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Methods to Identify Needed Highway Safety Improvements in South Dakota

Study SD2009-07
Final Report

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16. Abstract

The South Dakota Department of Transportation (SDDOT) sought to develop a network screening program to proactively identify locations where potential crash frequency can be reduced, and for prioritizing improvements based on maximizing system safety benefits within budget constraints. This program also needs to respond to SDDOT's challenge of being unable to fully invest its safety funding, and to invest in the most worthwhile manner. In order to respond to these needs, the Research Team conducted several tasks including the review of national and state literature, the evaluation of the existing prioritization process, the identification of roadway and crash data available, and the analysis of alternative methodologies. The findings of these tasks identified the need, among other things, of an improved performance measure for analyzing crashes along segments and intersections. For the data currently available in South Dakota, the Excess Proportion of Specific Crash Type was recommended as the new performance measure. A high crash location analysis was found to be appropriate to address safety prioritization on urban locations, while a high crash location and systematic crash analysis was found to be more appropriate for rural locations. A GIS-based tool called Crash Analysis Tool was developed by the team to aid the application of the proposed methodologies. The main recommendations of the research project are: (1) for urban environments, adopt the excess proportion method as applied in the Crash Analysis Tool as a performance measure for identifying high crash locations, and (2) for rural environments, adopt the excess proportion method as applied in the Crash Analysis Tool for identifying sites with potential for safety improvements, and adopt the systematic method as a means for identifying treatments for programmatic implementation. Additional recommendations related to data needs, funding, and program evaluation are also part of the research project.

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Acronym	Definition
AADT	Average Annual Daily Traffic
AMF	Accident Modification Factors
ARF	Accident Reduction Factors
AASHTO	American Association of State Highway and Transportation Officials
AADT	Average Annual Daily Traffic
BIA	Bureau of Indian Affairs
CVSP	Commercial Vehicle Safety Program
CMF	Crash Modification Factors
DOT	Department of Transportation
EMS	Emergency Medical Services
EB	Empirical Bayes
EPDO	Equivalent Property-Damage-Only
FARS	Fatality Analysis Reporting System
FHWA	Federal Highway Administration
GIS	Geographic Information System
GPS	Global Positioning System
GVW	Gross Vehicle Weights
HRRR	High Risk Rural Roads
HSIP	Highway Safety Improvement Programs
SMS	Highway Safety Management System
HSM	Highway Safety Manual
HSP	Highway Safety Plan
IDOT	Illinois Department of Transportation
ISMProcess	Integrated Safety Management Process
ISMSystem	Integrated Safety Management System
IT	Information Technology
ITSDS	Iowa Traffic Safety Data Services
MMUCC	Model Minimum Uniform Crash Criteria
MODOT	Missouri Department of Transportation
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
OHS	Office of Highway Safety
PDO	Property Damage Only
RCI	Railroad Crossing Improvement
RSA	Road Safety Audit
RSAR	Road Safety Audit Review
RSI	Roadway Safety Improvement
RTM	Regression to the Mean
SPF	Safety Performance Functions
SRR	Severity Reduction Ratios
SDDOT	South Dakota Department of Transportation
TSIP	State Traffic Safety Improvement Programs
STIP	Statewide Transportation Improvement Program
SHSP	Strategic Highway Safety Plan
TEAP	Traffic Engineering Assistance Program
VMT	Vehicle Miles Traveled

1.0 EXECUTIVE SUMMARY

1.1 Problem Statement

The South Dakota Department of Transportation (SDDOT) sought to develop a network screening program to proactively identify locations where potential crash severity and potential crash exposure can be reduced, and for prioritizing improvements based on maximizing system safety benefits within budget constraints. The program was to consider state and local roadways. This program also needed to respond to SDDOT's challenge of being unable to fully invest its safety funding, and to invest in the most worthwhile manner. With these challenges as the motivation for the project, the guiding principles for conducting this research project were:

- Develop a tool to proactively identify safety improvements for South Dakota's roadway system and maximize the benefits of investments.
- Ensure the program will be consistent with work already underway in the Strategic Highway Safety Plan (SHSP) and Highway Safety Plan (HSP).
- Support the tool using readily available information from state databases, or data that will be cost-effective to acquire.
- Have the program be readily implemented by SDDOT staff.
- Create a program that can be expanded as additional tools, data, or methods become available in the future.
- Create a program/process that can be supported with available SDDOT resources.

1.2 Research Objectives

Four research objectives drove the direction and outcomes of the project:

- Identify data analysis methodologies needed to prioritize highway safety improvements in a more proactive versus reactive approach and optimize the use of safety funds.
- Review state and local government roadway data sources to determine the availability of information needed to support the analysis methodologies.
- Estimate costs, benefits, and timeframes necessary to adopt the analysis capabilities at the SDDOT.
- Recommend and demonstrate the application of the optimal analysis methodologies to key transportation and safety officials in South Dakota.

1.3 Task Descriptions

There were ten project tasks. Included in these tasks were three meetings with the Technical Panel, and a presentation to the Research Review Board. The tasks, which are described completely in Section 4.0 of this report, are listed below:

Task 1 - Review Literature and Analysis Techniques

Review and summarize available literature on highway safety data and corresponding analysis techniques, including NCHRP Report 500, Volume 21: "Safety Data and Analysis in Developing Emphasis Area Plans."

Task 2 - Review Project Scope and Work Plan

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

Task 3 - Review State and Local Prioritization Procedures

Review SDDOT's Strategic Highway Safety Plan and procedures used by state and local government agencies in South Dakota to define and prioritize highway safety improvements.

Task 4 - Roadway System Data Evaluation

Evaluate SDDOT's state trunk and non-state trunk roadway systems data relative to the availability, quality, and completeness of roadway attribute information potentially needed to define and prioritize needed safety improvements on a statewide basis.

Task 5 - Safety Data Evaluation

Review the availability, quality, and completeness of related state and local government data, such as the Department of Public Safety's South Dakota Accident Reporting System, potentially needed to support a robust analysis of needed safety improvements.

Task 6 – Analysis Methodology Alternatives

Based on the findings of Tasks 1-5, identify or develop alternative analysis methodologies that:

- more proactively identify needed highway safety improvements;
- can be implemented using data that is currently available or that can be acquired economically;
- support the South Dakota Strategic Highway Safety Plan (http://www.sddot.com/docs/SouthDakotaStrategicHighwayPlan.pdf);
- avoid difficult or cumbersome processes;
- provide benefits that outweigh the costs of resources necessary to operate, support, and maintain them.

Task 7 – Technical Memorandum

Provide for review and approval by the project's Technical Panel a technical memorandum that presents the findings of Tasks 1 – 5, describes feasible analysis methodology alternatives, estimates the costs and benefits of each alternative, and recommends analysis methodologies most appropriate for SDDOT.

Task 8 – Prototype Methodology

Upon concurrence of the research team and the Technical Panel on the analysis methodologies deemed most appropriate for implementation at SDDOT, develop and demonstrate a working prototype of each methodology including complete user documentation that steps though the procedural operations.

Task 9 - Final Report

Upon delivery, testing, and final acceptance of the prototypes and supporting user documentation by the Technical Panel prepare a final report and executive summary of the research methodology, findings, conclusions, and recommendations.

Task 10 - Executive Presentation

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

1.4 Findings

The major findings from these tasks are summarized below. These and other more detailed findings are also presented in Chapter 5.

1.4.1 Prioritization Methods

The State currently identifies locations for safety improvements using traditional methods of identifying high crash locations. In both urban and rural environments, sites are located for potential improvements as a function of crash frequency and limited road characteristic data. If a site has experienced more than 5 crashes in the last three-year period, it is identified for more detailed study. The detailed study at each site which exceeds this threshold includes a detailed review of crash data, current and historical field and environmental conditions, past projects in the site vicinity, and engineering judgment. Subsequently, staff identifies potential improvement concepts at each site where it is appropriate, and conducts a cost/benefit analysis to select and prioritize improvements. Selected projects are forwarded into the STIP process. This method is described in more detail in Appendix C.

1.4.2 Data

The state has a GIS database that was very useful to the project. The database included both state and local roadway network data, but the data are limited to segment level attributes (e.g. shoulder width, number of lanes, surface type). Data on intersection characteristics, including control (e.g. traffic signal, stop sign) is available for those locations where there has been an intersection crash. This data is stored in the separate crash database called the South Dakota Accident Reporting System. However, this is not a comprehensive dataset in that intersection data is not compiled if a crash has not occurred at an intersection.

The state has complete traffic volume data on state facilities, but limited data on local roadway facilities. The crash data available to the project was complete and geo-coded for the local and state system.

1.4.3 Regression to the Mean Bias

As is typical for most DOTs, current SDDOT prioritization methods do not account for potential issues associated with regression to the mean bias. Crash frequencies naturally fluctuate up and down over time at any given site. As a result, a short-term average crash frequency may vary from the long-term average crash frequency. The randomness of accident occurrence indicates that short-term crash frequencies alone are not a reliable estimator of long-term crash frequency. If a three-year period of crashes were to be used as the sample to estimate crash frequency, it would be difficult to know whether this three-year period represents a high, average, or low crash frequency at the site compared to previous years.

When a period with a comparatively high crash frequency is observed, it is statistically probable that a lower crash frequency will be observed in the following period.[1] This tendency is known as regression-to-the-mean (RTM), and also applies to the statistical probability that a comparatively low crash frequency period will be followed by a higher crash frequency period.

[1] Ogden, *K.W. Safer Roads: A Guide to Road Safety Engineering.* Ashgate, Brookfield, VT, 1996

Failure to account for the effects of RTM introduces the potential for “RTM bias”, also known as “selection bias,” RTM bias occurs when sites are selected for treatment based on short-term trends in observed crash frequency. For example, a site is selected for treatment based on a high observed crash frequency during a very short period of time (e.g., two years). However, the site’s long-term crash frequency may actually be substantially lower and therefore the treatment may not have been as effective as it first appeared. Application of the treatment may have been more cost-effective at an alternate site.

The State’s high crash selection methodology could be improved by using a performance measure that either accounts for regression to the mean bias or is not affected by regression to the mean bias.

1.4.4 Excess Proportion Performance Measure

Based on the data availability and considerations related to regression to the mean, the Research Team selected the excess proportion of specific crash type performance measure to investigate in this project. This performance measure doesn’t need traffic volume data so is applicable on the many roads without traffic volume data. A performance threshold is developed with the methodology and it is not effected by RTM bias.

Under this performance measure, sites are prioritized based on the excess proportion of a particular crash type or severity, which is defined as the difference between the observed proportion of a specific crash type or severity and the threshold proportion for the reference population. For example if a specific location has 20% sideswipe crashes, and the statewide average for comparable locations is 5% then it is said that the site has an excess proportion. A larger excess value represents a site with more potential for a reduction in crash frequency. For example, a site is flagged for further investigation if the number of crashes for a particular crash type or severity when related to the total crashes is greater than what would be expected for the analysis region. Appendix F includes a step by step sample problem from the AASHTO Highway Safety Manual (HSM) to illustrate the application of this performance measure.

1.4.5 Spot Specific and Systematic Analysis

Spot specific crash analysis procedures focus on identifying particular locations with specific issues that will likely respond positively to one or more treatments. Recently, many jurisdictions are moving to what are called “systematic crash analysis procedures.” Systematic analysis procedures focus on evaluating the network to identify and prioritize improvements based on particular types or severity of crashes. For example, if based on the data analysis it is identified that run-off the road crashes on horizontal curves are an issue, in systematic analysis the State would focus on programmatic improvements to horizontal curves whether or not crashes are occurring at any given location. Jurisdictions are considering this approach as it addresses funding constraints and allows for policy and programmatic level implementation of improvements (e.g. wider striping, rumble strips, delineating guardrail, and larger signs).

In the systematic approach to crash evaluation, the crash data are evaluated for trends on crash type and severity related to geometric characteristics. The purpose of the evaluation is to identify if, from a system-wide perspective, there is a particular crash type or severity that might be reduced by changing a specific geometric condition. If this can be identified, next the condition could be changed programmatically throughout the state to potentially prevent the crashes from occurring. For example, if it were identified that run off the road crashes are occurring where are there no shoulders, and it is known that providing or widening shoulders will reduce crash frequency, it therefore could be determined that constructing shoulders has the potential to reduce crashes. Systematic analysis procedures focus on evaluating the network to identify and prioritize improvements based on understanding the relationships between geometric characteristics of facilities, crash types or severity, potential countermeasures and application to the system.

Alternatively, in urban locations jurisdictions continue to prioritize according to high crash location lists (sometimes called black spot lists). High crash lists remain adequate in urban locations because crashes tend to be concentrated at intersections and the issues associated with these crashes tend to be more local than systematic. This concept was integrated into the project solutions process.

1.4.6 Crash Analysis Tool

To support the spot specific analysis and inform the type of systematic analysis the Research Team developed a GIS application for SDDOT that is called the Crash Analysis Tool (CAT). The Crash Analysis Tool conducts the excess proportion ranking calculations for intersections and segments. The tool can be installed on any PC that has ArcGIS. Once installed, the tool is accessed directly through the standard ArcMap interface using a custom tool bar. The software provides as primary outputs:

- **Sites ranked by Excess Proportion by Crash Type (p_{DIFF}).** The p_{DIFF} represents the difference between the observed proportion of a specific crash type at a site and the average proportion of a specific crash type for the reference population (i.e. the threshold proportion). The reference population is the category of facilities under consideration (e.g urban four-legged signalized intersections, rural two-lane undivided roadways). The output allows SDDOT to understand where its safety improvement needs are. Urban areas are evaluated using this high crash location approach. The tool also calculates as a secondary output the statistical probability that the selected crash type is over-represented at each site.

The tool calculations are based on input roadway characteristics and crash history as well as the excess proportion crash analysis methodology. The CAT includes options to:

- Conduct analyses on fatal and injury-only crashes or conduct the analyses on all crash severities (fatal, injury, and property-damage-only crashes);
- Run the tool at the county, region or statewide level; and
- Select the crash type (e.g. rear-end, sideswipe) and facility (intersection or segment, urban or rural) for investigation.

These outputs of the tool can be cross-tabulated against roadway and intersection characteristics as well as mapped and examined for special correlation. For specifics on the GIS tool, please reference the User Guide provided in Appendix G.

1.5 Recommendations

1.5.1 Urban High Crash Location Ranking

For urban environments, SDDOT should adopt the excess proportion method as applied in the Crash Analysis Tool as a performance measure for identifying high crash locations.

The Crash Analysis Tool will provide a ranked list of sites with potential to respond to safety improvements. The urban sites are appropriate for the ranking performance measure because crashes tend to be concentrated at intersections in urban environments. In addition, the recommended performance measure will identify which, if any crash types are exceeding an expected threshold and therefore provide an initial focus for the site diagnosis and treatment investigation.

1.5.2 Rural High Crash Location and Systematic Ranking

For rural environments, SDDOT should adopt the excess proportion method as applied in the Crash Analysis Tool for identifying sites with potential for safety improvement. In addition, SDDOT should adopt the systematic method as a means for identifying treatments for programmatic implementation.

Applying a combined ranking approach and systematic approach will reveal both trends by location as well as trends related to geometric characteristics that may respond to a programmatic treatment.

The excess proportion method will identify specific sites with potential for safety improvements. Sites will be ranked from highest to lowest potential to respond to safety improvement. Subsequently, each site will be evaluated to identify contributing factors and potential treatments to reduce crash frequency. In the secondary systematic approach to crash evaluation, the crash data are evaluated for trends on crash type and severity related to geometric characteristics. Systematic analyses look to implement crash countermeasures programmatically throughout the system in addition to known site specific issues. The process to identify treatments for implementation relies on evaluation of crash data, familiarity with the transportation system and engineering judgment.

