not deal with these harsh winters. South Dakota also has its own driving demographic that may not match the demographic of the state or states where the SPFs were developed. Developing state-specific SPFs is most desirable, but would take a significant investment. Instead, SDDOT could calibrate the SPFs from the HSM to local conditions using the procedure outlined in the HSM.

SPFs for ten intersection types and eight segment types will need calibration. The HSM SPFs cover all facility types in South Dakota. Each facility type requires between 30 and 50 sites with like characteristics. States continue to develop new SPFs and these models should continue to improve. The development of a local calibration factor can be completed by a specialty group or contractor or by SDDOT staff. Specialty groups can include multiple contractors with a substantial background in developing SPFs. A number of Universities and private firms have been hired to assist state DOTs in developing SPFs. For calibration, careful attention to geometric conditions is important. The quality of locally developed SPFs will depend on the quality of the data, the ability of the study design to account for statistical variations, the sample size, and the ability of the researcher to account for possible sources of error.

There are conflicting viewpoints about the use of SPFs. WYDOT noticed with lower traffic volumes there is not much difference in the number of crashes predicted for different facility types, so they do

[17] American Association of State Highway Transportation Officials (AASHTO) *Highway Safety Manual, 1st Edition*, Washington, D.C. 2010.

not use SPFs to account for differences in crashes. Colorado has fully adopted the EB method and has had no issues with lower traffic volumes. The Colorado Department of Transportation has developed its own SPFs and has noted that the method has been effective at sites in which crashes are spread out over a long time, such as on rural roads. More states were satisfied with the method than not.

Among the states surveyed, the Empirical Bayes method was the second most common method used. Most states found that transitioning to the Empirical Bayes method was easier than using comparison sites or employing an analysis method that requires the development of models. The methodology is simple once the SPFs and CMFs have been developed. Many resources, including experienced peers from other states, are available to help make the transition to the EB method easier for SDDOT.

The EB method is data intensive. For it to be practical, analysts need the ability to query improvement locations by improvement type. There should be an investigations database documenting improvement types that have been installed and the information needed to perform evaluations.

5.8.3 Comparison Group Analysis

The comparison group method compares the crash frequency of a group of treated sites to a group of similar but untreated sites. An important distinction between the comparison group method and the cross-sectional method is that the comparison group method accounts for crash trends over time by comparing before and after data at both treated and untreated sites. The cross-sectional method only looks at data from treatment and comparison sites after a treatment has been implemented. The HSM provides equations to perform calculations for the comparison group method.

Comparison groups can be experimental or observational. For observational analysis, treatments have already been implemented, whereas experimental studies involve treatments that are installed specifically so they can be evaluated for their effectiveness. Experimental analysis is ideal but requires willingness by the state DOT to select random locations for safety improvements based on a specific site characteristic. It is often difficult to gain approval for the experimental method.

5.8.3.1 Calculation

The most important step in performing a comparison group analysis is ensuring that treatment and comparison sites are similar in traffic, crash, and geometric conditions. The composition and volume of traffic should be similar for treatment and comparison sites before and after treatments have been implemented. Crash trends for comparison and treatment sites should be similar prior to the implementation of treatments. Geometric conditions should be similar for treated and untreated sites and remain consistent throughout the period of analysis.

There are several ways to perform comparison group analysis. Data from treatment and non-treatment sites can be paired one-to-one or data from the entire treatment group can be combined and compared to data from the entire non-treatment group. Analysis can be performed with or without a comparability check. A comparability check is used to confirm that crash trends for comparison and treatment groups were similar prior to implementing treatments. Analysis can be performed with or without the use of SPFs.

The following discussion will refer to the method recommended by the HSM because the method defines safety effectiveness levels that indicate whether a treatment was successful, and the method requires the use of SPFs for increased reliability. The steps are outlined in Figure 3, which was taken from the HSM.

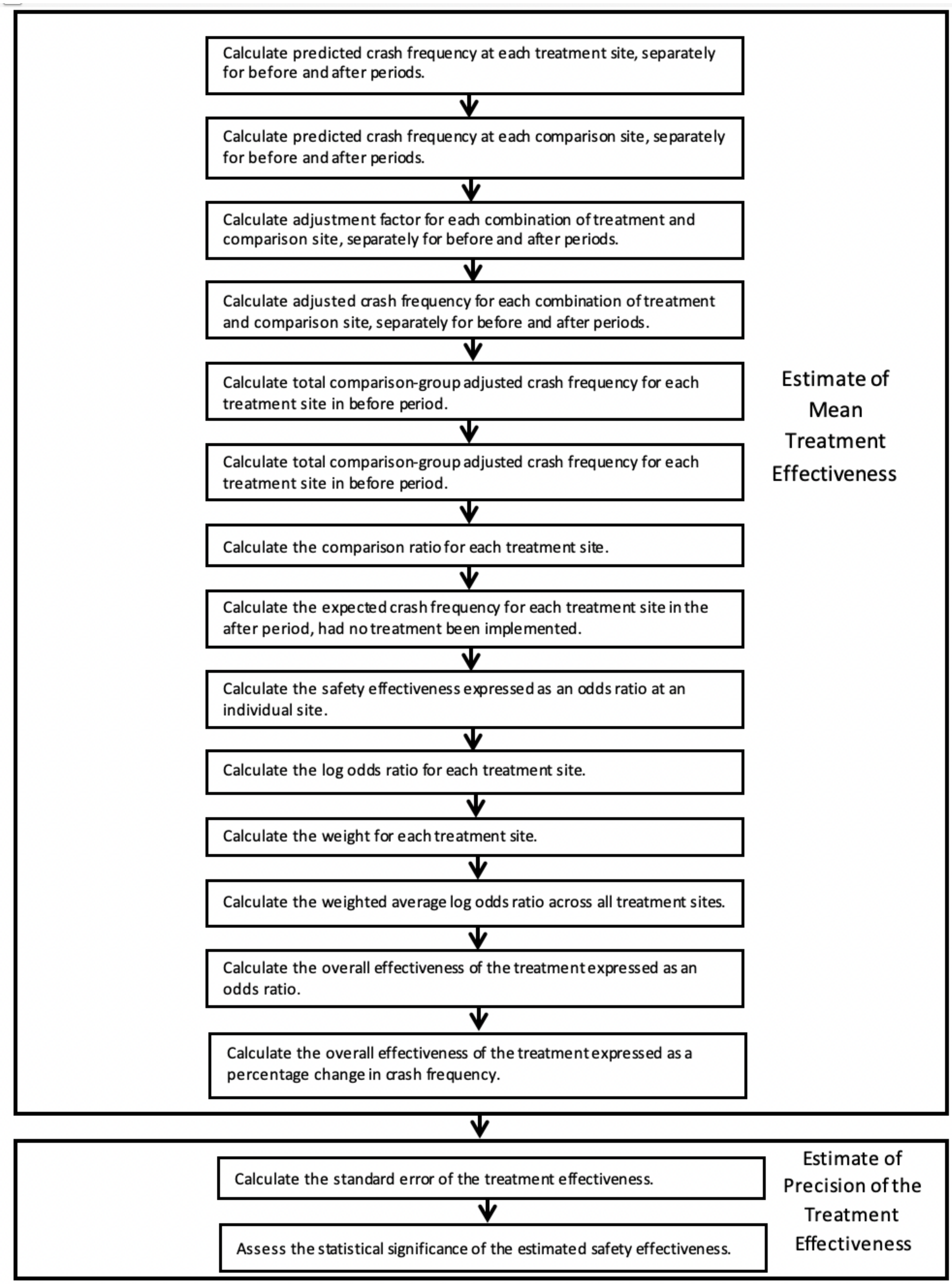

Figure 3: HSM Comparison Group Analysis

SPFs are used to adjust for differences in traffic volume between treatment and comparison sites. First, the predicted crash frequency is determined for both treatment and comparison sites before and after the implementation of treatments. The predicted crash frequency represents the number of crashes predicted without the presence of any treatments. An adjustment factor is calculated to account for the difference in crashes between the treatment and comparison sites in both the before period and the after period.

The adjustment factor calculated for the before period is multiplied by the observed number of crashes at comparison sites in the before period to determine an expected number of crashes at comparison sites in the before period. The adjustment factor calculated for the after period is multiplied by the observed number of crashes at comparison sites in the after period to determine an expected number of crashes at comparison sites in the after period.

The expected crash frequency for comparison sites is used to determine the expected number of crashes at treatment sites if no treatment had been implemented.