1.5.3 Intersection Database

SDDOT should build and maintain an intersection physical characteristics and traffic volume database on South Dakota's state and non-state trunk highway systems.

Intersection data (e.g. traffic volume, number of legs, traffic control) is currently only collected if a crash has occurred at the particular intersection and is recorded in the Department of Public Safety crash database. SDDOT needs a stand-alone intersection geometric characteristics database that includes all intersections on state and non-state trunk highway systems. Today there is a roadway segment database with geometric characteristics. The advantages of a similar intersection dataset are that intersections could be categorized with more complete data and therefore more consistent comparisons could be made. Further, if intersection data were collected off of the state highway system, SDDOT would be able to investigate and identify solutions for non-state system facilities.

1.5.4 Roadway Database

SDDOT should expand the roadway characteristics and roadway traffic volume database on South Dakota's state and non-state trunk highway systems.

The roadway characteristics and roadway traffic volume database that the State currently maintains is adequate for initial analyses, but there is limited data for the local roadway system. This is not uncommon, but it is a gap that can be closed over time so that the roadway system can be more comprehensively evaluated and crash occurrence off the state system can be studied and addressed. The array of geometric data that can be collected is presented in Section 5.7.2. Specific items will to some extent be driven by the types of roadways under investigation and the types of analysis methods being applied.

1.5.5 Fatal and Injury Crashes

SDDOT should use fatal and injury-only crashes in the prioritization process when possible.

Using fatal and injury-only crashes in the prioritization process ensures that the State is responding to the most severe crashes, and that the State is not spending limited resources providing treatments at sites with property-damage-only (PDO) crashes. Due to the low number of crashes, the State's current prioritization process considers all crash severities. Broadly speaking, PDO crashes occur where there are relatively slow travel speeds, and higher roadway congestion. In these cases, it can be difficult to identify solutions to reduce the frequency of crashes (beyond reducing traffic volume). Therefore, including PDO crashes in the prioritization process can yield "false positives." By excluding PDO crashes, the State can focus on the most severe crashes and have more opportunity to identify sites with potential to respond to safety improvements. In some cases, particularly rural areas, the number of crashes may be limited requiring that all crash severities, including PDO, be considered in the analysis.

1.5.6 Highway Safety Improvement Program Funding

SDDOT should program HSIP Funding in proportion to the costs of fatal and injury crashes in urban and rural environments.

The cost of improvements in urban and rural environments can vary dramatically as a function of right of way costs, degree of the surrounding development, and degree of surrounding infrastructure. In addition, the most severe crashes typically occur in rural environments because of higher travel speeds. To make sure that the State appropriately plans for and programs improvements addressing both urban and rural crashes, it is recommended that the State allocate HSIP funds in proportion to the financial impacts of urban versus rural crashes. For example, if it is estimated that the urban crashes are 40% of the costs of crashes in South Dakota, then it is recommended that 40% of the HSIP funding be spent on urban improvements. FHWA provides nationally developed crash costs.

1.5.7 Evaluation Program

SDDOT should establish an evaluation program to investigate the before/after benefits of the implemented programs.

One reason this research project was undertaken was to help SDDOT fully allocate its federal safety dollars to safety improvements. To ensure that this research project and subsequent SDDOT safety programs are effective, SDDOT staff should establish before/after evaluations to confirm that programmatic spending is yielding the desired benefits. The before/after studies would investigate changes in crash frequency and severity as a function of dollars spent over time and determine whether benefits were being achieved. If not, programs could and should be modified so that benefits are achieved. Caution is advised that the before/after studies should be conducted with appropriate statistical rigor to ensure results are statistically significant and do not reflect random variation in crash data.

1.5.8 Investigations Database

SDDOT should develop and maintain a site by site (i.e. intersection and segment) database recording issues studied, treatments implemented, and results observed.

As SDDOT's program matures, there will be a) many sites that are investigated for potential safety improvements; b) many sites that receive improvements; and c) many years of data and information about the investigations that have been conducted, the treatments that have been considered, and the treatments that have been installed. The State should begin developing a GIS-based database to record studies conducted, treatments implemented, constructions costs, roadway characteristics, etc. so engineers and planners can review the database and understand the history of analyses and investigations at any site. As locations are studied, information about the investigation would be recorded on a site by site basis into the database. A form could be developed for electronic data recording in the field and subsequent data entry. The database would flag locations with investigations information. The user could point and click on the symbol and review the data form of investigations at the particular site.

1.6 Benefits

The benefits of implementing the previously stated recommendations will be reduced crash frequency and crash severity on state and local roadways. The benefits will be achieved through a program of rigorous prioritization, programming, and subsequent evaluation to test the effectiveness of project and program spending. The project recommendations include developing an evaluation program. This element of the program should be considered as critical as the initial screening and programming elements.

The before/after evaluation program should be conducted to verify effective project and program spending and confirm that crash frequency and severity is decreasing and that investments are appropriately targeted. This evaluation program could also be integrated with the Strategic Highway Safety Plan to ensure success in its crash focus areas.

This research identified additional potential data needs and analysis methods assuming additional data is collected by SDDOT. As this data becomes available the analysis options for SDDOT will expand to potentially integrate into design procedures and include more rigorous prioritization procedures. In the long-term, it is anticipated that the more rigorous procedures will lead to even more efficient spending of State and Federal dollars.

Finally, many State Departments of Transportation are adopting Toward Zero Death policy positions. In these cases, eliminating fatal and severe injury crashes are the long-term performance measures for the DOTs. The Crash Analysis Tool and the systematic approach analysis methods support such policy decisions.

2.0 PROBLEM DESCRIPTION

2.1 Background

Over the past five to ten years, there have been significant strides made in the field of quantitative highway safety analysis. Many research projects and new tools are already available, or will soon be, that make it possible for safety engineers to more easily:

- manage safety on roadway systems—for example, the forthcoming AASHTO *Highway Safety Manual (*www.highwaysafetymanual.org) and *SafetyAnalyst* software (www.safetyanalyst.org, www.transportation.org/sites/aashtoware/docs/FY2010_Catalog_Final.pdf); or
- predict the effect of changing various geometric design features on crash frequency—for example, the forthcoming AASHTO Highway Safety Manual and the Interactive Highway Safety Design Model software (www.tfhrc.gov/safety/ihsdm/ihsdm.htm);

In addition, a number of state departments of transportation have been recently working actively to modify their approaches and tools for identifying highway safety improvements. For example:

- **Missouri Department of Transportation—**As part of completing its Strategic Highway Safety Plan, the Missouri Department of Transportation (MODOT) shifted its approach to roadway safety analysis. They moved from identifying high-crash locations through past crash trends to a focus on reducing fatal and disabling injuries from a systematic perspective. For example, early in the implementation of this program, Missouri's crash data showed that cross-median crashes were an unfortunate trend. A high crash location approach would say that a median guardrail would be installed at the locations where these crashes occurred. However, from a systematic perspective, the MODOT chose to integrate median guardrails into all current roadway projects, to invest in guardrails on the highest-traveled roads in the state, and invest in guardrails at critical locations that had a high frequency of crashes that might be reduced by guardrails. This proactive approach of identifying critical crash types (i.e., fatal and disabling injuries, ignoring moderate-injury and property-damage-only crashes), identifying and investing in system-wide improvements (not spot-specific improvements), and focusing on what could be done with the available funding yielded a steady downward trend in fatal and disabling injury crashes in Missouri for several years.[2]
- **Illinois Department of Transportation—** The Illinois Department of Transportation (IDOT) has recently implemented *SafetyAnalyst*, a new set of software tools for use by state and local highway agencies for highway safety management. These tools can be used to improve the programming of site-specific highway safety improvements following the process and procedures that will be in the forthcoming Highway Safety Manual (HSM). In Illinois, the software has been developed to focus on all roads under IDOT jurisdiction and will identify spot specific locations for improvements. IDOT staff was able to acquire the data, organize the information technology (IT) needs, and train staff to start using this program within approximately eight months. IDOT staff believes that it will take another year for all staff to be familiar with the tool and take full advantage of it. IDOT will measure the success of the tool based on efficiencies gained in programming and spending federal dollars, and more importantly through a reduction in fatalities on the roadway system.[3]

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[2] Conversation with Leanna Depue (Highway Safety Director), and John Miller (Traffic Safety Engineer), Missouri Department of Transportation, September 24, 2009.

[3] E-mail correspondence with Roseanne Nance, Safety Services Section Chief, Illinois Department of Transportation, September 25, 2009.

Focusing on South Dakota, the state currently undertakes a multi-pronged approach to improving highway safety. The Department of Public Safety's annual *Highway Safety Plan* identifies emphasis areas each year that target behavioral characteristics that can lead to crashes (e.g., impaired driving or speeding) or more severe crash consequences (e.g., lack of seat belt use), as well as demographic groups that experience particularly high crash rates (e.g., motorcyclists and young drivers) or are particularly vulnerable if a motor vehicle crash occurs (e.g., pedestrians and bicyclists). These emphasis areas are identified through an analysis of previous years' crash data, as well as from the consensus of the state's Roadway Safety Committee.

The SDDOT also manages several programs that address roadway design and operating conditions that may contribute to crashes and/or crash severity:

- 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 on-site 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 on-site 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.

2.2 Problem Statement

Recognizing these activities, the South Dakota Department of Transportation and the South Dakota Department of Public Safety have laid the foundation for a successful highway safety program. The Department of Public Safety's annual *Highway Safety Plan* and SDDOT's *Strategic Highway Safety Plan* (SHSP) are consistent with and supportive of each other, and the plans have been developed with input from a broad range of stakeholders including the state's Roadway Safety Advisory Committee and several other local agencies and private organizations. Similar to many states, in South Dakota the emphasis areas and action plans identified in these documents have been developed from a data-driven perspective using crash data from the Department of Public Safety's Accident Records Office. If these programs are to fully achieve their desired outcomes, it is imperative that the established collaboration continues and that the benefits of state spending on highway safety improvements be maximized.

Nationally, there have been many challenges to overcome to achieve success in reducing crash frequency. First, the process for identifying and evaluating highway safety has typically been reactive, in that jurisdictions seek to improve locations where crashes have already occurred. Second, existing tools are perceived to be data-hungry, requiring extensive analysis with limited certainty of results. Finally, identifying and prioritizing roadway safety projects can be complicated by the need to be responsive to public outcry about particular "unsafe" roadways or specific tragic crashes.

SDDOT needs a programmatic, repeatable, defensible approach to proactively identify locations where potential crash severity and potential crash exposure can be reduced, and for prioritizing improvements based on maximizing system safety benefits within budget constraints. This program also needs to respond to SDDOT's challenge of being unable to fully invest its safety funding, and to invest in the most worthwhile manner. With these challenges as the motivation for the project, the guiding principles for conducting this research project were:

1. Develop a tool to proactively identify safety improvements for South Dakota's roadway system and maximize the benefits of investments.
2. Ensure the program will be consistent with work already underway in the SHSP and Highway Safety Plan.
3. Support the tool using readily available information from state databases, or data that will be cost-effective to acquire.
4. Have the program be readily implemented by SDDOT staff.
5. Create a program that can be expanded as additional tools, data, or methods become available in the future.
6. Create a program/process that can be supported with available SDDOT resources.

3.0 RESEARCH OBJECTIVES

In light of the guiding principles outlined in Chapter 2, the key project research objectives were to:

1. ***Identify data analysis methodologies needed to prioritize highway safety improvements in a more proactive versus reactive approach and optimize use of federal funds.***

   To identify optional analysis methodologies, the research team drew from its expertise on the AASHTO Highway Safety Manual (HSM). Part B of the Highway Safety Manual contains a wide variety of methods for conducting network screening. These methods range from the simple frequency-based methods which do not account for regression to the mean, to statistically rigorous methods that predict expected average crash frequency for a particular facility type. The research team conducted the research to prepare this part of the forthcoming HSM, so is very familiar with the array of methods available for network screening. A relatively limited additional literature review was conducted to identify new network screening methods.

   In addition to the literature review we conducted interviews with representatives from other state departments of transportation. States were selected that were either peer states, or states that are considered to have exemplary programs. SDDOT reviewed and confirmed the states which were selected prior to conducting the interviews. The team recommended this activity because it is familiar with the fact that many valuable practices may not be documented in literature. The purpose of these interviews was to identify if there were any particular resources beyond the literature that SDDOT might consider integrating into their procedures and programs.

2. ***Review state and local government roadway data sources to determine the availability of information needed to support the analysis methodologies.***

   Reviewing SDDOT's databases for crash, roadway and traffic volume data allowed us to develop a correspondence between methods and data availability. The data was reviewed to identify what is currently available and on what facility types, as well as what type of data could be collected in the future in order to expand the types of analyses conducted (either by facility or method).

3. ***Estimate costs, benefits, and timeframes necessary to adopt the analysis capabilities at the SDDOT.***

   The modifications that the Research Team recommended to SDDOT were considered from the perspective of how easily they could be integrated into standard practice at SDDOT. It was most desirable to the Team that options be developed that were consistent with the guiding principles outlined in the Problem Statement and that would ultimately be cost-effective for SDDOT to implement. The methods developed were thus sensitive to current data availability, ease of understanding, and ease of application.

4. ***Recommend and demonstrate the application of the optimal analysis methodologies to key transportation and safety officials in South Dakota.***

   The pilot application of the Crash Analysis Tool was applied to Pennington County and presented to SDDOT. The analysis demonstrated the urban application to identify intersections with an excess proportion of a particular crash type and the rural application to identify potential contributing factors to crash types. Respectively, these demonstrate the Crash Analysis Tool and the systematic evaluation method.

   Although not applied in Pennington County, other analytical methods were developed that might be applied to the State's HSIP process. These recommendations were identified through conversations with peer states and conversations with staff at the SDDOT and are also documented in the findings and recommendations of this report.

4.0 TASK DESCRIPTIONS

4.1 Task 1 - Review Literature and Analysis Techniques

Review and summarize available literature on highway safety data and corresponding analysis techniques, including NCHRP Report 500, Volume 21: "Safety Data and Analysis in Developing Emphasis Area Plans."

The team reviewed national and state information. Much of the state information was provided by SDDOT. Much of the national information reviewed was already familiar to the Research Team through our ongoing practice. The literature review was conducted to identify resources available to the team for addressing the project needs and to understand the status of the current practice at the SDDOT. The major purpose of this task was to identify potential methods for implementation in South Dakota and to develop an understanding of the current practice in South Dakota. The Research Team also conducted conference calls with staff from SDDOT working on the Highway Safety Improvement Programs. The purpose of these conversations was to learn about methods being applied in the field to identify if there are feasible options from peer states.

4.2 Task 2 - Review Project Scope and Work Plan

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

The Research Team met with the project's Technical Panel to review the project scope and work plan. This activity was conducted during the project kick-off meeting held in Pierre, South Dakota on December 4, 2009. There were two key objectives to this task. One was to review the overall project goals, objectives, and schedule. The second and perhaps more important objective was to initiate discussion of the needs, desired outcomes, and measures of success for the research project.

As an outcome of this task, the project team developed an understanding of SDDOT's concern that its current programs may rely too heavily on identifying critical locations rather than identifying critical safety trends and that current methods may not allow them to completely program federal safety funds.

4.3 Task 3 - Review State and Local Prioritization Procedures

Review SDDOT's Strategic Highway Safety Plan and procedures used by state and local government agencies in South Dakota to define and prioritize highway safety improvements.

In this task, the Research Team conducted interviews with SDDOT staff to develop an understanding of existing prioritization procedures. The purpose of these interviews was to develop an understanding of existing procedures and as appropriate their strengths and weaknesses as perceived by State staff. Information from these interviews informed the process of identifying modified methods or performance measures for the state.

The value of this task is that as the Research Team learned more about existing state procedures and programs, the feasibility of alternative methods became more apparent. A critical goal for SDDOT and the Research Team was to develop methodologies that expanded current practice without being a wholesale modification.

4.4 Task 4 - Roadway System Data Evaluation

Evaluate SDDOT's state trunk and non-state trunk roadway systems data relative to the availability, quality, and completeness of roadway attribute information potentially needed to define and prioritize needed safety improvements on a statewide basis.

The information needed for more robust and statistically significant analyses includes: traffic volume; roadway and intersection geometric attribute information such as lane width, shoulder width, median width and type; and, intersection traffic control or number of approach legs (non-exhaustive list). The research team reviewed the roadway system data currently available through SDDOT for the purpose of comparing the available data to known performance measures and analysis methods. This informed the options available to SDDOT.

4.5 Task 5 - Safety Data Evaluation

Review the availability, quality, and completeness of related state and local government data, such as the Department of Public Safety's South Dakota Accident Reporting System, potentially needed to support a robust analyses of needed safety improvements.

In the same vein as the available roadway traffic volume and roadway geometric data, the available crash data informs the type of analysis and possible crash performance measures for the prioritization procedures.

An overall project objective was to improve reliability of the analysis results to identify sites with potential for safety improvement, without forcing the State to undertake substantial additional data collection. Tasks 4 and 5 are critical aspects of the project in that they provide information about data available for prioritization analyses today, and how the data sets might be expanded into the future to further improve the prioritization procedures.

4.6 Task 6 – Analysis Methodology Alternatives

Based on the findings of Tasks 1 – 5, identify or develop alternative analysis methodologies that:

- ***more proactively identify needed highway safety improvements;***
- ***can be implemented using data that is currently available or that can be acquired economically;***
- ***support the South Dakota Strategic Highway Safety Plan (http://www.sddot.com/docs/SouthDakotaStrategicHighwayPlan.pdf);***
- ***avoid difficult or cumbersome processes;***
- ***provide benefits that outweigh the costs of resources necessary to operate, support, and maintain them.***

In this task, the results of the assessments of Tasks 1-5 were evaluated to prepare preliminary project findings for the project Technical Memorandum (Task 7). This included preliminary project recommendations.

4.7 Task 7 – Technical Memorandum

Provide for review and approval by the project's Technical Panel a technical memorandum that presents the findings of Tasks 1 – 5, describes feasible analysis methodology alternatives, estimates the costs and benefits of each alternative, and recommends analysis methodologies most appropriate for SDDOT.

The Research Team presented the Technical Memorandum for review and discussion at the project Technical Panel meeting on March 25, 2010. At this meeting, the Research Team presented the preliminary project recommendations and provided examples of the analysis methods. The Technical Panel provided feedback that the concepts were adequate and that the Research Team could proceed with the approach under development.

4.8 Task 8 – Prototype Methodology

Upon concurrence of the research team and the Technical Panel on the analysis methodologies deemed most appropriate for implementation at SDDOT, develop and demonstrate a working

prototype of each methodology including complete user documentation that steps though the procedural operations.

In this task, the Research Team developed prototype methodologies for conducting the proposed prioritization and identification procedures. The prototype methodologies were demonstrated in Pennington County. On May 7, 2010, the Research Team conducted a webinar with the Technical Panel to review and discuss interim development of the project tool. At this time, the Technical Panel continued to agree with the concept under development.

4.9 Task 9 - Final Report

Upon delivery, testing, and final acceptance of the prototypes and supporting user documentation by the Technical Panel prepare a final report and executive summary of the research methodology, findings, conclusions, and recommendations.

The project's final report was developed using the standard SDDOT research report template. The report includes an executive summary, problem description, statement of the research objectives, statement of task descriptions, and the project findings and descriptions.

The final report also includes appendices providing detailed explanations of particular aspects of the research, including findings from the literature review, sample calculations for the proposed prioritization method, and user documentation of the tool developed in this project.

4.10Task 10 - Executive Presentation

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

In this final project task, the Research Team presented the project results and a subset of the recommendations to the SDDOT Research Review Board in June 2010. The purpose of this task was to provide the SDDOT's executive management with an initial understanding of the findings from the research and the Research Team's preliminary recommendations.

5.0 FINDINGS AND CONCLUSIONS

This section of the report documents the findings under the different tasks of this research project. First, a summary of the literature review conducted and peer states conversations findings are presented. Then, a summary of the existing prioritization procedure as well as roadway, traffic volume and crash data available is provided. Alternative methodologies are summarized, and methodologies as well as other findings for the improvement of the current procedures are described in detailed. As a final topic, this section provides general guidance for long-term development of the prioritization program.

5.1 Task 1 - Literature Review

There were two elements of the Task 1 – Literature Review: 1) a traditional literature review, and 2) a series of phone conversations with other state DOTs. States were selected that were either peer states, or states that are considered to have exemplary programs. SDDOT reviewed and confirmed the states which were selected prior to conducting the interviews. The following presents the findings from both of the literature review and the DOT interview process.

5.1.1 Literature Review

The Research Team reviewed national and state literature on highway safety to identify current analysis techniques and gain an understanding of the South Dakota's safety practices. A list of the literature reviewed is provided below, while a summary of each document and its potential application to this project is presented in Appendix A. Overall, the national literature highlighted standard procedures for safety planning and management and identified tools available to for network screening (i.e. Highway Safety Manual (HSM) and SafetyAnalyst) as well as alternatives for allocating safety resources. The state literature highlighted current safety practices, emphasis areas, crash trends, and areas of concerns in South Dakota.

5.1.1.1 National Literature

- *NCHRP Report 500, Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, Volume 21, Safety Data and Analysis in Developing Emphasis Area Plans
- *NCHRP Report 501, Integrated Safety Management Process*
- *NCHRP Research Results Digest 329, Highway Safety Manual Data Needs Guide*
- *Prediction of the Expected Safety Performance of Rural Two-Lane Highways*, FHWA-RD-99-207
- *Highway Safety Manual*, Part B: Roadway Safety Management Process, Chapter 4: Network Screening
- *SafetyAnalyst*, FHWA & AASHTO
- *Alternative Strategies for Safety Improvement Investments*, January 2010, NCHRP Project 17-18(19)

5.1.1.2 South Dakota Literature

- *South Dakota Strategic Highway Safety Plan (2007)*
- *Highway Safety Plan (2010)*
- *Highway Safety Plan (2009)*
- *South Dakota Motor Vehicle Traffic Crash Summary (2008)*
- *South Dakota Motor Vehicle Traffic Accident Reporting Instruction Manual (2006)*
- *Factors Contributing to South Dakota Crash and Fatality Rates (2005)*

- *Updating South Dakota Crash Frequencies and Crash Reduction Factors (2004)*
- *Improving Motor Vehicle Crash Reporting on Nine South Dakota Indian Reservations (2007)*
- *Identification of Abnormal Accident Patterns at Intersections (1999)*
- *Identification of Methods for Truck Crash Reduction (1999)*
- *Highway Needs and Project Analysis Report (2009)*

With knowledge of the issues in South Dakota as well as state of the practice nationally, the Research Team looked to the literature to identify network screening methods (i.e. methods for identifying sites likely to respond to safety improvements) that were more reliable than current methods applied in South Dakota as well as methods that could be applicable to situations where there is a relatively low frequency of crashes. In addition, we were aware at this stage of the project that the State has good traffic volume data on state-owned facilities and limited data on local facilities. Therefore the literature review also included an investigation of methods that have improved statistical reliability but do not require traffic volume data.

The literature review also identified that safety analysis methods, particularly for rural roads, are moving toward what are called “systematic” or “systemic” procedures. Systematic crash analysis procedures focus on evaluating the network to identify and prioritize improvements based on particular types or severity of crashes. For example, if based on the data analysis it is identified that run-off the road crashes on horizontal curves are an issue, in systematic analysis the State would focus on programmatic improvements to horizontal curves whether or not crashes are occurring at any given location. Jurisdictions are considering this approach as it allows for policy and programmatic level implementation of improvements (e.g. wider striping, rumble strips, delineating guardrail, and larger signs). Alternatively, in urban locations jurisdictions continue to prioritize according to high crash location lists (sometimes called black spot lists). High crash lists remain adequate in urban locations because crashes tend to be concentrated at intersections and the issues associated with these tend to be more distinct than systematic.

5.1.2 Peer State Conversations

The Research Team conducted phone conversations with staff from the Highway Safety Improvement Programs for the Iowa, Minnesota, Missouri, Montana, and Washington State Departments of Transportation (DOT). The intent of each conversation was to gain an understanding of the individual state safety prioritization and funding distribution procedures, data availability and lessons learned and to evaluate the applicability of the methods and experiences to South Dakota. The following set of questions was developed to guide the discussion with the representatives from each state.

1. Does your safety improvement prioritization process account for both high crash locations analysis and systematic method?
2. What network screening methods/tools are currently being used to prioritize safety improvements for the high crash location analysis program?
3. How did you go about establishing a systematic approach?
4. How long do you think it took the state to get the systematic approach up and running?
5. How does your agency allocate HSIP funding? Are there particular federal rules about allocating this funding? What does South Dakota need to know about flexible allocation of HSIP funding?
6. What are some of the other funding sources?
7. How are the funds distributed between rural and urban locations and state and local roadways? Does the current funding distribution address the fatal and serious-injury crash location needs?

8. How does your agency work to integrate safety improvements into other projects?
9. Tell us a little bit about your data availability and the evolution of it.
10. How would you start planning on developing local data?
11. Are there tribal lands in your state? If so, how are you dealing with data collection?
12. If you were starting over from scratch, what would you do?

The detailed notes from each of the conversations are included in Appendix B. The following presents an overall summary of the discussions:

- Most of the states (Iowa, Minnesota, Missouri, and Washington) are conducting a systematic approach and also have some sort of ranking component. The systematic method tends to be implemented at rural locations and the ranking approach at urban locations. Iowa currently combines a systematic approach with a ranking analysis by first selecting particular system strategies, and then implementing the strategies at specific locations based on crash history. Missouri uses the systematic approach to implement policies essentially more than treatments (e.g. integrating particular treatments into design guidelines instead of funding construction of treatments). Washington State has specific approaches for state versus local roadways under both the ranking and systematic method. For instance, under the systematic approach, low cost improvements are implemented system-wide on the state system, while severe crashes on High Risk Rural Roads are the driving force for funding distribution on the local system. Each of these states firmly believes in the value of a systematic program and encourages South Dakota to focus on developing such a program.
- All of the states identified the value in working to focus HSIP funding on rural roadways considering that most of the crash fatalities occur in these areas. A few of the states (in particular Iowa) also emphasized the need for controlling the funds at the Central Office level, which allows for systematic project implementation.
- The States that have completed a shift toward a systematic approach for rural roads emphasized the need for an educational program to facilitate senior management support and effectively manage the funding.
- Each of the states focused their prioritization programs (ranking and systematic) on fatal and serious-injury crashes.
- Most of the states had limited traffic volume data off the state highway system. Minnesota and Iowa had some, but the maturity of their programs has allowed them to focus more time on data collection. Most of the states also have limited roadway data (e.g. cross-sectional characteristics) off of the state system. None of the states suggested stopping to focus on data collection. All suggested doing what you can with the data you have now, and working to incrementally improve the data.

As far as collecting data on tribal lands, Washington State is working on getting crash data reports from the tribes that do not include any personal information (which is a major concern for the tribes). They are also trying to create a Traffic Safety Commission for the tribes to discuss funding distribution and safety needs. Montana has achieved some success by implementing reciprocal agreements between the highway patrol and the tribes that allow them to investigate crashes on the reservations. Both states mentioned that the success of the program depends on the tribe characteristics, relationships with the tribes, and the level of education and awareness of the importance of the data gathering.

The substantive findings from these conversations were:

- the emphasis on systematic analysis procedures for rural facilities;

- the focus of the other state prioritization programs on fatal and serious injury-only crashes, essentially ignoring property-damage-only crashes, and demonstrating a commitment to the most severe crashes;
- an emphasis on moving forward with the data available and a plan to collect more data as time goes by; and
- the possibility of collecting crash data on tribal lands without personal information.

5.2 Task 3 Findings - Existing Prioritization Procedure

South Dakota's existing state prioritization procedures are largely reactive ranking procedures for both urban and rural facilities following a typical process of identification, diagnosis of conditions, selection and prioritization of treatments, funding and implementation.. For both urban and rural environments the existing methodology focuses on selecting locations for improvements based on crash frequency and cost-benefit analysis. Sites above a threshold of five (5) or more crashes in the last three-years are screened to further study trends, detailed crash analysis, and developed crash rates when possible. Countermeasures are selected and cost-analysis is conducted based on the Benefit-To-Cost Ratio Method described on the Highway Safety Improvement Program Manual FHWA-SA-09-029. With this information, an inspection team involving representatives from traffic operations, roadway design, safety, law enforcement and the local agency evaluates and prioritize the locations to select a program of improvements. The program of improvements feeds into the Statewide Transportation Improvement Program (STIP).

In addition, South Dakota's SHSP has identified reducing run-off-road crashes as a priority. One action SDDOT has taken to address this is to plan for and implement stand-alone rumble strips projects as well as integrating rumble strips into all resurfacing projects. This is a systematic approach to reducing crashes because a countermeasure is being implemented system-wide where sufficient shoulder width exists instead of at specific locations with a high number of run-off-road crashes.

In the current prioritization process sites which have five or more crashes in the most recent three-year period are selected for more detailed crash data analysis, field investigation, engineering evaluation and possible selection and prioritization of safety treatments. This method, while very common, does not account for issues associated with regression to the mean bias. Therefore, it is possible that sites are unnecessarily selected for further study because of the random fluctuation in crash data. In addition, the existing procedure does not identify whether or not five crashes is an accurate threshold for further evaluating sites. Therefore, some sites could be overlooked, or some sites could be investigated when there are no issues (i.e. five crashes is what might be expected for the site conditions, traffic volume, land use, and roadway environment).

Additional information about the State's current prioritization procedures is included in Appendix C.

5.3 Task 4 and 5 Findings - Roadway, Traffic Volume, and Crash Data Availability

The Research Team received and reviewed roadway, traffic volume and crash data maintained by SDDOT. The team also held conference calls with Roger Brees, Transportation Specialist (GIS) from the SDDOT Office of Transportation Inventory Management, regarding the state roadway database and Chuck Fergen of the SD Department of Public Safety's Office of Highway Safety regarding the state crash database. The purpose of the data review and the meetings was to develop an understanding of the crash, traffic volume and roadway characteristics data availability.

5.3.1 Roadway and Traffic Volume Data

Information about the roadway and traffic volume data is summarized below according to segments and intersections. For roadway segments:

- State and local roadway segment geometric data is available (e.g. shoulder width, number of lanes, surface type). The roadway data is stored in a centralized geodatabase.
    - State roadway data are updated annually; usually available starting in November or December. The database is equipped for dynamic segmentation, which means that attributes can be coded by actual mile location rather than being applied to an entire roadway segment. This is particularly useful when identifying high risk areas along corridors.
    - Local roadway data is collected by planning districts, and must conform to standards established by SDDOT. The dynamic segmentation described above is only available on local road segments eligible for federal funding.
- State and local intersection characteristics, including control (e.g. traffic signal, stop sign) are available for those locations where there has been an intersection crash. Data is stored in the Department of Public Safety crash database, but only for intersections that have experienced a crash.
- Traffic volume roadway segment volume data is available on state-owned roadways, mostly for roadway segments and to a lesser extent for intersections. A more complete description of roadway data attributes and meeting notes are presented in Appendix D.