An odds ratio compares the expected number of crashes in the after period without the treatment to the observed number of crashes in the after period with the treatment. An odds ratio of less than one indicates a reduction in crashes.

The next steps involve calculating the log odds ratio for each site, weighting each treatment site, and calculating the weighted average log odds ratio, and calculating the safety effectiveness of the treatment. The log odds ratio is the natural log of the odds ratio calculated in the previous step. Each treatment site is given a weight as the inverse of the squared log odds ratio. The log odds ratio and weights are used to calculate an average log odds ratio for all treatment sites. Finally, the safety effectiveness is calculated as 100 multiplied by one minus the average of the log odds ratio.

In the final step of determining whether a safety improvement was effective, the absolute value of the ratio of the safety effectiveness and the standard error of safety effectiveness are determined. The safety effectiveness represents the percent reduction in crash frequency, and the standard error is calculated as the square root of the variance of the odds ratio found in the previous step. The HSM concludes that a ratio of less than 1.7 determines that a treatment was not effective. A ratio greater than 1.7 determines that a treatment was effective with 90 percent confidence and a ratio greater than 2.0 determines that a treatment was effective with 95 percent confidence.

5.8.3.2 Advantages and Disadvantages

When a large group of sites is used to evaluate the effectiveness of treatments, a higher confidence level is associated with the results as compared to methods that use fewer data. Also, the use of actual comparison groups is more beneficial than comparing a site to its own data.

Comparison groups are subject to RTM bias and effects from external factors. External factors, such as crash migration, maturation, and seasonal bias are accounted for using the same techniques used for simple analysis. When doing a one-to-one match of treatment sites, data cannot be compared for treatment sites where crash data for the after period equals zero, because one of the calculation steps involves the calculation of a log odds ratio. The log odds ratio is the natural log of the observed crashes at a treatment site in the after period divided by the expected crashes at a treatment site in the after period. The natural log of zero cannot be calculated because it does not exist, so the number of crashes in the after period cannot be zero. This limits the flexibility of this method, especially in rural areas where the number of crashes may be low or similar sites may be limited. One-to-one matching allows sites to be selected based on their similarities and can potentially improve the results of a study.

The goal of this method is to use comparison and treatment sites with similar site geometry, traffic volume, and other characteristics, but it may be difficult to determine if comparison groups are actually similar. Experience in safety effectiveness evaluations is beneficial when selecting sites that are similar.

5.8.3.3 Applicability to SDDOT

The Nebraska Department of Roads, which also has many rural roads, conducts a similar number of safety projects as South Dakota (approximately 10 to 15 projects per year) and has many rural roads, has tried comparison evaluations. NDOR found it very difficult to find control sites that are similar. As an example, they tried doing a comparison evaluation for some railroad projects a few years ago, but most of the similar locations had already been improved. In addition, there was site-to-site variation in geometric characteristics and not enough sites suitable for comparison. They tried looking at higher volume locations where lighting and gates had been installed at railroad crossings, but there were no comparison sites where lighting and gates had not been installed. SD might have similar issues. Wyoming is moving toward the comparison group method for more detailed studies.

In general, true comparison sites can be difficult to find. For example, NCDOT recently performed a roundabout study and found a great deal of variation between sites. Some roundabouts had a single lane and some had dual lanes. Some roundabouts had a large diameter and some had a small diameter. They noted issues keeping track of site differences.

SDDOT has the historical geometric feature data, ADT, and crash data necessary to perform evaluations, but may be limited in the number of suitable comparison sites available. It is difficult to conclude whether there are enough sites available for SDDOT to perform comparison group analysis because the sites must actually be examined for similarities and differences. "Also, the sites must be reviewed to determine whether the number of crashes at comparison sites is sufficiently large compared to the number of crashes at treatment sites."[18] Sites that are not suitable for the group are eliminated.

In a comparison group analysis, control variables are the variables other than the treatment that could influence the results of the experiment. The comparison group method does not attempt to control for any factors other than the treatment type, even though multiple factors are known to influence safety. For instance, CMFs can account for changes in safety due to differences in lane width, shoulder width, shoulder type, horizontal curvature, grade, driveway density, centerline rumble strips, passing lanes, two-way left turn lanes, roadside design lighting, and automated speed enforcement. Other methods can account for external variables, such as full Bayesian analysis or Empirical Bayes analysis.

5.8.4 Full Bayesian Analysis

Full Bayesian analysis uses a reference group to model expected crash numbers to compare to actual crashes observed at a location before and after an improvement has been implemented. The method is a modeling approach rather than a predetermined list of steps.

5.8.4.1 Calculation

This analysis does not have predetermined calculations; rather the analyst develops mathematical models used for analysis. Each variable that could potentially impact the safety at a site is included in the model and those that do not influence safety are left out of the model. Each variable is associated with a change in safety, typically the change in number of crashes. The EB method is a simplified version of Full Bayesian Analysis, but with EB analysis, each variable is assumed to have an exact effect on the

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[18] Shen, J. and Albert Gan. Development of Crash Reduction Factors: Methods, Problems, and Research Needs. *Transportation Research Record. No. 1840,* Washington, DC, 2003.

safety rather than considering that each variable has a distribution of likely outcomes. Full Bayesian analysis would not allow the use of SPF models or CMFs because the models assume an exact safety effect based on the traffic or geometric conditions rather than a distribution of possible values.

5.8.4.2 Advantages and Disadvantages

Full Bayesian analysis requires a considerable investment in resources and staff who can interpret the results of a study. The Iowa DOT is currently using full Bayesian analysis to conduct safety effectiveness evaluations. They currently have a two-year contract with the Iowa State University Statistics department to develop statistical methodologies for Bayesian network screening. ISU is also developing software for full Bayesian analysis. The traffic safety engineers working for Iowa DOT have a considerable background in statistical analysis. Several have doctoral degrees directly related to the application of these types of studies.

An advantage of full Bayesian analysis is that there is no need to develop or use Safety Performance Functions. Instead, all data elements that could potentially affect the safety at a site are considered during the analysis. Due to its complex nature and the flexibility of the method to consider factors that might be relevant to a specific state full Bayesian analysis is very accurate.

5.8.4.3 Applicability to SDDOT

As previously discussed, SDDOT has data elements needed to perform full Bayesian analysis, and the accuracy of South Dakota crash data relative is good relative to states that do not use computerized crash report forms. There are no data limitations other than the possible limit on the number of years of historical geometric data available, but Bayesian analysis is time-consuming and not practical for SDDOT.

At this point, SDDOT does not have the staff available to perform advanced modeling. The states that are developing models of their own have staff with advanced degrees, typically doctoral, in statistical modeling and traffic safety engineering. Some states have hired outside consultants from private firms or academe to develop procedures to perform advanced analysis, but experienced staff has the background to understand the process and apply the results at the conclusion of the research. As less demanding alternatives, such as the EB method, continue to improve, they become much more appealing.

Development of the methodology and a software package to perform analysis could take several years of research. Of the states interviewed, no respondents were aware of a statistical software package that would perform full Bayesian analysis. Most packages are geared toward the EB method.

5.8.5 Shift in Proportion Method

The shift in proportion method compares the proportion of a specified crash type in a period before an improvement was implemented to the proportion of the specified crash type in a period after an improvement was implemented. The method has several potential advantages but has not been widely used.

5.8.5.1 Calculation

Initially, two proportions are calculated, the proportion of a specific crash type to total crashes in the before period for each site and the proportion of a specific crash type to total crashes in the after period for each site. The difference between the proportions in the before and after period are calculated for each site. The average difference between proportions of crash types is determined for all sites.

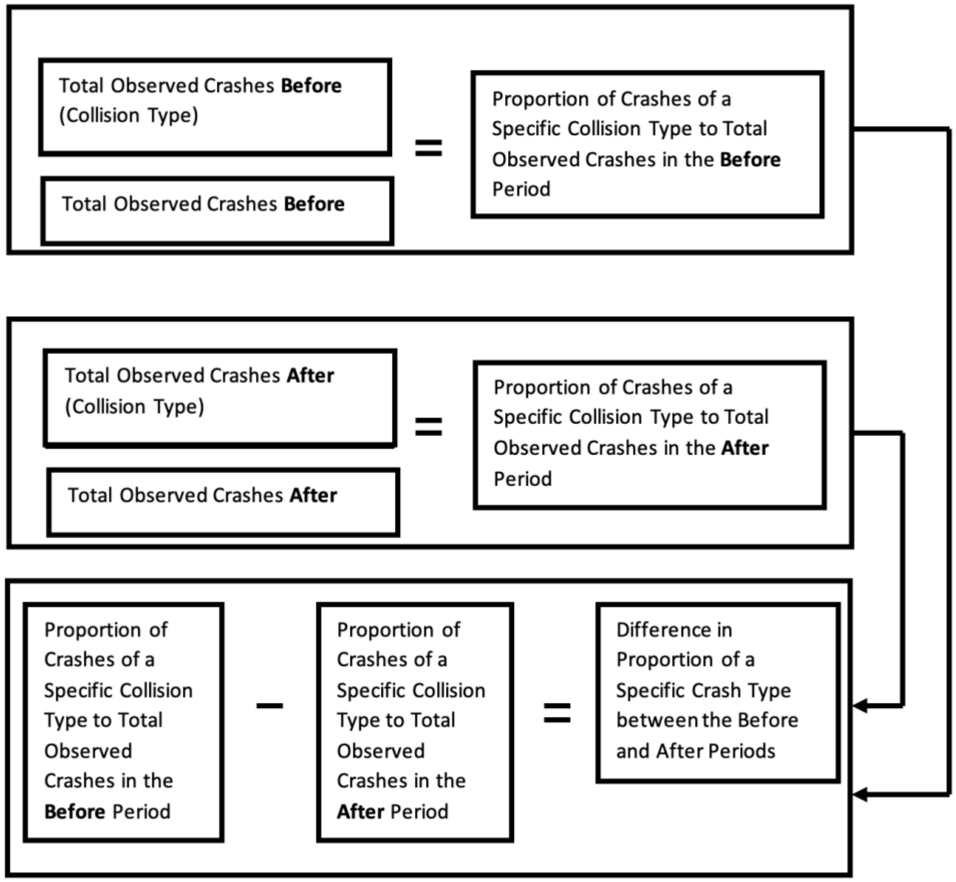

Figure 4: Proportion of Specific Crash Type Analysis

The Highway Safety Manual states that the target collision types addressed in this type of evaluation may include specific crash severity levels or crash types.

> "The Wilcoxon signed rank test is used to test whether the average difference in proportions calculated in the previous step is significantly different from zero at a predefined confidence level" (2). The highway Safety Manual provides steps to determine the significance of the results.

Careful attention should be given to the types of crashes analyzed when looking at particular countermeasures. For example, when looking at signalization at intersections, angle collisions and rear end collisions could be affected, so it would be better to look at the shift in proportion of the overall crash severity, rather than of one type of collision. When looking at one particular crash type, benefits or negative impacts of a countermeasure could be ignored; overall crash severity should be looked at in questionable situations.

5.8.5.2 Advantages and Disadvantages

In theory, the shift in proportion method has several advantages, but it has not been used much in practice and there may be some unknown disadvantages to the method. Of the states surveyed, none had implemented the shift in proportion frequency method, and staff of FHWA were unable to find any examples of application of the method. The shift in proportion method is not data intensive. The shift in proportion method looks strictly at numbers of crashes and does not require traffic volume data. For locations that do not have volume data this method could be very useful. Also, the observed number of crashes in the after period can be equal to zero if the change in proportion of crashes is not equal to zero.

While RTM bias is still an issue, this method looks at proportions of specific crashes or crash severities, rather than the number of total crashes before and after a safety improvement was implemented, thus reducing the likelihood that the crashes accounted for in the analysis were solely due to a natural high period.

An advantage to this method over simple analysis is that it eliminates other variables that could cause an increase or decrease in crashes by focusing on one particular crash type. Another advantage to this method is that it focuses on how abnormal the crash situation is for a particular location. For example, if there are seven overturning crashes out a total of 12 crashes within a three year period before any improvements have been implemented, the situation could be called abnormal. A major decrease in the percent of overturning crashes in the period after a safety improvement has been implemented further supports the idea that there was a specific issue causing a specific safety concern.

Another advantage to the method is that it can assess whether a specific goal was met, rather than looking at overall crash numbers. For example, if the initial goal of a safety project was to decrease angle collisions by adding signalization to an intersection, at least one of the performance measures must gauge the shift in severity of crashes. While signalization often decreases angle collisions, rear-end collisions often increase, resulting in no net change in the number of crashes. For this example, simply looking at the number of total crashes is not useful for evaluating safety effectiveness because the benefit of signalization comes from a decrease in the severity of crashes and injuries. For other types of improvements, it may be sufficient to look at the number of crashes before and after installation.

This method may produce misleading results if the analyst does not pay careful attention to how the shift in proportion was achieved or use enough data for analysis. In the table below, at sites 1, 4, and 5, a random fluctuation in the total number of crashes caused the proportion of FI crashes in the after period to decrease, even though the number of fatal and injury crashes remained constant. At sites 2 and 3, the number of fatal and injury crashes decreased, even though the proportion of fatal and injury crashes in the after period was higher than the before period. Table 7 illustrates some examples of situations where the proportion of a crash type may not properly reflect actual conditions. This method could be used to assess the effectiveness of safety improvements, especially fatal and injury crash types, but the results would need to be scrutinized to ensure that random fluctuations are not skewing the results. Because this method is not very popular, it is difficult to determine what other issues arise when implementing this method, but at sites with smaller crash numbers, like a majority of the locations in South Dakota, small changes could have a big impact on the results of analysis.

Table 7: Sample Proportions of Fatal & Injury Crashes Before and After a Treatment

State	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6
Total Crashes Before	1	20	6	2	4	5
Total Fatal & Injury Crashes Before	1	10	3	2	2	2
Proportion of FI Crashes Before	1.0	0.5	0.5	1.0	0.5	0.4
Total Crashes After	2	7	3	4	6	4
Total FI Crashes After	1	5	2	2	2	1
Proportion of FI Crashes After	0.5	0.7	0.67	0.5	0.33	0.25

5.8.5.3 Is it Practical?

None of the survey respondents have used the shift in proportion method, and staff of FHWA could not identify states that do. Available literature suggests that this method is not affected by RTM bias, but there could be issues with low traffic locations that do not experience the high crash numbers. The method is very simple, and could easily be tested in conjunction with other more proven methods, such as the EB method and simple analysis.

5.8.6 The Cross-sectional Method

Cross-sectional studies use modeling techniques to compare sites with and without a particular treatment. The cross-sectional study is unique in that the analyst does not look at crash data during the period before the treatment type was implemented. Due to potential differences in site characteristics, it may be difficult to determine whether the treatment or differences in site characteristics were the cause of fewer crashes without actually comparing the number of crashes at sites before and after a treatment was implemented. This study is generally used when historical crash data are limited, but SDDOT does not have issues with missing data. Due to its inconclusive nature, this study is not appropriate for SDDOT because other methods are available.

5.8.6.1 Calculation

The cross-sectional study compares treated and untreated sites using data after treatments have been installed. "The cross-sectional study focuses on the difference in safety between locations rather than changes in safety over time."[19] This means that no before data is collected at sites. The analysis involves developing a model to compare the difference in change of crash frequencies for treatment and non-treatment sites. The Highway Safety Manual does not provide a step-by-step method of calculation for the cross-sectional method because it requires the development of mathematical models rather than a simple series of calculations. The Highway Safety Manual suggests that the generalized linear model is most commonly used to model yearly crash frequencies.

5.8.6.2 Advantages and Disadvantages

The main advantage to cross-sectional studies is that there are fewer data requirements. Before data are not required for treated and untreated sites, making this type of analysis particularly useful when "there are insufficient instances where a countermeasure is actually applied. For example, there may be few or no projects where the shoulder is widened from four feet to six feet, yet there are many road segments with a shoulder width of four feet and many with a shoulder width of six feet. In this case, crash data could be collected for the two groups of segments for use in a cross-sectional design, but a before and after design would be less feasible because there are too few actual projects that widen the shoulder from four feet to six feet."[20] When treatment installation dates are unavailable or no crash and traffic volume data are available for sites before a treatment was installed, the cross-sectional method may be used.

The main disadvantage of the cross-sectional study is that it assumes that any difference in crash frequency between treated and untreated sites is due to the treatment. This method does not look at changes in crash frequency over time, making it particularly susceptible to RTM bias. External factors are also difficult to address because site conditions may be unknown.

Step by step calculations are not available because this method requires the development of models which can be time-consuming. Also, due to the modeling required to complete the cross-sectional study, more than one treatment and non-treatment site must be available for analysis.

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[19] Shen. J. and Albert Gan. *Development of Crash Modification Factors: Methods, Problems, and Research Needs.* Transportation Research Record No. 1840, Washington, D.C., 2003.