5.3.2 Crash Data

Information about crashes (i.e. the event, the vehicle, the location, the people) is collected and reported by law enforcement personnel. As part of the data collection and reduction process the crashes are associated with specific locations on both the state and local roadway systems. Some attributes from the crash database can be used to supplement missing elements of the roadway database such as intersection control. Crash data is stored by the Department of Public Safety in a centralized database. Data is collected at the local level, submitted to the department, quality checked, and either uploaded into the database or returned to the reporting officer for completion. Every effort is made to ensure that all incidents entered into the database are complete and accurate. The Department of Public Safety provides detailed guidance to ensure consistency. The crash database uses the roadway database managed by SDDOT for its network. The roadway layer is expected to be refreshed annually, as updated by SDDOT, but historically this has not been done that frequently. A more detailed description of the crash data and meeting notes are included in Appendix E.

The Research Team considers that roadway data is collected in a consistent manner, updated periodically, and useful for identifying potential contributing factors of specific crash types on both urban and rural segments. Additional attributes can be introduced over time as gaps are identified as part of the prioritization process implementation to allow SDDOT to employ more sophisticated safety analysis methods. In particular, there is a need for traffic volume, intersection control, and geometric data at all intersection legs independent of the crash database. Traffic volume data is particularly weak off the state system. The crash database is maintained as a seamless statewide resource and already contains the necessary attributes for robust analysis. Data transfers between the crash database and the roadway database can be handled on a regular basis as the roadway data is updated each year.

5.4 Task 6 Findings – Alternative Methodologies

The AASHTO Highway Safety Manual, published in July 2010 is the first of its kind manual in the United States providing quantitative methods for developing roadway safety management procedures, estimating the potential change in crash frequency associated with a change in roadway cross-section or traffic volume, or the change in crash frequency associated with a particular treatment. The manual presents the best science-based quantitative methods available as of publication of the document. Part B: Roadway Safety Management Process introduces a number of new procedures for roadway safety management. Critical among these are some of the network screening methods introduced in Chapter 4 – Network Screening. This chapter provides thirteen performance measures for identifying and ranking sites with potential for safety improvements. Kittelson & Associates, Inc. was the primary contractor on NCHRP 17-34: HSM Part IV Safety Management of a Roadway System which later became Part B of the HSM. From our work conducting this research we have become intimately familiar with the array of network screening performance measures available. Table 1 provides a summary of available performance measures and the data needed to calculate each of them.

Table 1: Summary of Data Needs for Performance Measures

	Data and Inputs					
Performance Measure	Crash Data	Roadway Information for Categorization	Traffic Volume	Calibrated Safety Performance Function and Overdispersion Parameter	Other Information Needed	Does SDDOT Have Data?
Average Crash Frequency	X	X				Yes
Crash Rate	X	X	X			Yes for Segments No for Intersections
Equivalent Property-Damage-Only (EPDO) Average Crash Frequency	X	X			EPDO Weighting Factors	Yes
Relative Severity Index[4]	X	X			Relative Severity Indices	Yes
Critical Rate[5]	X	X	X			Yes for Segments No for Intersections
Excess Predicted Average Crash Frequency Using Method of Moments	X	X	X			Yes for Segments No for Intersections
Level of Service of Safety	X	X	X	X		No
Excess Predicted Average Crash Frequency using Safety Performance Functions (SPF)	X	X	X	X		No
Probability of Specific Crash Types Exceeding Threshold Proportion	X	X				Yes
Excess Proportion of Specific Crash Types	X	X				Yes
Expected Average Crash Frequency with Empirical Bayes (EB) Adjustment	X	X	X	X		No
Equivalent Property-Damage-Only (EPDO) Average Crash Frequency with EB Adjustment	X	X	X	X	EPDO Weighting Factors	No
Excess Expected Average Crash Frequency with EB Adjustment	X	X	X	X		No

Source: NCHRP 17-36: Production of the first edition Highway Safety Manual, Exhibit 4-7.

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[4] Monetary crash costs are assigned to each crash type and the total cost of all crashes is calculated for each site. An average crash cost per site is compared to an overall average crash cost for the site's reference population.

[5] The observed crash rate is compared to a calculated critical rate for each site. The critical rate is a function of the average crash rate at similar sites, traffic volume and a statistical constant that represents a confidence interval.

A safety performance function is a regression equation—usually estimated using negative binomial regression models—that predicts crash frequency as a function of traffic volume and geometric characteristics. The overdispersion parameter is provided as part of the modeling process. The closer the parameter is to zero, the closer the variance of the data is to mean of the data and thus the more closely the data fits a Poisson distribution. The overdispersion parameter is used in different analysis methodologies including the Empirical Bayes Method (EB). The EB method is a weighting process to revise the predicted crash frequency estimated from the safety performance function as a function of the observed crash data and the overdispersion parameter.

In addition to data availability, selection of performance measures is influenced by how well the performance measure addresses regression to the mean bias, and if the performance measure provides a performance threshold. The following provides a summary of these issues.

5.4.1 Regression-to-the-Mean Bias

Crash frequencies naturally fluctuate up and down over time at any given site. As a result, a short-term average crash frequency may vary significantly from the long-term average crash frequency. The randomness of accident occurrence indicates that short-term crash frequencies alone are not a reliable estimator of long-term crash frequency. If a three-year period of crashes were to be used to estimate crash frequency, it would be difficult to know whether this three-year period represents a high, average, or low crash frequency at the site compared to previous years.

When a period with a comparatively high crash frequency is observed, it is statistically probable that a lower crash frequency will be observed in the following period.[6] This tendency is known as regression-to-the-mean (RTM), and also applies to the statistical probability that a comparatively low crash frequency period will be followed by a higher crash frequency period.

Failure to account for the effects of RTM introduces the potential for “RTM bias,” also known as “selection bias.” RTM bias occurs when sites are selected for treatment based on short-term trends in observed crash frequency, for example, when a site is selected for treatment based on a high observed crash frequency during a very short period of time (e.g., two years). However, the site’s long-term crash frequency may actually be substantially lower and therefore the treatment may not have been as effective as it first appeared. Application of the treatment may have been more cost-effective at an alternate site.

To address this issue in South Dakota, it is recommended, based on the data available, that the excess proportion performance measure be applied. In Table 2, “Assumes Not Influenced by RTM” means that it is generally assumed that this performance measure is not affected by RTM bias. RTM is a count-based statistical issue where crash counts (in this case) fluctuate higher or lower than a long term expected average. This performance measure is a function of proportions where the proportions of crashes is not influenced by whether the count of crashes is higher or lower than the long term expected average (e.g. whether higher or lower than the mean).

5.4.2 Performance Threshold

A performance threshold value provides a reference point for comparison of performance measure scores within a reference population. Sites can be grouped based on whether the estimated performance measure score for each site is greater than or less than the threshold value. Those sites with a performance measure score less than the threshold value can be studied in further detail to determine if reduction in crash frequency or severity is possible.

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[6] Ogden, *[K.W. Safer Roads: A Guide to Road Safety Engineering.]* Ashgate, Brookfield, VT, 1996

The method for determining a threshold performance value is dependent on the performance measure selected. The threshold performance value can be a subjectively assumed value, or calculated as part of the performance measure methodology. Threshold values can be estimated based on: the average of the observed crash frequency for the reference population, an appropriate safety performance function, or Empirical Bayes (EB) methods. Table 2 summarizes whether or not each of the performance measures accounts for regression-to-the-mean bias and/or estimates a performance threshold. The performance measures are presented in relative order of complexity, from least to most complex. Typically, the methods that require more data and address RTM bias produce more reliable performance threshold values.

Table 2: Stability of Performance Measures

Performance Measure	Accounts for RTM Bias	Method Estimates a Performance Threshold
Average Crash Frequency	No	No
Crash Rate	No	No
Equivalent Property-Damage-Only (EPDO) Average Crash Frequency	No	No
Relative Severity Index	No	Yes
Critical Rate	Considers data variance but does not account for RTM bias	Yes
Excess Predicted Average Crash Frequency Using Method of Moments	Considers data variance but does not account for RTM bias	Yes
Level of Service of Safety	Considers data variance but does not account for RTM bias	Expected average crash frequency plus/minus 1.5 standard deviations
Excess Expected Average Crash Frequency Using Safety Performance Functions (SPF)	No	Predicted average crash frequency at the site
Probability of Specific Crash Types Exceeding Threshold Proportion	Assumes not influenced by RTM bias	Yes
Excess Proportions of Specific Crash Types	Assumes not influenced by RTM bias	Yes
Expected Average Crash Frequency with Empirical Bayes (EB) Adjustments	Yes	Expected average crash frequency at the site
Equivalent Property-Damage-Only (EPDO) Average Crash Frequency with EB Adjustment	Yes	Expected average crash frequency at the site
Excess Expected Average Crash Frequency with EB Adjustments	Yes	Expected average crash frequency per year at the site

Source: NCHRP 17-36: Production of the first edition Highway Safety Manual, Exhibit 4-8.

5.4.3 Performance Measure

Based on data availability and the criteria for performance thresholds and RTM bias, the Research Team found that the performance measure excess proportion of specific crash types was a viable solution for the available data in South Dakota. Because this performance measure does not need traffic volume data, it is applicable to SDDOT in that it can be used on the many roads without traffic volume data.

Under this performance measure, sites are prioritized based on the excess proportion of a particular crash type or severity, which is defined as the difference between the observed proportion of a specific crash type or severity and the threshold proportion from the reference population (e.g. two-lane roadways, four-lane divided roadways, arterial-arterial signalized intersection or collector-local two-way stop intersection). A larger excess value represents a site with more potential for a reduction in crash frequency. For example, a site is flagged for further investigation if the number of crashes for a particular crash type or severity when related to the total crashes is greater than what would be expected for the analysis region. Appendix F includes a step by step sample problem from the forthcoming AASHTO Highway Safety Manual (HSM) to illustrate the application of this performance measure.

In summary, the methodology compares the observed proportion of crashes (by type or severity) at a particular site to the observed proportion of crashes (by type or severity) for the comparable reference population. Sites are ranked by the difference between the observed proportion of crashes by type or severity and the threshold proportion of crashes by type or severity $p_{DIFF} = p_i - p_i^*$. In addition it is possible to calculate a probability that the observed proportion exceeds the threshold proportion. The greater the excess proportion the more likely a site is to respond to safety improvements. This performance measure is generally assumed to be not affected by RTM bias because it is measuring and ranking on proportions instead of counts. The assumption is that the proportion of crashes by type or severity is not influenced by whether the count of crashes is higher or lower than the long term expected average (e.g. whether higher or lower than the mean).

5.4.4 Applying the Performance Measure to Intersections and Segments

Performance measures for network screening are applied to both intersections and roadway segments (sections of roads without intersections). For intersections, the performance measure is calculated at each intersection. The intersections are then grouped by reference population (e.g. facility type, urban vs. rural, etc) and ranked according to the results of the performance measure.

Roadway segments are first categorized by reference population and then a stepwise application of the performance measure is conducted for each segment in order to identify the location on the roadway segment with the most potential to respond to a safety improvement. The method to conduct this screening is called "sliding window."

Conceptually, in the sliding window method a "window" of a particular length (e.g. 1 mile) is moved along a roadway segment in specific increments (e.g. 0.25 miles for each position of the window). The performance measure is calculated for each position of the window. For a given segment, the window that, according to the particular performance measure, shows the most potential to respond to a safety improvement is selected to represent the entire segment. Table 3 illustrates how the sliding window method can be used to study a 2-mile segment assuming a 1-mile window and 0.25-mile increments. In this example, subsegment A4 would be identified as the segment representing the safety performance of the entire segment A. Appendix F includes a step-by-step sample problem from the HSM to illustrate the applications of this screening method.

Table 3: Sliding Window Example Application (hypothetical situation and numbers)

Subsegment	Window Position (mile point)	Excess Proportion of Specific Crash Types
A1	0.00 to 1.00	1.30
A2	0.25 to 1.25	0.80
A3	0.50 to 1.50	1.10
A4	0.75 to 1.75	1.80
A5	1.00 to 2.00	0.90

5.5 Task 8 Findings – Prototype Methodology

The Research Team developed a GIS-based Crash Analysis Tool (CAT) tool for the State to use in applying the excess proportion network screening performance measures for urban and rural intersections and segments. If adopted by the SDDOT, the CAT will be used by staff to conduct the network screening activity within the overall roadway safety management process (i.e. network screening, evaluating conditions, selecting and prioritizing improvements).

5.5.1 Crash Analysis Tool to Apply Excess Proportion Method

The CAT replaces the State's current network screening process of crash frequency assessment described in Appendix C. The CAT has been developed to conduct network screening at a county, multiple counties, or at a statewide level. The CAT can run on any PC that has a licensed installation of ESRI's ArcGIS software at the ArcView 9.3 level or higher. The Crash Analysis Tool conducts the excess proportion ranking calculations for intersections and segments. The calculations are based on input roadway characteristics and crash history as well as the excess proportion analysis methodology described above and in Appendix F. Analysis options allow users to:

- Conduct analyses on fatal and injury-only crashes or conduct the analyses on all crash severities (fatal, injury, and property-damage-only crashes);
- Run the tool at the County, Region, or Statewide level; and
- Select the crash type (e.g. rear-end, sideswipe) and facility (intersection or segment, urban or rural) for investigation.

Once the analysis is completed, the software provides as primarily outputs:

- **Sites ranked by Excess Proportion by Crash Type (p_{DIFF})**. The p_{DIFF} represents the difference between the observed proportion of a specific crash type at a site and the threshold proportion from reference population for the same crash type. This output allows SDDOT to understand where its safety improvement needs are. Urban areas can be evaluated using this high crash location approach. The tool also calculates as a secondary output the statistical probability that the selected crash type is over-represented at each site.
- **Number of sites with an Excess Proportion.** This output is considered as one portion of the systematic analysis that will be described in more detailed below. Rural areas are also evaluated using a systematic approach.

In addition, outputs of the tool can be cross-tabulated against roadway and intersection characteristics as well as mapped and examined for spatial correlation.

Figure 1 shows a snapshot of the analysis result output table for the evaluation of rear-end crashes (fatal and injury-only) at urban signalized intersections in Pennington County. The last column of the table shows the sites ranked in descending order of p_{DIFF}. The greater the value of p_{DIFF}, the greater the likelihood that the site will benefit from a countermeasure that addresses the crash type in consideration.

Starting at the top of the p_{DIFF} column and working down, SDDOT staff would identify sites for further investigation. The sites which are selected for further investigation are those sites which are relatively high on the list, sites that have not had recent changes in roadway cross-section, and sites that do not have previously identified feasible or unfeasible solutions. The additional investigation will include detailed review of crash data, field investigation, identifying potential mitigation measures, and selecting and prioritizing mitigation measures to reduce crash frequency. The steps for this stage of the evaluation and prioritization process are not presented here as they are consistent with what is currently conducted by the SDDOT.