[20] Gross, F., B. Persaud, and C. Lyon. *A Guide to Developing Quality Crash Modification Factors.* Report No. FHWA-SA-10-032, Federal Highway Administration, Washington D.C., 2010.

5.8.6.3 Applicability to SDDOT

Modeling methods are not practical at SDDOT. SDDOT does not have the staff available to perform advanced modeling and complete the workload requirements for the safety program. The states that are currently developing models of their own, including developing SPFs for the EB method, have staff with advanced degrees, typically doctoral, in statistical modeling and traffic safety engineering. Some states have hired outside consultants from private firms or academe to develop procedures to perform advanced analysis, but experienced staff has the background to understand the process and apply the results at the conclusion of the research.

6 RECOMMENDATIONS

6.1 Empirical Bayes Analysis for Multiple Site Evaluations

SDDOT should use the EB method to analyze the effectiveness of safety improvements where an improvement has been installed at 10 or more locations.

SDDOT currently uses simple analysis to evaluate safety improvements but should instead use the EB method when there is sufficient data. SDDOT has all the data and resources needed to implement the EB method, but in some instances there are not enough sample sites where a particular treatment has been installed to use EB analysis. Available literature agrees that there should be a minimum of 10 sample sites with a particular treatment for EB analysis to be accurate. Many treatment types are commonly used throughout the state to increase safety, such as lighting, ADA improvements, signing, and delineation projects. There should be sufficient sample sites to perform EB analysis on a variety of countermeasures used by the SDDOT. While historical data may be initially difficult to find, with the creation of an investigations database and some data improvements, all the needed data should be readily available for use. Traffic Safety engineers will need to determine which improvement types have been installed at 10 or more locations within the last five or more years, gather and group crash data, geometric data, and traffic data by improvement type, and use the procedures outlined in the HSM to analyze the effectiveness of implemented improvements.

Empirical Bayes analysis is more statistically sound than simple analysis, applies to South Dakota's low traffic locations, and can be verified by using other methods. It is common for highway agencies to perform a simple analysis parallel to EB analysis to be used as a reference. Simple analysis will typically show slightly higher reductions in crash rates, but the results should be similar. SDDOT should use simple analysis to validate the results of EB analysis.

6.2 Simple Analysis for Single Site Evaluations

SDDOT should use simple analysis to evaluate the effectiveness of improvements in situations where there are limited improvements of a particular type or there are unique site conditions.

Simple analysis is the quickest and easiest method available. When there is only one site that exhibits a particular treatment, the statistical significance cannot be determined, so it makes sense to use the simplest method. Also, when a particular site has unique features, such as added safety mechanisms that are not accounted for by available CMFs and SPFs, simple analysis is practical. The Safety Edge is an example of a fairly new safety feature that has been installed in limited locations in South Dakota. This safety feature currently has no CMF, but FHWA is in the process of conducting a study to determine a CMF value for the Safety Edge. At these sites simple analysis would be most practical.

6.3 Apply EB Method in Conjunction with other methods to Assess Performance of Crash Analysis Tool or Other Non-Traditional Site Screening Methods

SDDOT should use the EB method to assess the effectiveness of the excess proportion screening method applied using the Crash Analysis Tool during the two-year pilot period or other non-traditional site screening methods implemented at SDDOT.

The implementation plan for study SD2009-07 proposed the use of a new GIS-based network screening tool developed for SDDOT. Staff of SDDOT are in the process of deciding whether to use the tool or other site screening options, but they do plan on modifying the current black spot approach to screening sites for potential safety improvements. The EB method is statistically sound and should be used to evaluate the new Crash Analysis Tool or any non-traditional site screening methods used.

The Crash Analysis Tool (CAT) uses the excess proportion screening method to determine which sites exhibit an excess proportion of a specific crash type and can be used to find locations with a high proportion of fatal and injury crashes. If fatal and injury crashes are the focus of screening, as recommended in the new surface transportation act, the evaluation method should be able to determine whether site screening methods were successful in reducing serious injuries and fatalities. Both the shift in proportion method and EB method can be used to determine whether site screening methods reduced serious injuries and fatalities. The HSM contains default distributions that can be applied to SPFs to predict how many fatal and injury crashes will occur at a site. The predicted fatal and injury crashes can be applied in the EB method. The shift in proportion of specific crash type method of evaluation is similar to the proposed site screening method in that focus can be placed on the proportion of serious injury and fatal crashes and is simple enough that it can be used in conjunction with the EB method to assess the effectiveness of the CAT.

To apply the EB method, there should be a minimum of 10 sample sites with an improvement type. The CAT may or may not select locations that require similar treatments, so it may take several years of using the tool before the data can be analyzed for effectiveness.

6.4 Investigations Database

SDDOT should develop and maintain a site-by-site database that records the type of safety improvements installed at a location, identifies all locations where safety improvements have been implemented including systematic improvement types, the year of installation, geometric site characteristics, and before and after crash data.

This recommendation was contained in the final report for SD2009-07 *Methods to Identify Needed Highway Safety Improvements for SDDOT* but was not adopted in the implementation plan. The traffic safety engineers in the central office felt that an investigations database would be very helpful in performing future evaluations, but it was not needed for use in the network screening methods recommended by the project.

To perform analysis types that need multiple sample sites with a particular improvement, a central database is a necessity. There is a layer in the central GIS database maintained by SDDOT called "accomplishments" that was updated in November of 2012. This layer can be used to search for locations where specific project types or improvements were implemented, such as ADA improvements or lane and shoulder widening.

The accomplishments layer will be helpful in performing effectiveness evaluations on particular treatments, but there are some limitations. The data includes the project location, project and improvement description, and contract award date, but does not include any geometric or crash data. GIS layers can be combined, so geometric segment data and crash data should be merged with the accomplishments layer in the future. Second, region wide and county wide improvements, such as signing, delineation, or painting are not included in the layer because regions do not keep track of improvement locations. Third,no documentation of site visits is available in the layer.

A separate investigations database should be created to bring all information needed for safety effectiveness evaluations to one location, include site visit documentation, and keep track of improvement types that are not documented in the accomplishments layer. Essential data include the location and description of completed safety improvements, geometric segment or intersection data before and after the improvement was implemented, a minimum of three years before and after crash data, and historical traffic information. Information, such as site visit notes and notes regarding any major site changes should also be included. The database should be searchable by improvement type or project type. Safety engineers would need to record the locations of site visits, notes from site visits including the geometric conditions prior to any improvements being implemented, and provide the data to GIS professionals form TIM. Safety engineers should also identify locations where improvements have been implemented using HSIP funding and provide the data to TIM. If locational data were provided for region wide improvements, that data could also be included. The GIS specialists could merge existing crash data and geometric site data into the investigations database. The database would provide a single location where the essential data elements needed to perform safety effectiveness evaluations could be located. For evaluation methods to be practical, the ability to find information about completed safety projects and sort safety projects by category is needed.

6.5 Report Locations of Region Wide Improvements

SDDOT should report the location of region wide improvements and data should be stored in a new investigations database.

The location of region wide improvements should be reported annually to traffic safety engineers and entered into either a new investigations database or the existing accomplishments database. Each region office is given funding annually for certain region wide improvements, such as bridge painting, pavement markings, rumble strips, and signing projects, but the location of improvements is not reported. The MRM displacement, improvement type, and date of improvement for region wide improvements should be recorded by region engineers and the data sent to the traffic and safety engineers. This information could be recorded by crew members as work is being performed and entered into a file format that is acceptable to the traffic safety engineers and GIS specialists of SDDOT.

Without locational data, the effectiveness of region wide improvements cannot be evaluated and old and new construction methods cannot be compared. For example, SDDOT only uses rectangular shoulder rumble strips, but in the future SDDOT may consider using football shaped rumble strips. If region wide improvements were documented, safety engineers would have the data needed to compare the effectiveness of both rumble strip types and determine which type to use in the future. Even simple design elements such as the rumble strip or pavement markings can improve over time, and SDDOT should maintain data so those elements can be evaluated against alternatives in the future.

6.6 Calibrate Safety Performance Functions

SDDOT should use the method outlined in the HSM to calibrate Safety Performance Functions to Local Conditions.

Safety Performance Functions are used to predict the number of crashes at a site based on the average annual daily traffic for that site. The number of crashes is affected by geometric site conditions, driver behavior, animal behavior, and weather conditions. National CMF values are available to adjust for geometric changes, such as the widening of a road, but there is no way to adjust SPFs based on the other factors, except to calibrate them to local data. SDDOT should calibrate the SPFs from the HSM to local conditions using the procedure outlined in the HSM.

Calibration of SPFs will involve a considerable amount of data collection and analysis and should be accomplished as a contract research project. The first step in calibration involves collecting geometric and crash data from sample sites. Most of the required data elements are available in RIS and in the DPS crash database. There are 10 intersection types and eight segment types for which HSM SPFs are available and will need calibration. For each segment type, data from approximately 100 0.1 mile segments is needed, and for each intersection type, data from approximately 100 intersection locations is needed. The HSM recommends between 30 and 50 sites for calibration, but South Dakota has many low crash locations and will likely require 100 sample sites per calibration. The second step involves calculating the expected number of crashes at each site using SPFs and CMFs for the most recent year in which crash data is available. The expected number of crashes and actual number of crashes from the most recent year are used to determine the calibration factor.

6.7 Formal GIS Training for Traffic Safety Engineers

The traffic safety engineers in Project Development and other offices should have access to basic and advanced GIS training and GIS training specific to SDDOT's GIS crash database.

To perform safety effectiveness evaluations, traffic safety engineers must be able to navigate the GIS database to find the required data elements, such as the type of improvement, the number of crashes in the before and after period, and the site characteristics. The SDDOT GIS database is structured so that engineers can find some of the information quickly, but some changes will need to be made to the database to make other data elements readily available. If safety engineers have knowledge of the capabilities of GIS software, they will be prepared to either make the needed changes or recommend what changes should be made.

One example of an essential GIS layer file that was developed was the ability to find the top 5 locations exhibiting the most need for safety improvements, for the 5 percent report. Until Congress passed SAFETEA-LU, there was no need for engineers to find the top 5 percent of sites in South Dakota and without additions to the GIS database, engineers would have had to manually look through each crash location in the state and determine the number of crashes at each site. The layer file allows safety engineers to quickly find relevant crash data within the state's GIS database.

In addition, when there are staffing changes, it would be helpful to have SDDOT-specific GIS training that frames the uses of crash data and shows how each of those elements can be located in the database. For safety effectiveness evaluations, some important data needs include locating sites where safety improvements have been implemented, locating sites where a specific improvement has been implemented (a function that is not yet available), determining crash numbers at sites, determining roadway characteristics at sites, and determining site features and other notes from investigative reports (a function that is not yet available). Knowledge of GIS software will help safety engineers in the transition to a new safety effectiveness evaluation method and a new screening method and adapt to any other changes in the traffic safety field, such as new federal reporting requirements.

6.8 Ensure End-of-Year Features File Contain All Needed Geometric Data Elements

SDDOT should create an end-of-year feature file with all the geometric segment and intersection data elements necessary to perform safety effectiveness evaluations.

The Model Inventory of Roadway Elements (MIRE) Version 1.0 recommends that states track the date of change for each MIRE element in the geometric data file or track the posting date.[21] Currently the SDDOT RIS file records the date that elements were last updated, but that date does not always correspond to the date a particular roadway feature changed. The RIS file was recently updated and all dates associated with data elements reflect the update, rather than the last date an actual change was made to the data. Feature files that contain geometric data elements from RIS are currently archived on the SDDOT shared drive each year from 2005 to the present in pdf files, but some of the data elements needed for safety effectiveness evaluations are not contained in the feature files. Missing data elements include horizontal and vertical alignment, grade, and lighting. Major changes would be required in the RIS database to record the date and type of each change that occurs in the state network. If possible, it would be ideal to record the date of change, instead of the date of last update for data elements in RIS,

[21] Lefler, N. et al. *Model Inventory Roadway Elements* Report No. FHWA-SA-10-018, Federal Highway Administration. Washington D.C., October 2010.

and ensure that all of the data elements used in safety effectiveness evaluations are contained in the feature files. Traffic safety engineers could determine what the roadway geometric conditions were at each site prior to any changes using the feature files, and they would know what year to look for changes.

6.9 Update the GIS Roadway Database Used by the Department of Public Safety

SDDOT should update the GIS Roadway Database used by the Department of Public Safety to store crash data.

The GIS database used by the Department of Public Safety should be updated to ensure accurate data is available for use in safety effectiveness evaluations. The GIS roadway database used by the Department of Public Safety to store crash data has not been updated since 2007. If any changes have occurred since 2007, such as changes in the naming of a particular road segment, the data will not be accurate, or the location of reported crashes will not be accurately referenced.

7 Research Benefits

The benefits of implementing the recommendations include increased efficiency and awareness among the traffic safety engineers. Improvements in how data is maintained will help traffic safety engineers to quickly perform before and after analysis, as well as quickly find data for other safety applications such as site screening and data reporting. Improving the method used to perform safety effectiveness evaluations will help traffic safety engineers determine if their current decision process for identifying locations in need of safety improvements is correct or if they need to make changes in the selection of safety projects. Using the proposed methods, the EB method and simple analysis, traffic safety engineers may determine whether fatal and injury crashes, which are a focus of the current surface transportation act, are decreasing because of implemented improvements. Traffic safety engineers should be using the most rigorous techniques available so that they may better understand what effect their decisions have on the safety of South Dakota's roads.

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APPENDIX A: SDDOT TRAFFIC SAFETY ENGINEERS SURVEY

The following questions need to be addressed by SDDOT safety engineers in order to determine which safety effectiveness evaluation methods will best fit SDDOT:

Selection of Safety Improvements

1. Research study SD2009-07 *Methods to Identify Needed Highway Safety Improvements* cites four ways that safety improvements are implemented at SDDOT:
   - "The Roadway Safety Improvement (RSI) program is currently funded at $10.5 million annually, which supports 10-15 projects annually with a 10% local match. According to the SHSP, an onsite inspection of a location is where there is a crash rate of at least 2.0 per million vehicle miles, crash patterns, and a preliminary benefit/cost ratio of at least 1.0. The outcome of the onsite inspection may be a specific recommendation for a project in the Statewide Transportation Improvement Program (STIP).
   - The Railroad Crossing Improvement (RCI) program is currently funded at about $2.0 million annually, which supports 14-20 projects with a 10% local match (the match may be waived in situations where crossings are closed or consolidated). According to the SHSP, project needs are generated from road authority and railroad requests, upcoming road construction projects, crash history, and crossings rated high by an index rating formula (this formula was not provided in the SHSP).
   - Through the federal section 164 program, SDDOT provides $5 million annually to local jurisdictions for improving signs and provides staff support as requested and possible to counties that lack traffic or safety engineering staff.
   - SDDOT evaluates safety issues when designing rehabilitation and reconstruction projects and incorporates safety improvements into those projects when needed. The improvements are not generally eligible for safety funding."

Which of these are you involved in? What is your level of involvement? Are there any additional ways that safety improvements are implemented through your office or at SDDOT?

There are two traffic safety engineering positions in the central office and two region traffic safety engineering positions. The central office positions are responsible for funding and administrative activities and the initial screening of sites statewide.

The RSI program involves screening all sites with five or more crashes, looking for behavioral or other influences, and narrowing down the list of sites to approximately 25 sites that exhibit the most potential for improvement. All SDDOT traffic safety engineers, a road design engineer, county or city representatives, and law officials participate in site inspections to determine what improvements will be made. Traffic safety engineers at SDDOT also e-mail all Class 1 cities to determine if there are any other sites that should be inspected.

SDDOT traffic safety engineers also administer funds to approximately three counties per year for the county-wide signing improvement program. Approximately $2.5 million dollars are administered to counties annually.

SDDOT traffic safety engineers also participate in safety inspections with road design engineers where there are safety concerns and review road design plans for potential safety improvements.

2. Are there any "preferred safety countermeasures?" or systematic safety improvements being implemented (e.g. rumblestrips)?

SDDOT is implementing rumble strips on all sites statewide. Guardrails, pavement markings, and signing are replaced yearly. Susan Dutton is currently working on a signing inventory, and all signs will be replaced according to the date of installation. By next year, the whole state should be covered with rumble strips, we will basically need to maintain rumble strips, painting and signing after that. Chevrons and delineation are implemented system wide on the county level.

3. If so, do you keep a record of when, where, and what type of improvement was implemented? Do you also keep track of site characteristics?

   There is no central database for keeping track of safety improvements. It would be time consuming to actually determine what improvements were installed in a particular year. Old projects can be viewed in C2C or Construction Measurement and Payment. The safety project number of all safety projects begins with a PH prefix.

4. What is the rationale for determining which measures are preferred (i.e. cheap, based on findings from studies, recommended by FHWA, etc.?)

   The type of improvements selected depend on what FHWA approves and what is most cost effective, (benefit/cost ratio).