Attributes of Rear End_Urban Signal_Fatal or Injury_Pennington Co (50)

Control_1	Urb_Rur_1	Distance_2	OID_	OBJECTID_2	SUM_Join_C	SUM_CType	Prob	PDiff
Signal	U	0	89	3290	2	2	0.999418	0.689403
Signal	U	0	222	4482	2	2	0.999418	0.689403
Signal	U	0	569	71770	3	3	0.999737	0.689403
Signal	U	0	343	30944	2	2	0.999418	0.689403
Signal	U	0	485	57762	3	3	0.999737	0.689403
Signal	U	0	417	31766	2	2	0.999418	0.689403
Signal	U	0	286	21456	2	2	0.999418	0.689403
Signal	U	0	295	24948	2	2	0.999418	0.689403
Signal	U	0	203	4376	2	2	0.999418	0.689403
Signal	U	0	483	57617	2	2	0.999418	0.689403
Signal	U	0	555	71598	6	5	0.999888	0.522737
Signal	U	0	289	23468	5	4	0.999753	0.489403
Signal	U	0	17	2872	4	3	0.999464	0.439403
Signal	U	0	288	23467	4	3	0.999464	0.439403
Signal	U	0	304	28282	4	3	0.999464	0.439403
Signal	U	0	463	38282	8	6	0.999895	0.439403
Signal	U	0	500	59275	4	3	0.999464	0.439403

Record: 0 Show: All Selected Records (0 out of 50 Selected) Options

Figure 1: High Crash Location Tool Output (Tabulated)

Figure 2 presents another output of the tool, which graphically shows the results presented in the tables. The orange dots represent urban signalized intersections found to have an excess proportion of rear end crashes in Pennington County. The presentation of this information could be modified with GIS mapping tools to show different categories of rankings in different colors or different shapes to help with interpretation.

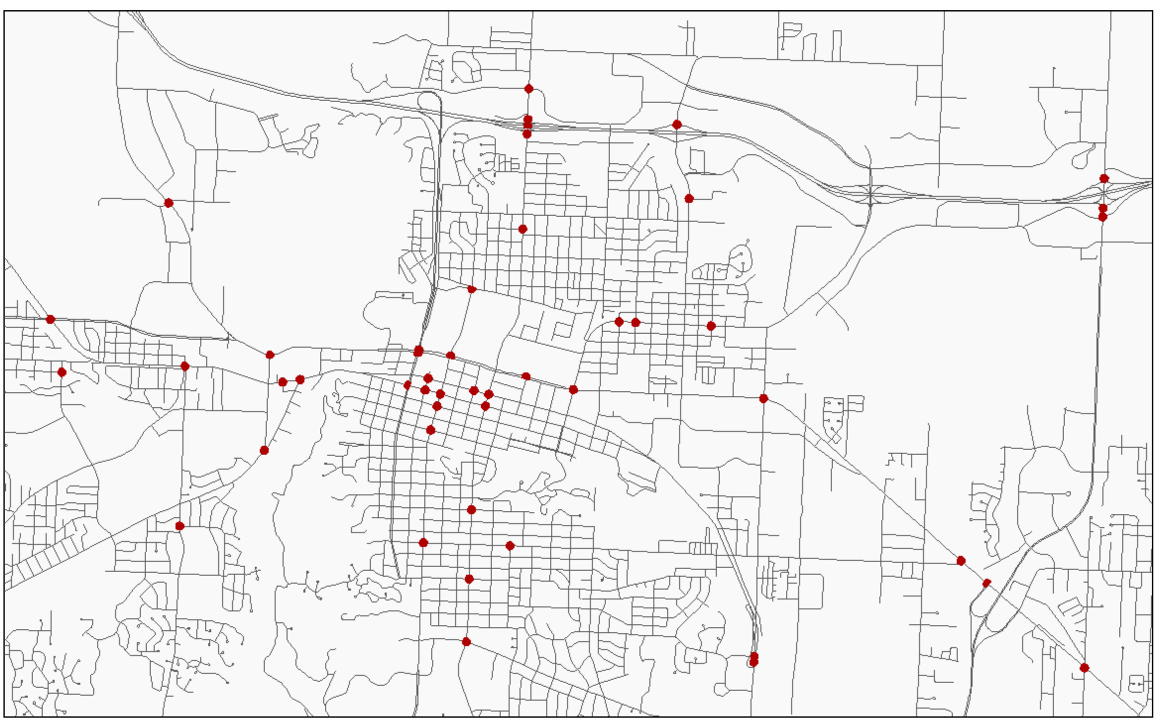

Figure 2: High Crash Location Tool Output (Graphical)

5.5.2 Systematic Analysis

As previously noted, rural roadways are evaluated with the Crash Analysis Tool to identify those segments with an excess proportion of a specific crash type. To conduct a systematic analysis and identify treatments for programmatic implementation, the analyst will next seek to understand the contributing factors to the crashes on the segments with an excess proportion. The analyst is seeking to identify possible treatments for specific sites that could be implemented programmatically statewide to prevent similar crashes from occurring in other locations. An example of a systematic treatment is shoulder rumble strips. South Dakota DOT has been installing these programmatically throughout its transportation network to help reduce run-off-the-road crashes.

The methods available for identifying systematic improvements vary as a function of data availability and statistical analysis resources. Some options are:

- *Qualitative Investigation*— When the sample size is too small to complete a statistical analysis a qualitative analysis of the geometric characteristics of the sites will be necessary. In this case the analyst will consider the descriptive statistics of the sites (e.g. cross-tabulations of crash types against geometric characteristics), and field visits to identify potential treatments that may address a particular crash type.
- *Quantitative Analysis: Analysis of Variance*— As applied to this project, ANOVA is a statistical analysis that can compare the Crash Analysis Tool performance measure, p_{DIFF}, to geometric characteristics in the roadway segment database to identify which of the geometric characteristics, if any, are statistically significant contributing factors to the dependent variable. The ANOVA analysis tests the roadway segment geometric characteristics in the database (e.g. surface width and pavement type) to determine which if any are statistically significant contributing factors to the p_{DIFF} performance measure. If one or more of the characteristics are found to be contributing factors, the analyst studies the sites, and the identified statistically significant characteristics in more detail to understand if there are potential treatments that could be implemented at the site and programmatically to reduce crashes.

  Two points should be considered when applying an ANOVA test:

  - *Dependent Variable:* In order to satisfy the ANOVA assumptions, the dependent variable must be in a continuous numerical scale and be normally distributed. For this project, two variables can be used from the Crash Analysis Tool output (Figure 1): the calculated probability (Prob) and the excess proportion by crash type (Pdiff). These two variables satisfy the basic ANOVA assumptions because they can assume any value between 0 and 1; and a normal distribution can be expected if the sample size conditions are met.
  - *Sample Size:* A significant amount of sites with calculated excess proportion by crash type (or crash probability) should be identified in order for the ANOVA test results to be meaningful. A sample size of 30 or more sites (which is the threshold found in the literature and applies to this research as well) is required to perform the test. This requirement will assure proper distribution of the different geometric characteristics, resulting in more reliable conclusions.

  In the analyses that support safety, contributing factors are not equal to causal factors. Therefore if the ANOVA analysis reveals contributing factors, these cannot be assumed to be the same as causes of crashes. Crashes are a result of a convergence of a series of events of a variety of contributing factors. Contributing factors include driver behavior, conditions related to the vehicle, and conditions related to the roadway environment. Therefore, engineering judgment is necessary for the selection of site specific and programmatic treatments. The

ANOVA analysis or other statistical analysis to identify contributing factors provides information but not ultimate deterministic results.

- *Quantitative Analysis: Regression Analysis*—As applied to this project, if there is insufficient data to conduct an ANOVA, from a quantitative perspective, the next step would be for SDDOT staff to conduct a regression analysis to compare the crash frequency against the geometric characteristics in the database to identify potential geometric contributing factors or trends that might transfer across the transportation network. Performing a linear regression analysis using P_{DIFF} as the dependent variable and using the geometric characteristics as independent variables would yield to the same results as of the ANOVA analysis.
- Due to the distribution characteristics of crash data, the application of standard linear regression models is not suitable to this type of data. Crash data is considered count data that usually follows a Poisson or Negative Binomial distribution. The fitted regression model is able to estimate the average crash frequency for each segment (or facility type) per year. Usually AADT and segment length are the two main independent variables of the model, but to identify if geometric characteristics influence the number of accidents at the studied site(s), they must be used as independent variables as well. The influence of each geometric characteristic is determined by the significance of its coefficient estimated by the model.

  In terms of sample size requirements, there is no common agreement on specific thresholds in the literature. Nevertheless, very small sample sizes (<10) may result in unreliable regression models, therefore caution should be used. Poisson and Negative Binomial regression analysis can be conducted with a statistical software package such as SPSS or SAS,

  It is out of the scope of this project to provide guidance on count data regression models but further details can be found on the recently published Highway Safety Manual (HSM) and related publications.

Again, the purpose of the systematic investigation is to further evaluate the sites which have an excess proportion of specific crash type to identify if: there are characteristics of the sites that have the potential to respond to safety treatments, characteristics of the sites that are common throughout the state or a portion of the state; treatments that could be implemented programmatically to reduce crash frequency. The following provides an example qualitative analysis from Pennington County and an example ANOVA analysis from statewide data.

5.5.3 Qualitative Analysis in Pennington County

A qualitative systematic evaluation will vary as a function of the data available, familiarity with the transportation system, and the crashes that are occurring. The purpose of the analysis is to gain an understanding of:

- What types of crashes are occurring most commonly?
- Where are the most common crash types occurring?
- Are there any similarities in the locations where the most common crash types are occurring?
- Are there any treatments that are known to address these crash types?
- In addition to the sites identified with the CAT, are there other locations in the state that have similar characteristics that should be treated with the potential treatment?

These questions can be answered by reviewing the ranked and mapped list of sites from the CAT, as well as with familiarity with the transportation system. In addition, the CAT database contains geometric data that can be mapped with the GIS tools associated with the software and that will also inform the analysis. The following provides an outline of typical questions the analyst should consider as part of the systematic evaluation:

1) Outcome from CAT is segments ranked by p_{DIFF}.
2) In a non-statistical systematic evaluation, review geometric and crash characteristics of ranked segments. Consider information in the database and local knowledge, seeking to understand potential crash contributing factors, site conditions and possible qualitative trends.
3) Consider:
    a) What are the geometric characteristics of the segments that are highly ranked?
        i) Rural/suburban/urban
        ii) Divided/undivided
        iii) Two-lane rural facility, rural, multi-lane facility
        iv) Pavement width
        v) Shoulder width
        vi) Lane width
        vii) Tangent/curvilinear
        viii) Presence of rumble strips (shoulder or centerline)
        ix) High volume/low volume
        x) Pavement conditions
        xi) etc.
    b) What are the characteristics of the crashes that are occurring?
        i) Daytime, nighttime
        ii) Weather conditions
        iii) Driver behavior
        iv) Crash type
        v) Crash severity
        vi) etc.
    c) Are there any linkages between "a" and "b"?
        i) Apply engineering judgment
        ii) Consider different categories of contributing factors: human, vehicle, environment and timing of event: before, during and after the crash
4) Possible Outcomes:
    a) What are known countermeasures that are effective on the segments that are under consideration? Source for countermeasures:
        i) AASHTO Highway Safety Manual - Review HSM Part D Crash Modifications Factors Chapter 13 Roadway Segments look for CMFs that are applicable to the setting under consideration (i.e. for two lane rural highways: adding or widening paved shoulders, modifying lane width, flattening side slopes)
        ii) FHWA Crash Modification Factor Clearinghouse
    b) Based on review of geometric characteristics and crash types would any of these countermeasures be applicable system-wide?
        i) Based on familiarity with the system via local knowledge or assessment of the system using the CAT how common are the conditions under consideration?
        ii) Based on CAT output, how common are the crash types under consideration?

For rural facilities in Pennington County, the crash types with the highest number of sites with an excess proportion were "animal" and "fixed objects off road" crashes. Figure 3 shows the results for rural facilities with "animal" and "fixed objects off road" crash types. The parentheses in Figure 3 indicate the number of sites with calculated excess proportion for each crash/facility type. This figure is a screen capture directly from the Crash Analysis Tool.

As shown, for Animal and Fixed Object Off Road Crashes, there are no facilities types with more than 30 segments identified by the performance measure. Therefore a statistical analysis is likely not possible based on the typically required sample size of 30 sites.

Table 4 and Figure 4 show example qualitative summaries for surface width as compared to the P_{DIFF} performance measure. From the two exhibits it can be seen that the majority of the segments which were identified as having an excess proportion had a roadway width of 24 feet; however there were a few that had wider and narrower widths. On a relative basis, the extremely wide (32 feet) and extremely narrow (22 feet) showed the highest mean performance measure. Therefore, using the Crash Analysis Tool, the relatively wide and relatively narrow segments could be located and evaluated further to consider further whether or not surface width is a contributing factor to the run off the road crash types.

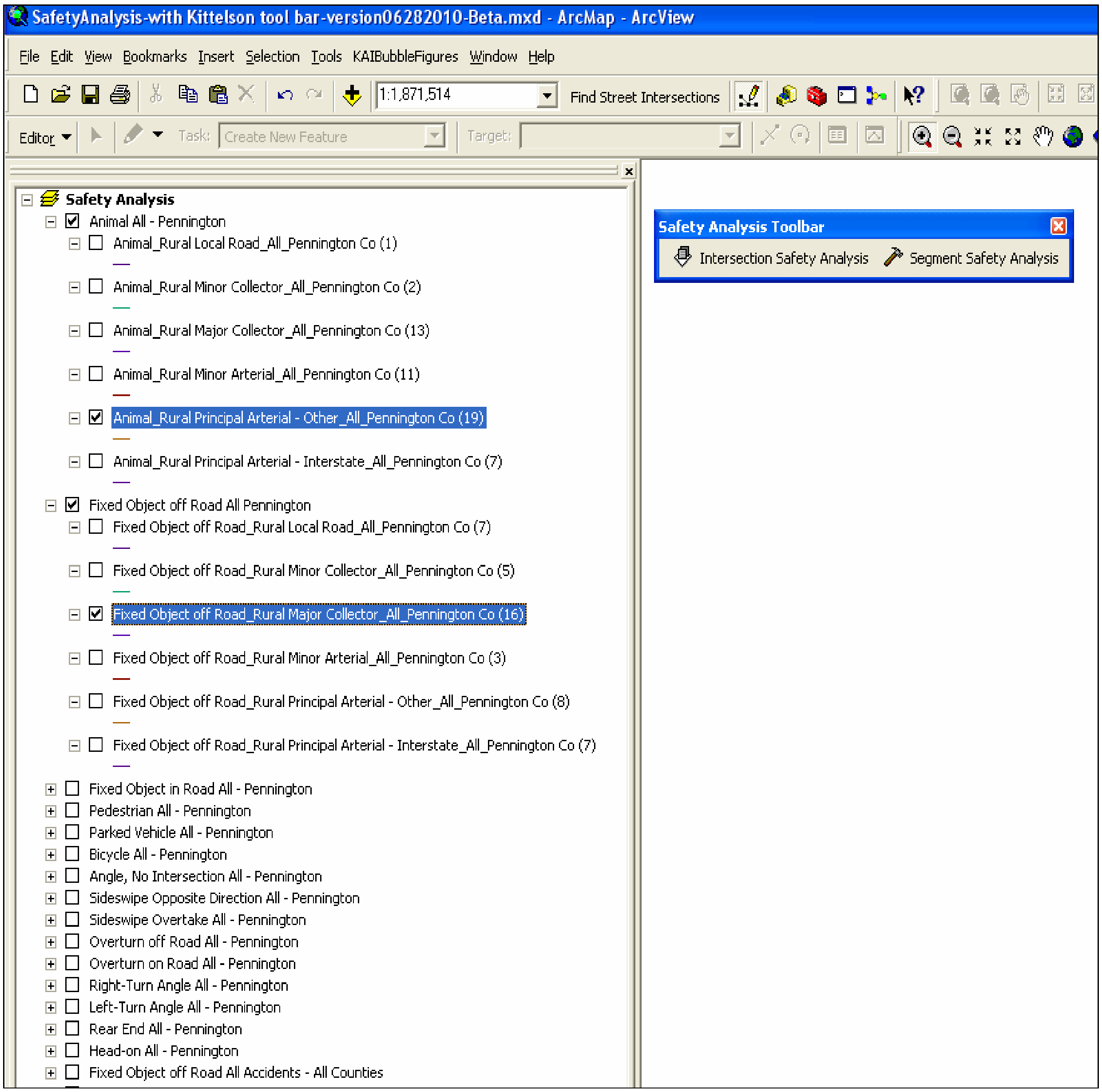

Figure 3: Crash Analysis Output–Pennington County/Rural Facilities

Table 4: Tabular Summary of Surface Width versus P_{DIFF}

SURFACE WIDTH (feet)	Mean Pdiff	N	Std. Deviation
22	0.65	1	.
24	0.33	9	0.25
26	0.31	2	0.00
28	0.35	2	0.42
32	0.65	2	0.00
Total	0.39	16	0.25