5. Are there any guidelines or documents that you follow when deciding which safety measures to implement?

   The MUTCD and HSM are the two main safety documents used. SDDOT has policies, such as implemented rumble strips on any project with shoulders over four feet, but the policies are currently in review.

6. The 2007 Strategic Highway Safety Plan (SHSP) lists several emphasis areas, one of which is reducing run-off-the-road and head-on collisions. Do systematic and "preferred" safety countermeasures emphasize reducing these collision types?

   Preferred measures are more focused on run-off-the-road crashes.

7. One of the strategies developed in the 2007 SHSP involves evaluating countermeasures to be used as routine accommodations for projects in the STIP. The countermeasures are contained in the following list:

   - "Continue reviewing current shoulder rumble strip policy and develop recommendations on policy modification with consideration for all modes of transportation.
   - Continue reviewing pavement marking and signage placement policy and quality of materials.
   - Continue removing, relocating or shielding roadside fixed objects.
   - Continue reviewing guardrail placement procedures and materials.
   - Continue improving shoulders and their maintenance to moderate edge drop-off.
   - Consider implementing Intelligent Transportation System features.
   - Consider installation of longitudinal and median barriers at locations of left-side roadway departures.
   - Continue improving public information and access to weather and road condition reports.
   - Continue slope and ditch flattening and traversable culvert end treatments.
   - Continue reviewing super-elevation of curves and consider corrective actions including reduced speed limits.
   - Continue to improve skid resistance of pavements.
   - Initiate RSA training for all project facets, including design, construction and maintenance.
   - Continued emphasis on use of safety restraint systems.
   - Continue using RSI and RSA procedures to evaluate and implement countermeasures."

   When you perform policy reviews and evaluate current procedures for installing particular improvements, do you use the results of before and after studies local or national?

We mainly use CMF values to determine which measures make more sense according to a benefit/cost analysis. Traffic safety engineers are involved in all activities from the previous list, except for road weather information. Also, skid resistance for South Dakota would refer to chip seals, not other forms of skid resistance.

Site Visits and Documentation

1. How many site visits are conducted annually for HSIP projects, road design projects, other?

   Traffic safety engineers participate in approximately 25 RSI inspections, plus any RSA requests from local entities.

2. Are site evaluations documented and saved?

   We do not have a particular report form. We document site conditions that are significant to safety.

Improvements and documentation

1. Do you document the date that an improvement was installed? If so, how long do you keep a record of installation dates? Do you record any other data elements when you install a safety improvement, such as site conditions?

   There is no improvement database.

2. If so, what improvements (HSIP) have been installed over the last year, last 5 years, and last 10 years?

   n/a

3. Is there a record of non-HSIP projects that have been installed?

   n/a

4. At the sites where safety improvements have been installed, is there typically only one improvement installed at each site, two improvements, or multiple improvements?

Comfort level with analysis and available time

1. Are there documented standard procedures for performing safety improvement evaluations and network screening, such as an HSIP manual? If so, is the manual updated annually?

   There is no official manual, but due to recent changes in staffing, we have recently documented job duties and procedures.

2. Does your office have an Excel spreadsheet available to perform simple before and after evaluations?

   No.

3. What is your experience with traffic safety engineering?

   There is a variety of experience.

4. What is your comfort level with statistical analysis? (i.e. Not comfortable at all, could perform a study with some assistance, or do not like statistics)

   Minimal training in the class and no need for recent application.

5. Are you familiar with the Empirical Bayes method or Bayesian analysis?

   No.

6. How would you characterize the activities in your office and what amounts of time do allocate to various activities (e.g. three months for field visits, one month for safety effectiveness evaluations, etc.?)

   We spend 2 – 3 months on field visits, 1 month programming.

APPENDIX B: SOUTH DAKOTA DEPARTMENT OF PUBLIC SAFETY SURVEY

Date: 08/20/12

Attendees: Chuck Fergen, Jenny Serbousek, and Megan Steever

The following questions were addressed by a member of the South Dakota Department of Public Safety in order to determine which safety effectiveness evaluation methods will best fit SDDOT:

Crash Data Availability

The researchers for study SD2009-07 *Methods to Identify Needed Highway Safety Improvements* determined the data elements needed to perform network screening of crash locations. Table 1 lists those data elements in gray. Please review the tables and answer the following questions.

Table B- 1: Crash Data Elements

Data Need	Department of Public Safety Data Available	If not, can data be derived?	Please note any recent changes in data collection procedures.
Intersection/Segment Location	Yes		
Fatal	Yes		
Injury	Yes		
PDO	Yes		
Rear End	Yes		
Sideswipe (Overtaking/opposite direction)	Yes		
Angle (Intersection/ no intersection)	Yes		
Angle (Left/right)	Yes		
Pedestrian	Yes		
Bike	Yes		
Motorcycle	Yes		
Head-on	Yes		
Fixed Object (On road/ off road)	Yes		
Parked Vehicle	Yes		
Construction	Yes		
Animal Collision	Yes		
Deer	Yes		
Roll-over (On road/ off road)	Yes		

1. Is the crash data in the Department of Public Safety database MMUCC compliant?

   Yes………we are compliant either 86 of the 107(80.4%) or 101 of the 107 (94.4%) MMUCC, depending on how the standards are interpreted. Any crash data element not available can be derived. SDDOT personnel can access anything in the crash database.

2. Are all of the crash data elements listed in the table available?

   Yes. The only data item not available to the public is the DL or SSN as some of the old military are still not renewed yet.

3. Would you say that unreported collisions occur more on the county level or the state system?

   Can't say…..probably one of our biggest data concerns are reservation areas, both urban and rural.

4. Can you estimate the frequency of crashes that go unreported due to crash reports that are not submitted to the Department of Public Safety by counties or townships?

   No

5. Can you estimate the frequency of crashes that go unreported because the driver failed to report the collision?

   No. We do hear a lot of instances where people did not know that they have to report animal hits. If there is $1000 to a person's property or an injury or death, the crash must be reported. We do not anticipate any legislative changes regarding the reporting limits.

6. Can you estimate which crash types are unreported most often?

   No

7. Are there instances when crashes are improperly coded?

   Yes, but staff work to use validation procedures to reduce this occurrence, and we will send reports back to LE agency for clarification and completion. Electronic reporting greatly reduces the opportunity for incomplete and in accurate reporting. TraCS, the electronic reporting system currently used by the highway patrol, performs automatic checks for errors or questionable data. We still have to check paper reports sent to us by local agencies. It is more difficult to find errors in the paper reports. Not all agencies are able to afford to invest in TraCS at this time.

8. If so, is it easy to determine what the proper crash code should be? How often does this happen?

   It is not easy. Most of the time, the narrative doesn't not indicate what the data fields have indicated.

9. How long has the South Dakota Highway Patrol been using TRACS and do you feel that this tool has successfully increased the accuracy of crash reports?

   SDHP has been using the software since 2007, and it has greatly enhanced SDHP and also those agencies utilizing TraCS software since 2010. We would like to see all public agencies adopt TraCS in the future. One of the main limitations is funding.

Geometric Data Availability

The researchers for study SD2009-07 *Methods to Identify Needed Highway Safety Improvements* determined the data elements needed to perform network screening of crash locations. Table 2 and Table 3 list those data elements in gray. Please review the tables and answer the following questions.

1. Are any of the geometric elements listed in the tables available on the crash reporting form? Please answer yes or no even if SDDOT data is already available.

   Yes, see table.

2. Could you provide a copy of a blank crash reporting form?

   Yes, see attached.

Table B- 2: Geometric Intersection Data Elements[22]

Data Need	SDDOT Data Available	Is there a date associated with the following data element?	If not, can data be derived?	Please note any recent changes in data collection procedures.	Department of Public Safety data available?
Area type (urban/rural)	Yes	Yes[23]		2011[24]	
Intersection volume (AADT)[25]	ADT	Yes		2011	
Number of intersection legs (3 or 4)	Yes	Yes		2011	
Type of traffic control (minor road stop or signal control)	Yes	Yes		2011	Yes
Intersection skew angle (degrees departure from 90 degrees	Yes	Yes		2011	
Number of approaches with intersection left-turn lanes (0,1,2,3, or 4)	Yes	Yes		2011	
Number of approaches with intersection right-turn lanes (0,1,2,3, or 4)	Yes	Yes		2011	
Presence or absence of intersection lighting	Yes	Yes		2011	Yes

[22] Geometric intersection data is available on intersecting state highways and state highways that intersect federal aid county or city intersections.

[23] All data elements for intersections were collected in 2011. If any changes are made, the date and previous conditions will not be available in the current system.

[24] In 2011, additional geometric segment and intersection data elements were collected as a part of a pilot study.

[25] The bolded data elements may be collected as a part of the implementation plan for SD2009-07.

5 SDARS data for all crash locations including those off of state system.

Table B- 3: Geometric Segment Data Elements

Data Need	SDDOT Data Available	Is there a date associated with the following data element?	If not, can data be derived?	Please note any recent changes in data collection procedures.	Department of Public Safety data available?
Area type (urban/rural)	Yes	No			Yes – 1A
Number of lanes	Yes	No			YES
Segment length	Yes	No			
Segment volume (AADT)	ADT	No			
Shoulder type and width	Yes	No			
Lane width	No	No		Surface width/#lanes	
Median Type (divided/undivided)	Yes[26]	No			Yes
Number of driveways	No	No			
Presence or absence of centerline rumble-strips	N/A[27]	No			
Passing lane presence	No	No		# lanes	
Vertical curvature[28]		No			
Design Speed	Yes	No			
Grade	Yes	No			
k-value	Yes	No			
Horizontal curvature[29]		No			
Curve Degree	Yes	No			
Speed	Yes	No			Yes
Super-elevation	No	No			
Roadside hazard data/rating	No	No			
On-street parking	Yes[30]	No			
Lighting	Yes	No	2011[31]		Yes
Presence of a short four-lane section	Yes[32]	No			
Presence of a two-way left-turn lane	Yes	No	2011		
Presence of automated speed enforcement	N/A				

1a – Based on location of crash within town of 5,000 population or greater = URBAN. All others RURAL.

[26] Median type is only provided for the state highway system. County data does not include this roadway characteristic.

[27] At this time, there are no centerline rumblestrips installed on South Dakota's highway system. Automated speed enforcement is not currently being used in South Dakota.

[28] Vertical curvature is only provided for the state highway system.

[29] Horizontal curvature data is only provided for the state highway system.

[30] Parking is only provided for county data.

[31] In 2011, additional geometric segment and intersection data elements were collected as a part of a pilot study.

[32] Data is available for sections greater than 500 feet.

APPENDIX C: SDDOT TRAFFIC AND PAVEMENT CONDITION ENGINEERS SURVEY

Date: 08/10/12

Attendees: Rocky Hook, Kenny Marks, Michael Behm, and Megan Steever.

The following questions were addressed by members of SDDOT Transportation Inventory Management (TIM) in order to determine which safety effectiveness evaluation methods will best fit SDDOT:

Data Availability

The researchers for study SD2009-07 *Methods to Identify Needed Highway Safety Improvements* determined the data elements needed to perform network screening of crash locations. Table C- 2 lists those data elements in gray. Please review the tables and answer the following questions.

Table C- 1 Geometric Intersection Data Elements[33]

Data Need	SDDOT Data Available	Is there a date associated with the following data element?	If not, can data be derived?	Please note any recent changes in data collection procedures.
Area type (urban/rural)	Yes[34]	Yes[35]		2011[36]
Intersection volume (AADT)	ADT	Yes		2011
Number of intersection legs (3 or 4)	Yes	Yes		2011
Type of traffic control (minor road stop or signal control)	Yes	Yes		2011
Intersection skew angle (degrees departure from 90 degrees	Yes	Yes		2011
Number of approaches with intersection left-turn lanes (0,1,2,3, or 4)	Yes	Yes		2011
Number of approaches with intersection right-turn lanes (0,1,2,3, or 4)	Yes	Yes		2011
Presence or absence of intersection lighting	Yes	Yes		2011

[33] Geometric intersection data is available on intersecting state highways and state highways that intersect federal aid county or city intersections. There are approximately 1,200 to 1,500 intersections for which data is currently available. Adding state highways that intersect non-federal aid county roads would increase the number of intersections to approximately 10,000.

[34] Previously the area type and intersection volume could not be viewed in the intersection database, but BIT has made recent changes to allow users to view these data elements while looking at intersection features.

[35] All data elements for intersections were collected in 2011. If any changes are made, the date and previous conditions will not be available in the current system.

[36] In 2011, additional geometric segment and intersection data elements were collected as a part of a pilot study.

Table C- 2: Geometric Segment Data Elements

Data Need	SDDOT Data Available	If not, can data be derived	Is there a date associated with the following data element?	Please note any recent changes in data collection procedures.
Area type (urban/rural)	Yes		No	
Number of lanes	Yes		No	
Segment length	Yes		No	
Segment volume (AADT)	ADT		Historical data is available for state highways.	
Shoulder type and width	Yes		No	
Lane width	No	Surface width/#lanes	No	
Median Type (divided/undivided)	Yes[37]		No	
Number of driveways	No		No	
Presence or absence of centerline rumble-strips	N/A			
Passing lane presence	No	# lanes	No	
Vertical curvature[38]			No	
Design Speed	Yes		No	
Grade	Yes		No	
k-value	Yes		No	
Horizontal curvature[39]			No	
Curve Degree	Yes		No	
Speed	Yes		No	
Super-elevation	No		No	
Roadside hazard data/rating	No			
On-street parking	Yes[40]		No	
Lighting	Yes		No	2011[41]
Presence of a short four-lane section	Yes[42]		No	
Presence of a two-way left-turn lane	Yes		No	2011
Presence of automated speed enforcement	N/A			

1. If a data element was not available in 2009, is it being collected now?

   Yes, the RIS file contains all the intersection data elements listed in Table 1 from 2011 to the present. In addition, the presence of a two-way left-turn lane and lighting are also being collected.

[37] Median type is only provided for the state highway system. County data does not include this roadway characteristic.

[38] Vertical curvature is only provided for the state highway system.

[39] Horizontal curvature is only provided for the state highway system.

[40] Parking is only provided for county data.

[41] In 2011, additional geometric segment and intersection data elements were collected as a part of a pilot study.

[42] Data are available for sections greater than 500 feet.

2. One piece of data that appears to be missing is the date that features are changed. To what extent do you document the year that changes are made to each segment and intersection. You record the year of last major improvement, but do you keep track of when smaller improvements were installed, such as the addition of lighting, changes in the roadway width, or the year that a particular segment transitions from a rural facility to an urban facility. Please consider the data elements listed in the table and describe whether there is a date associated with the particular data element.

   The RIS file does not record the year that a change was made. The date that a data element was last updated is recorded, but this date may not correspond to a date that an actual change was made. Historical ADT is saved on state highways. Intersection data was collected in 2011 and no changes have been made to the database since that time. When the information is updated, the date of update is recorded, but the previous conditions are not saved.

3. If a data element is not available in RES or RIS, could it be collected or found in an alternate source?

   The SDDOT Research Library contains a copy of the SDDOT Highway Needs and Project Analysis Report for each year between 1979 and the present date. All reports contain the surface width, which is the combined width of surface driving lanes. All reports contain ADT and combined shoulder width. Starting in 1984, the report listed area type (urban/rural). None of the reports contain the number of lanes, number of driveways, presence of a passing lane, presence of short four-lane section, or presence of a two-way left-turn lane. This data could be used to estimate when and what changes may have taken place at a particular site. Date information would be useful in determining how many years of data should be used in an analysis.

4. How long do you keep historical AADT, ADT, and other traffic data?

   Historical ADT should be available back to 1979.

5. The previous study suggests that you have both county and state system data for each data element collected except median type and ADT. Is this true? Are you aware of any other data elements that are not available on the county level?

   Vertical curvature, horizontal curvature, and median type are only available on the highway system. Parking is only available on the county system. Geometric intersection data is available on intersecting state highways and state highways that intersect federal aid county or city intersections. There are approximately 1,200 to 1,500 intersections for which data is currently available. Adding state highways that intersect non-federal aid county roads would increase the number of intersections to approximately 10,000. ADT is available mostly on state highways.

6. If a data element is not available, could it be inferred from another data element? For example the Highway Safety Manual suggests vertical alignment can be inferred from terrain type, the number of driveways could be estimated using aerial maps, the presence or absence of passing lanes could be inferred from roadway, shoulder, and surfacing widths. Please list any data inferences that could be made.

   Lane width is equal to the surface width divided by the number of lanes. The passing lane presence is apparent when viewing the number of lanes.

7. Is the data easily accessible?

   All DOT employees have access to data within the RIS file.