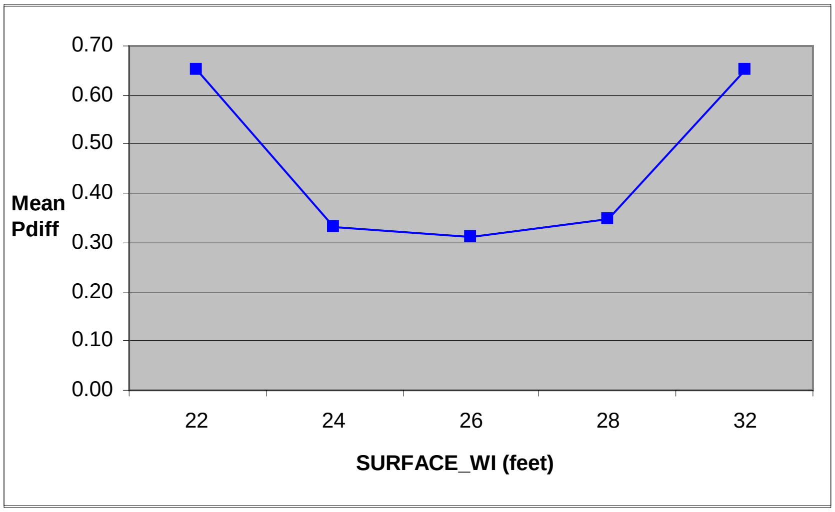

Figure 4: Graphical Summary of Surface Width versus P_{DIFF}

As described above, if the additional evaluations have identified potential countermeasures for the segment under consideration, the next step is to consider whether there is a need for a systematic improvement.

The characteristics of the spot site and potential countermeasures are used to identify potential applications throughout the state. The decision about application throughout the state is made through information about how common the geometric characteristics and potential contributing factors are in the state. If, based on the data available, local knowledge, and engineering judgment it is determined that the characteristics are common throughout the state and that the countermeasure could be effective throughout the state, then the countermeasure should be applied as appropriate throughout the state, independent of crash frequency. After the treatments has been installed and in place for two to five years, before/after analyses are conducted to verify safety effectiveness and the efficiencies of investment.

A similar qualitative assessment for shoulder width is shown below (Table 5 and Figure 5) and considering fixed object run off the road crashes. As shown in these two exhibits, considering frequency, there are a number of locations that have no shoulder and an excess proportion of run-off-the-road-crashes. While there are also locations that have two- and four foot-shoulders that had fixed object run off the road crashes and excess proportion performance measures, the relatively higher frequency of locations without shoulders would lead to further investigation at these locations first. In addition, there are known countermeasures that indicate that widening shoulders will reduce run-off the road crashes. Therefore, for the ranked locations widening shoulder would be beneficial. In addition and from a programmatic (systematic) perspective, identifying two-lane rural highways without shoulders and adding shoulders would reduce crashes and therefore have a longer term benefit that could be measured in follow up safety effectiveness evaluations.

Table 5: Tabular Summary of Shoulder Width versus P_{DIFF}

SHOULDER WIDTH (feet)	Mean P_{DIFF}	N	Std. Deviation
0	0.38	12	0.25
2	0.65	2	0.00
4	0.18	2	0.18
Total	0.39	16	0.25

Figure 5: Graphical Summary of Shoulder Width versus P_{DIFF}

Appendix H provides a summary of all of the geometric characteristics as compared to the mean P_{DIFF} for Pennington County.

5.5.4 Statewide ANOVA Analysis

While the sample size of segments with an excess proportion of crashes was not large enough at a County level to conduct an ANOVA analysis, through iterative analysis it was found that the sample size was large enough for some crash types at the statewide level. “Animal” and “fixed object off road” were the crash types with the highest number of sites with excess proportions; 555 and 116 sites respectively. Although SHOULDER_ W (feet) ties could have enough data for the ANOVA analysis. In the following, fixed object off road crashes are used to demonstrate how to interpret the results of an ANOVA analysis.

As described in Section 5.5.2, an ANOVA analysis is conducted using a statistical software analysis package such as SPSS or SAS. In this example, the SPSS software package was used. P_{DIFF} was the dependent variable and the following geometric characteristics were the independent variables:

- Surface width (SURFAC_WI)
- Surface condition (SURFACE_CO)
- Curb and shoulder configuration (i.e. on right and left, none, right only, left only) (CURB_SHLDR)
- Shoulder type (SHOULDER_T)
- Shoulder width (SHOULDER W)
- Speed Limit (SPEED_LIMI)
- Terrain (TERRAIN)
- Rideability (RIDEABILT)

Assuming a 95% confidence level, the independent variable coefficients with a significance level (Sig.) lower than 5% (.05) are identified as contributing factors to the P_{DIFF}. The main reason to look at these values is that if they are lower than 0.05, their estimated coefficients are significantly different from zero, and therefore relevant to the model (i.e., the variable is causing significant impact on P_{DIFF}). Table 6 provides a summary of the ANOVA output from SPSS. Appendix I provides more the detailed ANOVA output that statisticians would also consider.

Table 6: ANOVA Main Output – Significance of Coefficient Analysis

Source	Sig.
Corrected Model	.943
Intercept	.049
SURFACE_WI	.886
SURFACE_CO	.628
CURB_SHLDR	.491
SHOULDER_T	.653
SHOULDER_W	.516
SPEED_LIMI	.841
TERRAIN	.416
RIDEABILIT	.507
Dependent Variable: P_{DIFF} R Squared = .197 (Adjusted R Squared = -.126)	

As shown in Table 6, none of the independent variables presented an estimated significance level lower than 0.05 (with the exception of the model intercept). Thus, we can conclude that none of the considered geometric characteristics had a statistically significant impact at P_{DIFF}. This conclusion is supported by the scatter plots (P_{DIFF} compared to different geometric characteristics) presented in Appendix I and demonstrated in Figure 6.

The results here and details in Appendix I demonstrate the output and how to interpret results from an ANOVA analysis. As shown here results may be negative in that there are no identified contributing factors to the P_{DIFF} performance measure. Note that there may be other contributing factors (driver behavior, weather) not tested in this analysis. Therefore, this test is not necessarily comprehensive based on the data available in the database. It is also important to note, that in order to get a sample size large enough to apply the ANOVA test, the CAT had to be applied at the statewide level. This is important to note for future applications.

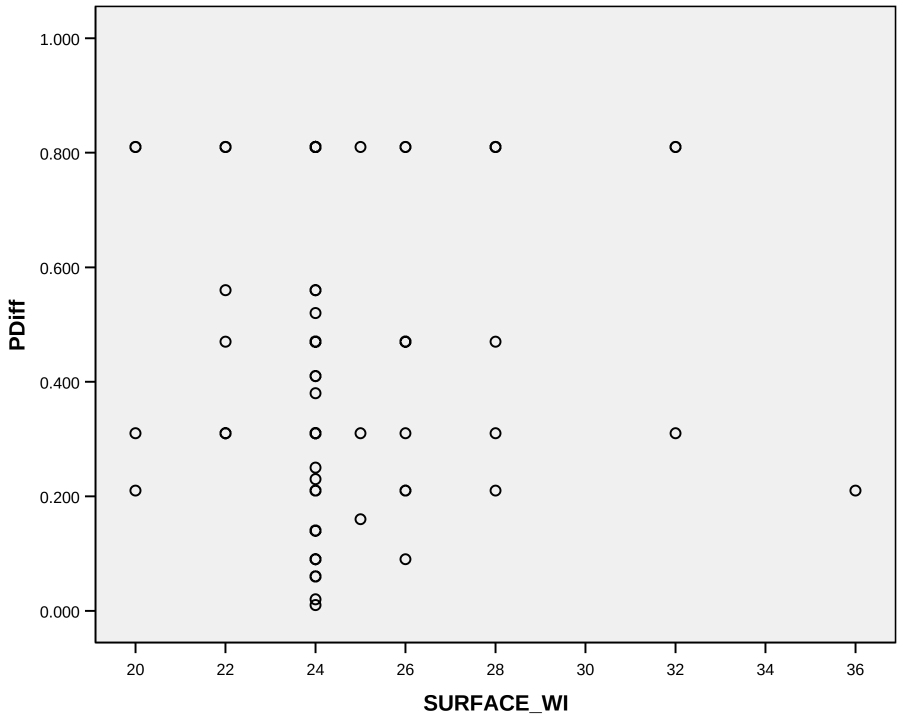

Figure 6: Scatter Plot – P_{DIFF} versus Surface Width

5.5.5 Potential Challenges and Suggested Solutions

The obvious potential challenges with a systematic analysis are that the crash data analyses do not provide statistically significant contributing factors, as demonstrated above. As identified above, this could be because the appropriate contributing factors were not in the database, or because the factors in the database did not contribute to the crashes under consideration.

In these cases, analysts are potentially faced with the challenge of moving forward with identifying and implementing systematic improvements without quantitative certainty of their decision. As is common in these cases, engineers will move forward relying on best practices from other engineering case studies to identify:

- What types of crashes are occurring most commonly?
- Where are the most common crash types occurring?
- Are there any similarities in the locations where the most common crash types are occurring?
- Are there any treatments that are known to address these crash types?
- In addition to the sites identified with the CAT, are there other locations in the state the have similar characteristics that should be treated with the potential treatment?

5.6 Other Findings

5.6.1 Project Identification at the Central or Regional Office

Two States in the Peer Review conversations believed that a critical consideration for SDDOT is whether the strategies and project identification occurs at the Central Office or Regional Office level. During Task 1, the Research Team learned that two of the peer states emphasized the importance of central office control over project identification and selection. The guidance from these States indicated that there would be a more efficient move toward programming of systematic improvements if project programming decisions were made at the Central Office level. However, the approach for project identification (i.e. central or regional) is heavily dependent on the organizational structure of SDDOT; therefore, this was subject to discussion at the Panel Meeting #2 in March 2010, and it was determined that a collaborative approach between the Central and Regional Offices should be maintained.

5.6.2 Programming – Funding Urban versus Rural of Improvements

As part of the prioritization/programming step of the process, other states are committing HSIP funds in proportion to the urban/rural split for fatal and serious-injury crashes. This distribution of funding would be consistent with the economic and social cost of crashes on the transportation system in the State. This could also be another way of forcing systematic improvements through a focus on rural improvements.

5.6.3 Programmatic Benefit-Cost Analysis

SDDOT currently applies benefit-cost analysis at the site specific level to identify the best treatments for a particular site. A programmatic benefit-cost analysis can also be conducted to determine the best mix of site project improvements/crash reduction for the investment. As an added value to this programmatic benefit-cost analysis, the SDDOT could implement incremental benefit-cost analysis procedures. This method is similar to a benefit-cost analysis, but provides additional insight on whether the increment of additional cost of a particular project at a specific site is economically justified; therefore it can be determined if (programmatically) the funding is being most effectively spent.

This method allows SDDOT to identify the mix of projects that provides the most safety benefit as compared to the cost. In this method the benefit cost ratio for each project is calculated. The projects and their benefit cost ratios are listed from highest to lowest benefit cost ratio (smallest cost is listed first). Starting with the largest benefit cost ratio, compare the difference between the benefits and the costs of project 1 and project 2 (i.e. benefits of project 1 – benefits of project 2 divided by cost of project 1 – costs of project 2). If the incremental benefit cost ratio is greater than 1.0, the project with the higher costs is compared to the next project on the list. If the incremental benefit cost ratio is less than 1.0, then the project with the lower cost is compared to the next project on the list. The process is repeated for all projects; each iteration leaving out the previously ranked projects. The resulting list is the best economic investment. A spreadsheet can be used to apply this method. Appendix F includes a sample problem from the HSM to illustrate the applications of the incremental benefit-cost analysis.

5.6.4 Evaluation – Before/After Studies

Periodically, SDDOT can evaluate its crash data to consider if fatal and injury crashes (and/or all crashes) are decreasing. The crash data would be considered against the investment programs to confirm spending has been effective. For example, if there has been an investment program to reduce single vehicle run off the road crashes, the SDDOT may want to conduct a before/after evaluation to confirm the effectiveness of the investment program. The evaluations could be done at a county, district, and/or statewide level depending on how crash reduction treatments have been programmed and what the safety effectiveness questions are.

There are a variety of types of before/after studies that can be conducted to test effectiveness of safety spending. It is critical that the before/after study methodology account for the potential impacts of regression-to-the-mean bias of crash data and have statistically adequate sample sizes. The AASHTO HSM provides guidance on how to conduct statistically correct before/after analyses. The critical element of these studies is that there is sufficient data and that proper sites are compared to avoid the impact of regression to the mean and either over or under-estimating the effectiveness of a particular program. With data currently available, SDDOT could conduct observational before/after studies which identify whether there has been a statistically significant shift in the proportion of crash types or severities. Details about how to conduct before/after studies are in the AASHTO Highway Safety Manual.

5.6.5 Investigations Database

As part of the evaluation step of the process, the Research Team has found that a site by site (i.e. intersection and segment) database recording issues studied, treatments implemented and results observed is a valuable tool for a jurisdiction. The database would provide information about what has been investigated at which sites, recommendations that have been considered and rejected and when treatments have been implemented. In the long run this database would be helpful at the safety evaluation level, by being able to more easily access data for before/after studies, and would add value for future safety decision-making as well as policy development. The database would be developed in a GIS environment.

5.7 Long-Term Program Development

The changes to the prioritization process previously described are intended to be enhanced in the long-term by introducing methods that account not only for observed crashes but also long-term estimates of crashes. This section describes longer-term considerations for the SDDOT related to analysis methods and data needs. The proposed modifications focus on the crash analysis, prioritization/programming and evaluation steps of the prioritization process.

5.7.1 Safety Performance Functions (SPFs)

The new AASHTO Highway Safety Manual will include safety performance functions (SPFs), which are equations that predict average crash frequency as a function of traffic volume and roadway or intersection geometric characteristics. The SPFs can be integrated into the network screening process to improve the identification of long-term expected average crash frequency for particular categories of sites (e.g. urban four-legged intersections, rural, multi-lane highways). The empirical Bayes method could then be applied to estimate an adjusted long-term expected average crash frequency as compared to observed crash frequency. The performance measures that use safety performance functions are the:

- Level of Service of Safety,
- Excess Predicted Average Crash Frequency Using Safety Performance Functions,
- Expected Average Crash Frequency with Empirical Bayes Adjustment,
- Equivalent Property-Damage-Only Average Crash Frequency with Empirical Bayes Adjustment, and
- Excess Expected Average Crash Frequency with Empirical Bayes Adjustment.

Detailed information about these methodologies can be found in Chapter 4: Network Screening of the AASHTO Highway Safety Manual. The SPFs provided in the HSM are shown in Table 7. These should be calibrated to local conditions prior to application in South Dakota.