8. Are there any additional data elements available that would be useful to safety studies?

   The RIS file contains the predicted average crash frequency for each intersection using Safety Performance Functions in the HSM. The predicted crash frequency is calculated by multiplying the safety performance of each intersection by CMFs. The CMFs are calculated for each intersection using the formulas found in Volume 2 of the HSM. Two scenarios for predicted crash reduction are listed by each intersection. One scenario includes the addition of lighting and the other scenario does not include the addition of lighting.

APPENDIX D: SDDOT GIS EXPERT SURVEY INSTRUMENT

Date: 08/16/12

Attendees: Terry Erickson

The following questions were addressed by SDDOT GIS Experts in order to determine which safety effectiveness evaluation methods will best fit SDDOT:

Data Availability

The researchers for study SD2009-07 *Methods to Identify Needed Highway Safety Improvements* determined the data elements needed to perform network screening of crash locations. Tables 1 and Table 2 list those data elements in gray. Please review the tables and answer the following questions.

Table D- 1: Geometric Intersection Data Elements[43]

Data Need	SDDOT Data Available	Is there a date associated with the following data element?	Please note any recent changes in data collection procedures.	GIS data available?
Area type (urban/rural)	Yes	Yes[44]	2011[45]	Yes
Intersection volume (AADT)[46]	ADT	Yes	2011	Yes
Number of intersection legs (3 or 4)	Yes	Yes	2011	Yes
Type of traffic control (minor road stop or signal control)	Yes	Yes	2011	Yes
Intersection skew angle (degrees departure from 90 degrees	Yes	Yes	2011	Yes
Number of approaches with intersection left-turn lanes (0,1,2,3, or 4)	Yes	Yes	2011	Yes
Number of approaches with intersection right-turn lanes (0,1,2,3, or 4)	Yes	Yes	2011	Yes
Presence or absence of intersection lighting	Yes	Yes	2011	Yes

1. If a data element is not available, can an inference be made using aerial maps or other data? For instance, could you estimate the number of driveways per mile or determine the presence or absence of a passing lane by looking at a map? Could you estimate lane width? Please look at the tables and determine which data elements could be inferred.

   You may be able to use aerial maps to estimate a driveway density in rural environments. In urban environments, barriers and approaches might be hard to differentiate. Historical aerial maps are made available to SDDOT by the Farm Service Administration (FSA) every other year starting in 2004 on the entire state system. Sioux Falls and Rapid City also provide aerial maps to SDDOT. In addition, as a part of the Imagery for the Nation initiative aerial maps are available for Pierre.

[43] Geometric intersection data is available on intersecting state highways and state highways that intersect federal aid county or city intersections.

[44] All data elements for intersections were collected in 2011. If any changes are made, the date and previous conditions will not be available in the current system.

[45] In 2011, additional geometric segment and intersection data elements were collected as a part of a pilot study.

[46] The bolded data elements may be collected as a part of the implementation plan for SD2009-07.

Table D- 2: Geometric Segment Data Elements

Data Need	SDDOT Data Available	Please note any recent changes in data collection procedures.	If not, can data be derived?
Area type (urban/rural)	Yes		
Number of lanes	Yes		
Segment length	Yes		
Segment volume (AADT)	ADT		
Shoulder type and width	Yes		
Lane width	No		Surface width/#lanes
Median Type (divided/undivided)	Yes[47]		
Number of driveways	No		
Passing lane presence	No		# lanes
Vertical curvature[48]			
Design Speed	Yes		
Grade	Yes		
k-value	Yes		
Horizontal curvature[49]			
Curve Degree	Yes		
Speed	Yes		
Super-elevation	No		
Roadside hazard data/rating	No		
On-street parking	Yes[50]		
Lighting	Yes	2011[51]	
Presence of a short four-lane section	Yes[52]		
Presence of a two-way left-turn lane	Yes	2011	

2. How often are aerial maps updated and do you keep track of the year that images were taken?

    See above comments.

3. Are geometric segment and intersection changes tracked in the geodatabase? For instance, if a 10-foot-wide road segment increased by 2 feet, would the geodatabase indicate the year that the road section changed to 12 foot and would the database indicate how wide the road was before the width changed?

    Most of the data available in RIS is available in the GIS database, and if it is not currently available, we can make it available. Similar to RIS, the geodatabase does not track changes, such as the year a change was made or the previous road conditions. Historical site plans are available.

    The number of intersection legs and type of traffic control may be available in the sign inventory for all state highways.

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[47] Median type is only provided for the state highway system. County data does not include this roadway characteristic.

[48] Vertical curvature is only provided for the state highway system.

[49] Horizontal curvature data is only provided for the state highway system.

[50] Parking is only provided for county data.

[51] In 2011, additional geometric segment and intersection data elements were collected as a part of a pilot study.

[52] Data is available for sections greater than 500 feet.

4. Are other relevant data elements kept in the database?

Crash data provided by the Department of Public Safety is available in our GIS database. The crash data is available from 2004 to the present date. There is also data from 2001 to 2003, but this data may not be accurate because the naming convention changed from mile reference markers to latitude and longitude coordinates in 2004. Where mile reference markers are used, if there were any changes in the name of a highway or the length of a segment referenced, data may be inaccurate. The GIS database used by the Department of Public Safety has not been updated since 2007, so if there have been any changes in roadway names or other changes, data for locations may not match up exactly with SDDOT locations.

A driveway density survey was completed in the past. The survey has not been updated and there were issues with the survey data, notably the driveway locations were not correctly identified, so data is questionable. Recent discussion has taken place to update and complete an accurate survey.

APPENDIX E: RESOURCES

The following appendix lists the training opportunities, manuals, resources, and case studies that safety engineers participating in the state surveys identified as valuable.

Training opportunities

Several training opportunities were identified to help safety engineers become familiar with particular safety measures, general safety concepts, and the Highway Safety Manual. In some cases, traffic safety engineers mentioned specific classes and in other cases the references were more general.

- Countermeasure specific seminars are offered by FHWA.
- National Highway Institute offers specific safety courses including some free web-based training sessions.
- Multiple states mentioned the two-week Traffic and Transportation Engineering Seminar held at Northwestern University Center for Public Safety in Evanston, IL. The course covers a broad range of topics relevant to urban and rural transportation problems and management of transportation systems. Major topics include studies and analysis methods, planning and design, and management and operations.
- The Transportation Learning Network (TLN) recently hosted a National Highway Institute (NHI) course available to SDDOT employees titled *Highway Safety Manual Practitioners Guide for Rural Two-Lane Roads.* The course provided guidelines for using CMFs used to predict safety outcomes on two-lane rural highways.
- There are courses offered by NHI specific to applying the analysis techniques suggested in the Highway Safety Manual, these would be most valuable for applying different analysis techniques.
- MUTCD training was also seen as beneficial.

Manuals and Case Studies

The researchers for study SD2009-07 *Methods to Identify Needed Highway Safety Improvements* recommended the following resources for safety analysis applications.

- CMF Clearinghouse, funded by FHWA http://www.cmfclearinghouse.org/
- TRB Special Report 314
- NCHRP Report 162
- A series of TRB papers is listed on DiExSys's website. http://diexsys.com/ The papers includes topics that discuss the relationship between safety and congestion and safety and traffic volume and network screening.
- Benefit/Cost Evaluation of MoDOT's Total Striping and Delineation Program: Phase II, June 2011
- Evaluation of the Conversion from Two-Way Stop Sign Control to All-Way Stop Sign Control at 53 Locations in North Carolina
- Highway Safety Improvement Program Manual
- A Guide to Developing Crash Modification Factors
- Safety Impacts of "Road Diets" in Iowa

- NCHRP 500 Reports
- The Manual on Identification, Analysis and Correction of High-Crash Locations (Hal Manual)
- Highway Safety Manual
- Highway Safety Evaluation Procedural Guide, FHWA 1981
- Observation before and after evaluations, Ezra Hauer
- Interactive Highway Safety Design Module (IHSDM)
- ISAT E from NCHRP 1745 discusses the human factor

Software

The researchers for study SD2009-07 *Methods to Identify Needed Highway Safety Improvements* recommended the following software for use in safety effectiveness evaluations.

- VisionZero Suite, The software has a universal converter which makes it compatible with any database format. It has the same level of sophistication as the SafetyAnalyst Software, but takes much less training.
- SafetyAnalyst, This software is comprehensive but may require safety engineers to make assumptions when data elements are not available.
- The Alaska DOT has created an excel-based spreadsheet that can perform simple analysis, the spreadsheet has been published online. http://www.dot.state.ak.us/stwddes/dcstraffic/pop_hsip.shtml
- NCHRP 1738 Spreadsheet used to perform HSM calculations: http://www.apbp.org/news/62826/