Table 7: Safety Performance Functions Provided in the HSM

Facility Type	Undivided Roadway Segment	Divided Roadway Segment	Intersections: Stop Control on Minor Leg (s) 3-Leg	Intersections: Stop Control on Minor Leg (s) 4-Leg	Intersections: Signalized 3-Leg	Intersections: Signalized 4-Leg
Rural Two-Lane Two—Way Roads	✓	-	✓	✓	-	✓
Rural Multilane Highways	✓	✓	✓	✓	-	✓
Urban and Suburban Arterials	✓	✓	✓	✓	✓	✓

SDDOT could pursue a phased program of developing calibration factors for the SPFs in the HSM, in which the calibration factors are developed for highest to lowest priority facilities (for example, by center lane miles of facility, or frequency of intersection type, or frequency and severity of crash type).

5.7.2 Data Improvements

Incorporating SPFs requires additional data beside crashes by severity, type and location. The additional data needed is generally described below. A detailed list of the data required is presented in *NCHRP Research Results Digest 329*.

- traffic volumes (i.e. Average Annual Daily Traffic (AADT) for segment analysis, and AADT along the major and minor roads for intersection analysis);
- basic site characteristics such as roadway cross-section, shoulder type, intersection control, number of intersection legs, and lighting;
- calibrated SPFs and overdispersion parameters (as estimated in the model development)

Recognizing the expense and challenges of collecting data, the data could be collected as a function of:

- funding available for data collection;
- gaps identified in the data. The project team identified the need for collecting traffic volume (i.e. daily traffic volume) and geometric data at all intersection legs independent of the crash data history. The data should be collected as a separate database from the crash data. Additional gaps in the data would be identified as the prioritization process is implemented. The need for data collection based on this consideration is directly linked to the funding available and the need to further investigate crashes at specific locations.
- type and location of crashes identified as a priority from the crash analysis. As the prioritization process is implemented, SDDOT will be able to periodically understand what type of crashes are occurring the most and on which facilities. This will allow it to prioritize the types and locations of the data collection effort required.

5.7.3 Evaluation – Observational Before/After Studies

Incorporating SPFs into the prioritization process allows for implementing two additional study types for safety effectiveness evaluations. These observational before/after studies are the Empirical Bayes (EB) method and the Comparison-Group method, which are briefly described below.

- The Before/After analysis compares the observed crash frequency after a treatment has been implemented on a facility with the expected average crash frequency in the after period had the treatment not been implemented. The expected average crash frequency is calculated by applying the Empirical Bayes (EB) method which combines a SPF prediction of future crash frequency with observed crashes to obtain a more reliable estimate of crashes. The calculation is essentially a weighting that considers observed crash data and how well the safety performance function fits the data it was originally developed from. If the SPF fits the data very well, then the prediction is derived more heavily from the SPF. Conversely if the SPF did not fit the original data very well, then the prediction is derived more heavily from the observed crash data. Figure 7 provides a graphic demonstrating this concept.

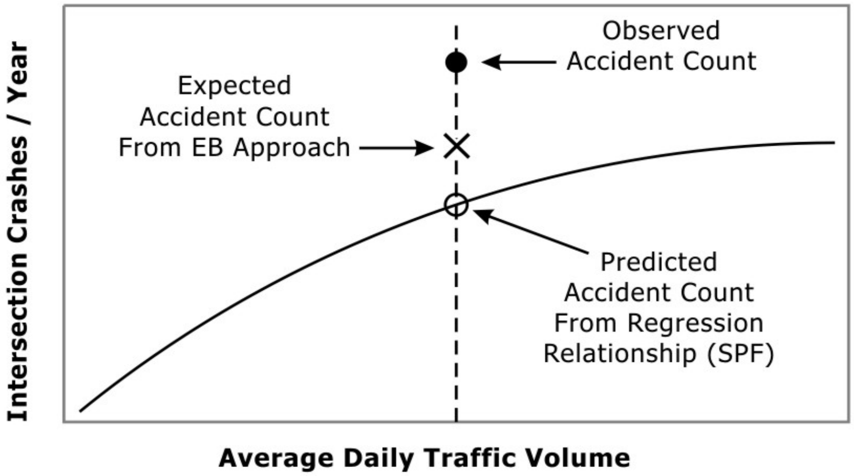

Figure 7: Example Demonstrating Empirical Bayes Concept

- The Comparison-Group method focuses on comparing the treatment group with non-treatment sites. The non-treatment sites are locations comparable with the treatment group from the point of view of site characteristics such as traffic volume and geometry. Under this method, the SPFs are used to adjust for the nonlinear relationship between crashes and traffic volumes in the before and after period.

A more detailed description of these types of safety effectiveness evaluations, data needs and sample problems can be found in Chapter 9 of the AASHTO HSM.

6.0 RECOMMENDATIONS

The project recommendations follow:

6.1.1 Urban High Crash Location Ranking

For urban environments, SDDOT should adopt the excess proportion method as applied in the Crash Analysis Tool as a performance measure for identifying high crash locations.

The Crash Analysis Tool will provide a ranked list of sites with potential to respond to safety improvements. The urban sites are appropriate for the ranking performance measure because crashes tend to be concentrated at intersections in urban environments. In addition, the recommended performance measure will identify which, if any crash types are exceeding an expected threshold and therefore provide an initial focus for the site diagnosis and treatment investigation.

6.1.2 Rural High Crash Location and Systematic Ranking

For rural environments, SDDOT should adopt the excess proportion method as applied in the Crash Analysis Tool for identifying sites with potential for safety improvement. In addition, SDDOT should adopt the systematic method as a means for identifying treatments for programmatic implementation.

Applying a combined ranking approach and systematic approach will reveal both trends by location as well as trends related to geometric characteristics that may respond to a programmatic treatment.

The excess proportion method will identify specific sites with potential for safety improvements. Sites will be ranked from highest to lowest potential to respond to safety improvement. Subsequently, each site will be evaluated to identify contributing factors and potential treatments to reduce crash frequency. In the secondary systematic approach to crash evaluation, the crash data are evaluated for trends on crash type and severity related to geometric characteristics. Systematic analyses look to implement crash countermeasures programmatically throughout the system in addition to known site specific issues. The process to identify treatments for implementation relies on evaluation of crash data, familiarity with the transportation system and engineering judgment.

6.1.3 Intersection Database

SDDOT should build and maintain an intersection physical characteristics and traffic volume database on South Dakota's state and non-state trunk highway systems.

Intersection data (e.g. traffic volume, number of legs, traffic control) is currently only collected if a crash has occurred at the particular intersection and is recorded in the Department of Public Safety crash database. SDDOT needs a stand-alone intersection geometric characteristics database that includes all intersections on state and non-state trunk highway systems. Today there is a roadway segment database with geometric characteristics. The advantages of a similar intersection dataset are that intersections could be categorized with more complete data and therefore more consistent comparisons could be made. Further, if intersection data were collected off of the state highway system, SDDOT would be able to investigate and identify solutions for non-state system facilities.

6.1.4 Roadway Database

SDDOT should expand the roadway characteristics and roadway traffic volume database on South Dakota's state and non-state trunk highway systems.

The roadway characteristics and roadway traffic volume database that the State currently maintains is adequate for initial analyses, but there is limited data for the local roadway system. This is not uncommon, but it is a gap that can be closed over time so that the roadway system can be more comprehensively evaluated and crash occurrence off the state system can be studied and addressed. The array of geometric data that can be collected is presented in Section 5.7.2. Specific items will to some extent be driven by the types of roadways under investigation and the types of analysis methods being applied.

6.1.5 Fatal and Injury Crashes

SDDOT should use fatal and injury-only crashes in the prioritization process when possible.

Using fatal and injury-only crashes in the prioritization process ensures that the State is responding to the most severe crashes, and that the State is not spending limited resources providing treatments at sites with property-damage-only (PDO) crashes. Due to the low number of crashes, the State's current prioritization process considers all crash severities. Broadly speaking, PDO crashes occur where there are relatively slow travel speeds, and higher roadway congestion. In these cases, it can be difficult to identify solutions to reduce the frequency of crashes (beyond reducing traffic volume). Therefore, including PDO crashes in the prioritization process can yield "false positives." By excluding PDO crashes, the State can focus on the most severe crashes and have more opportunity to identify sites with potential to respond to safety improvements. In some cases, particularly rural areas, the number of crashes may be limited requiring that all crash severities, including PDO, be considered in the analysis.

6.1.6 HSIP Funding

SDDOT should program HSIP Funding in proportion to the costs of fatal and injury crashes in urban and rural environments.

The cost of improvements in urban and rural environments can vary dramatically as a function of right of way costs, degree of the surrounding development, and degree of surrounding infrastructure. In addition, the most severe crashes typically occur in rural environments because of higher travel speeds. To make sure that the State appropriately plans for and programs improvements addressing both urban and rural crashes, it is recommended that the State allocate HSIP funds in proportion to the financial impacts of urban versus rural crashes. For example, if it is estimated that the urban crashes are 40% of the costs of crashes in South Dakota, then it is recommended that 40% of the HSIP funding be spent on urban improvements. FHWA provides nationally developed crash costs.

6.1.7 Evaluation Program

SDDOT should establish an evaluation program to investigate the before/after benefits of the implemented programs.

One reason this research project was undertaken was to help SDDOT fully allocate its federal safety dollars to safety improvements. To ensure that this research project and subsequent SDDOT safety programs are effective, SDDOT staff should establish before/after evaluations to confirm that programmatic spending is yielding the desired benefits. The before/after studies would investigate changes in crash frequency and severity as a function of dollars spent over time and determine whether benefits were being achieved. If not, programs could and should be modified so that benefits are achieved. Caution is advised that the before/after studies should be conducted with appropriate statistical rigor to ensure results are statistically significant and do not reflect random variation in crash data.

6.1.8 Investigations Database

SDDOT should develop and maintain a site by site (i.e. intersection and segment) database recording issues studied, treatments implemented, and results observed.

As SDDOT's program matures, there will be a) many sites that are investigated for potential safety improvements; b) many sites that receive improvements; and c) many years of data and information about the investigations that have been conducted, the treatments that have been considered, and the treatments that have been installed. The State should begin developing a GIS-based database to record studies conducted, treatments implemented, constructions costs, roadway characteristics, etc. so engineers and planners can review the database and understand the history of analyses and investigations at any site. As locations are studied, information about the investigation would be recorded on a site by site basis into the database. A form could be developed for electronic data recording in the field and subsequent data entry. The database would flag locations with investigations information. The user could point and click on the symbol and review the data form of investigations at the particular site.

7.0 RESEARCH BENEFITS

The benefits of implementing the previously stated recommendations will be reduced crash frequency and crash severity on state and local roadways. The benefits will be achieved through a program of rigorous prioritization, programming, and subsequent evaluation to test the effectiveness of project and program spending. The project recommendations include developing an evaluation program. This element of the program should be considered as critical as the initial screening and programming elements.

The before/after evaluation program should be conducted to verify effective project and program spending and confirm that crash frequency and severity is decreasing and that investments are appropriately targeted. This evaluation program could also be integrated with the Strategic Highway Safety Plan to ensure success in its crash focus areas.

This research identified additional potential data needs and analysis methods assuming additional data is collected by SDDOT. As this data becomes available the analysis options for SDDOT will expand to potentially integrate into design procedures and include more rigorous prioritization procedures. In the long-term, it is anticipated that the more rigorous procedures will lead to yet more efficient spending of State and Federal dollars.

Finally, many State Departments of Transportation are currently adopting Toward Zero Death policy positions. In these cases, eliminating fatal and severe injury crashes are the long-term performance measures for the DOTs. The Crash Analysis Tool and the Systematic Evaluation are analysis methods to support such policy decisions.

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APPENDIX A: LITERATURE REVIEW

National Literature Review

NCHRP Report 500, Guidance for Implementation of the AASHTO Strategic Highway Safety Plan, Volume 21, Safety Data and Analysis in Developing Emphasis Area Plans

This guide focuses on emphasis area safety planning under AASHTO's Strategic Highway Safety Plan (SHSP) addressing situations in which relevant crash data are available. The guide introduces a three-stage procedure for identifying the emphasis area plan: (1) define and choose the emphasis area, (2) set a crash, injury or death reduction goal, and (3) define treatment strategies and the target population to meet the goal. This third step of the process is further divided into four procedures based on data availability:

- Procedure 1: For roadway treatments with known effectiveness and a complete set of data (crash data, roadway inventory and traffic data);
- Procedure 2: For roadway treatments with known effectiveness and crash data;
- Procedure 3: For roadway treatments with no specific level of effectiveness (i.e. not known crash/injury) and driver treatments with or without known effectiveness; and
- Procedure 4: Combination of Procedures 1, 2 and 3 for both treatments with and without known effectiveness.

The guide also provides information related to safety planning data types (e.g. crash data, roadway inventory data, traffic volume data, driver history files, vehicle registration files, Statewide Injury Surveillance System, National Emergency Medical Services Information System, Census files and citation tracking and DUI tracking) and specific applications of the process for roadway segments, junctions, special road users, illegal driver actions, unsafe driver actions, special vehicles, work zones, and Emergency Medical Services (EMS). General discussion relating to improvement of agency data systems is also provided.

The three-stage process described above is a potential application for treatment selection when developing the analysis methodology alternatives under Task 6. This process would allow the evaluation of treatments based on benefit-cost analysis (Procedure 1, 2 and 4) and non-economic analysis (Procedures 3 and 4). It is significant to note that the development of separate plans for each emphasis area identified as priority for SDDOT would be required under this methodology.

NCHRP Report 501, Integrated Safety Management Process

The report describes the Integrated Safety Management System (ISMSystem) with a focus on the Integrated Safety Management Process (ISMProcess), a six-step procedure to maximize highway safety. The ISMSystem allows integrating the efforts of different agencies within a jurisdiction to maximize safety by allocating different responsibilities to specific groups or people. The ISMSystem was developed to support safety plans. The ISMProcess, a component of the ISMSystem, allows agencies to develop a detailed action plan. The steps of the ISMProcess as defined in this report are:

1. Review highway safety information.
2. Establish emphasis area goal.
3. Develop objectives, strategies, and preliminary action plans to address the emphasis areas.
4. Determine the appropriate combination of strategies for identified emphasis areas.
5. Develop detailed action plans.
6. Implement SHS Plan and evaluation performance.

As part of Step 3, the report provides examples for identifying crash concern and developing strategies. Some of the example methods provided include: network screening, *SafetyAnalyst*, frequency-rate method, an integrated roadway-crash file used in Alabama. The optimization of strategies is identified as part of Step 4, and is divided in the following three stages: (1) identify the subset of data that will provide information on the emphases areas and objectives, (2) analyze crash characteristics of emphasis area subsets to identify potential benefits, and (3) determine the most effective combination of strategies considering elements such as cost, funds, and effectiveness.

The information presented in this report provides general tools for planning, optimization, and implementation of highway safety, and allows for a clear understanding of the needed coordination among agencies to maximize safety. The example provided under Step 3 as well as the optimization stages are elements to consider when identifying methodology alternatives under Task 6 of this project.

NCHRP Research Results Digest 329, Highway Safety Manual Data Needs Guide

This guide provides a summary of the data required to apply the methodologies presented in Part C – Predictive Methods of the Highway Safety Manual (HSM), 1st Edition, which focuses on safety predictions for rural two-lane and multi-lane highways as well as for urban and suburban arterials. The three data types needed to conduct the analysis are defined as site characteristics data, traffic volume data, and crash data for roadways and intersections. The data is intended to be used for: (1) dividing the project into homogeneous roadway segments and intersection, (2) calibrating the predicted model, (3) applying the methodologies, and (4) applying the EB method. The guide presents a complete list and detailed descriptions of all data required for Part C analysis. This information is a useful resource for determining data needs for safety improvements under Tasks 4 and 5, as well as for evaluating analysis methodologies under Task 6.

Prediction of the Expected Safety Performance of Rural Two-Lane Highways, FHWA-RD-99-207

This report presents an accident prediction algorithm for rural two-lane highways that combines the previously used safety estimation approaches of historical crash data, regression analysis, before-and-after studies, and expert judgment. The algorithm is based on a base model, accident modification factors (AMF), calibration factors, and Empirical Bayes (EB) method. This report includes a base model for roadway segments and three types of at-grade intersections (three-and four-leg intersections stop controlled on minor approaches and four-leg signalized intersections). AMFs to account for site-specific geometric and traffic control characteristics as well as calibration factors to account for local conditions are documented in this report. The EB method is intended to be used when historical crash data is available to better estimate the expected crashes of a given location. The overall process described in this report is consistent with the predicted methods in Part C of the HSM. Potential application to this project relates to estimates of expected average crash frequency on rural two-lane roadways considering both historical data and predicted methods, and can be considered as a methodology alternative under Task 6 of this project.

Highway Safety Manual, Part B: Roadway Safety Management Process, Chapter 4: Network Screening

The first edition of the Highway Safety Manual (HSM), scheduled for publication in early 2010, will provide the tools to assess the quantitative safety effects of planning, design, operational and policy decisions. The HSM will be organized in four parts: Part A Introduction and Fundamentals, Part B Roadway Safety Management Process, Part C Predictive Methods, and Part D Crash Modification Factors. Part B, Chapter 4 presents the network screening process, which is the first step of the roadway safety management process. This chapter provides the tools for reviewing a transportation network to identify and rank locations with the greater potential of a reduction in crash frequency following a particular countermeasure. The five steps of the network screening process are:

- Step 1 – Establish Focus
- Step 2 – Identify Network and Establish Reference Population
- Step 3 – Select Performance Measures
- Step 4 – Select Screening Method
- Step 5 – Screen and Evaluate Results

When selecting performance measures data availability, regression-to-the-mean bias, and how the performance threshold is established are the key factors to consider. The three screening methods (sliding window, peak searching, and simple ranking) presented in this chapter can be applied to segments, nodes or facilities to identify sites in need for further study. The network screening process is a potential application to consider under the analysis methodologies alternatives (Task 6) of this project.

SafetyAnalyst, FHWA & AASHTO

SafetyAnalyst is a set of software tools developed to guide and improve the programming of site-specific highway safety improvements at the state and local level. *SafetyAnalyst* can analyze the safety performance of a site, recommend countermeasures, quantify the benefit and evaluate the effectives of the countermeasures. The six software programs provided are:

- Network Screening Tool
- Diagnosis Tool
- Countermeasure Selection Tool
- Economic Appraisal Tool
- Priority Ranking Tool
- Evaluation Tool

The network screening toll is intended to help highway agencies identify sites for safety improvements for spot locations and roadway segments. The tool allows for the identification of sites with higher than expected crash frequency and sites with crash frequency not higher than expected but with enough crashes to warrant cost-effective measures. Sites with high level of severe crashes or particular crash types can also be identified. The network screening tool is a useful resource to consider as an alternative to be evaluated under Task 6 of the project.

Alternative Strategies for Safety Improvement Investments, January 2010, NCHRP Project 17-18(19)

This report highlights that states are currently trying to focus their safety planning efforts toward fatal and serious injury crashes. The passage of the SAFETEA-LU required the development of Highway Safety Improvement Programs (HSIP) that document the process for reducing fatal and serious-injury crashes on ALL public roads. The report also describes the high crash location and systematic methods, and identifies concerns of the high crash location approach when allocating safety resources such as the tendency to point to urban areas with high traffic volumes. The systematic approach is described as a way to address the low density of severe crashes in rural areas and to complement the high crash location analysis. Crash statistics are also presented. For example, it is shown that nationwide 56% of fatal crashes are reported to occur in rural areas and approximately 50% of these in the local system. The report also documents case studies of how Iowa, Minnesota, Missouri, and North Carolina are allocating their funds for safety improvements. For each state, the document describes:

current method (high crash location vs. systematic), rural vs. urban and state vs. local funding distribution, SHSP considerations, organizational structure, funding mechanism, and evaluation, as well as strengths, weakness, and potential improvements of the HSIP approach. The participating states are all attempting to transition to a program that accounts for rural/urban funding distribution that relates to their severe crashes and that balance high crash location method for particular locations with a systematic approach that allows for low cost improvements on the rural system. Finally, the report identifies the following two key challenges for the transition: 1) methodologies and tools to support safety planning efforts, and 2) safety experience at the local level.

State Literature Review

South Dakota Strategic Highway Safety Plan (2007)

The *Strategic Highway Safety Plan* (SHSP), produced by the SDDOT, is intended to be "an interagency, multidisciplinary plan for greater cooperation among the South Dakota public and private organizations wanting to reduce needless deaths" on the state's highways. State organizations with a role in traffic safety include the following:

- **Department of Public** Safety
  - Office of Highway Safety—develops the annual Highway Safety Plan and coordinates driver education efforts
  - South Dakota Highway Patrol—enforces traffic laws on state highways
  - Office of Motor Carrier Safety—prepares a commercial vehicle safety plan
  - Office of Emergency Medical Services—in partnership with the Office of Highway Safety, supports ambulance services and training
  - Driver Licensing Program—administers drivers' licensing and maintains driving records
  - Office of Accident Records—receives and processes traffic crash reports and produces the annual Motor Vehicle Traffic Crash Summary
- **Department of** Transportation
  - Roadway Safety Improvement (RSI) Program—identifies and reviews crash-prone locations and generates safety improvement projects for inclusion in the Statewide Transportation Improvement Program (STIP).
  - Office of Road Design—incorporates safety elements into projects conducted for other reasons (e.g., resurfacing)
  - Traffic and Safety Engineer—with funding from the federal section 402 highway safety program, supports local governments on signing and safety issues.
  - Road Safety Audit (RSA) and Road Safety Audit Review (RSAR)—new processes at SDDOT, these use independent teams to analyze design plans for safety-related deficiencies (RSA) and to conduct on-site roadway inspections (RSAR).
  - Railroad Crossing Improvement (RCI) Program—implements safety improvements at public grade crossings of active railroad tracks.
  - Office of Transportation Inventory Management—manages transportation data used in safety improvement efforts
- **Office of the Attorney General—**Supports efforts to aggressively prosecute individuals who sell alcohol to minors, funds alcohol monitoring bracelets for individuals convicted of drunk driving, and hosts a Traffic Safety Resource Prosecutor.

- **Department of Education—**Monitors school bus driver training and certifies driver education instructors.
- **Department of Health—**Promotes safety for children walking to and from school.
- **Department of Social Services**—Supports child seat usage efforts.

The above agencies, along with about 60 other private and public organizations, are represented on the state's Roadway Safety Advisory Committee.

The SHSP reports the following traffic safety statistics in the following categories:

- Fatal crashes per 100 million vehicle miles traveled (VMT), with trends and comparisons to neighboring states
- Traffic crash fatalities per 100,000 population, with comparisons to neighboring states
- Total crashes, injury crashes, fatal crashes, and deaths, with trends.
- Percentage of fatal crashes involving alcohol use.
- Percentage of crashes involving an animal.

According to the SHSP, the state's data on fatal crashes is accurate, but knowledge of total crashes is incomplete because crashes on Indian reservations are underreported. In addition, hospital trauma reporting is "spotty" and records of emergency medical service provision are considered incomplete after 2001.

The SHSP identifies the following goals for reducing fatalities:

- By 2010, reduce the fatality rate per 100 million VMT to just above the 2005 national average, and by 2015, reduce total fatalities by 53% from 2005 levels.
- Reduce both the total number of fatalities and the total number of crashes by 5% annually through 2010.

Core strategies for reducing highway fatalities and crashes consist of education, enforcement, engineering, and emergency services. The safety emphasis areas are: impaired drivers, occupant protection, run-off-the-road and head-on collisions, preventing crash fatalities and injuries among young drivers, speed management, emergency response services, preventing deer-auto collisions, improving data collection, and improving data analysis. The SHSP provides goals, strategies, and performance measures for each of these emphasis areas.

The SHSP identifies DOT safety-related programs that have built-in prioritization processes, but generally does not provide details of the processes. These programs include:

- Roadway Safety Improvement (RSI) Program: "A review team performs an on-site inspection of a location when warranted by the crash pattern, crash rate of 2.0 or greater, and a potential benefit/cost ratio of 1:1 or more. The review team then recommends any safety improvement for the location as an RSI project in the STIP."
- Railroad Crossing Improvement (RCI) Program: "Potential projects for the RCI program are identified in various ways, such as a request from the roadway authority or railroad; crossings that require attention due to highway construction; crossings that are crash scenes; and crossings that are rated high by index rating formula. Projects eligible for these funds are ranked and programmed according to the allowable budget. The RCI projects are listed in the annual STIP."

The SHSP supports Task 3, by identifying some of the highway safety programs that have prioritization processes in place, and Task 5, by providing insights into the quality of some of the state's safety-related data. Task 6 specifically calls out that the analysis methodology selected by this project must support the SHSP.

Highway Safety Plan (2010)

This plan, prepared by Office of Highway Safety (OHS), identifies the 2010 highway safety priority areas and performance goals relating to the performance (core outcome) measures mandated by the National Highway Traffic Safety Administration (NHTSA). The state's Roadway Safety Advisory Committee and the Traffic Records Coordinating Committee provided input to the plan. The highway safety priority areas identified are divided in three different types:

- Major Contributing Factors: Occupant Protection, Impaired Driving, and Speeding.
- Special Populations: Motorcycle Safety, Young Drivers and Pedestrian and Bicyclist Safety
- Additional Areas: Traffic Records, Engineering, Roadway Safety Committee , Sioux Empire Driver Education, Emergency Response Services, DUI Court – 6th District, Driver Attitude and Awareness Survey, Safe Community Program Management, Planning and Administration

The plan presents detailed data of core outcome and behavior measures, identifies performance goals, and describes specific programs/projects for each of the priority areas.

Highway Safety Plan (2009)

Consistent with the 2010 Highway Safety Plan described above, this plan identifies highway safety focus areas for 2009, "The goal was to identify the most significant problem areas impacting the State's crash statistics." Focus areas for 2009 relating to contributing circumstances to injury and fatality crashes are: alcohol-impaired drivers, occupant protection, and speed enforcement. Focus areas relating to special highway user populations are: motorcyclists, young (under 21) drivers, and pedestrians and bicyclists. The plan describes the circumstances that led each focus area to be selected, presents data related to the focus area, identifies performance goals and measures, and describes fiscal year 2009 projects pertaining to the focus area.

The Highway Safety Plan supports Tasks 3, 4, and 6, by identifying the state's highway safety focus areas and performance measures that will be used to determine the state's progress toward meeting its safety-related goals.

South Dakota Motor Vehicle Traffic Crash Summary (2008)

This document provides trend information on alcohol involvement, injury severity, sex of drivers, and restraint usage associated with motor vehicle crashes, as well as overall crash trends. Additional information provided includes summaries by travel mode (e.g., trucks, pickups/vans, motorcycles), vehicle type, first harmful event, manner of collision (e.g., rear-end, angle), highway system, county, city, roadway surface condition, time of day/month/week, age of drivers and drinking drivers, contributing circumstances (vision obscurement: road conditions, including presence of animals, pedestrians, and bicyclists; and driver errors), motorcyclist age and helmet use, pedestrian age and alcohol use, and bicyclist age. The document also provides a timeline of important events that may have impacted crash trends (e.g., enactment and later repeal of the national 55 mph speed limit) and includes definitions of key safety-related terms.

South Dakota's Crash Data System is said to conform to the Model Minimum Uniform Crash Criteria (MMUCC) guidelines, allowing South Dakota's data to be directly compared to data from other states.

Crash data are compiled by the Office of Accident Records (Department of Public Safety). South Dakota law currently requires accident reports to be filed for each motor vehicle crash resulting in the death or injury of a person, $1,000 or more of damage to any one person's property, or $2,000 or more of cumulative damage.

This document supports Task 5, by helping to identify some of the types of crash data collected and summarized in South Dakota.

South Dakota Motor Vehicle Traffic Accident Reporting Instruction Manual (2006)

This manual, prepared by the Office of Accident Records (Department of Public Safety) is written for the use of South Dakota's law enforcement personnel in determining whether an accident is reportable and, if so, how to complete an accident record. From the standpoint of this project, this document identifies all of the data that are routinely collected on South Dakota's accident reports and provides keys to all of the codes used for each field in the accident report. Definitions of terms used on accident records are also provided. This information will support Task 5, by identifying the specific crash data collected and reported in South Dakota.

The manual also clarifies that the $2,000 cumulative property damage threshold that triggers the filing of an accident report must involve property belonging to <u>three</u> or more persons.

Factors Contributing to South Dakota Crash and Fatality Rates (2005)

This report, prepared by Purdue University for SDDOT, focuses on identifying reasons why South Dakota's crash and fatality rates are higher than those of peer states. The study was hampered by data availability issues with neighboring states, tribal governments, and lack of federal approval for a survey of Fatality Analysis Reporting System (FARS) analysts. Specifically:

- "[Neighboring] state crash databases, much of the demographic data by county, and information on traffic crash reporting procedures could not be obtained through publicly available resources for all six states. These data elements were specifically pursued by working with representatives from each state, and success rates varied."
- A "survey was created to be sent to individual tribal communities in order to determine reporting practices on Indian Reservations, as well as seek out tribes who might be willing to share their internal crash databases…. However, SDDOT deemed such a survey to be outside the scope of the project and did not want to risk the alienation of state-tribal relations at that time, and thus the survey was never administered."
- Another short survey was prepared for FARS analysts, "for an assessment of their data collection procedures and how they interpret the variables collected. However, a national FARS representative from the National Highway Traffic Safety Administration (NHTSA) advised Purdue… that FARS is a federally funded program and clearance must be obtained through the NHTSA headquarters office to administer such a survey before the State FARS analysts could participate; additionally, [Purdue] was advised that such a survey would not be granted clearance because FARS analysts are not paid to spend their time offering perceptions or opinions."

The project listed six key focus areas that the research identified as contributing to South Dakota's higher fatality and accident rates, or that involved incomplete traffic record data that will need to be addressed before accurate state-to-state comparisons can be made. These focus areas were:

- Underreporting of Native American crashes. The research identified that this was a problem not acknowledged at the time in the SHSP, but one that needed to be addressed before accurate comparisons could be made. The research developed an underreporting model based on comparisons of reported crashes in counties with tribal lands to reported crashes in counties without tribal lands.
- Rollover crashes. The percentage of South Dakota crashes where vehicle rollover was coded as the first harmful event was three times the national average in 2003, and the fatal rollover rate per 100 million vehicle miles traveled (VMT) has been increasing since 1998.
- Restraint usage. At the time, South Dakota had only a secondary seat belt law for motor vehicle occupants aged 18 and up (i.e., an occupant can only be cited if the vehicle is pulled over for

another reason). The law was primary for occupants aged 0–17 years. Between 1998 and 2003, the percentage of motor vehicle fatalities that were restrained dropped from 24% to 18%.

- Alcohol usage. The percentage of alcohol involvement in crashes has been trending upward at the same time that overall South Dakota fatality rates increased. The percentage of alcohol involvement in South Dakota crashes was much higher than the national average. Because of underreporting of Native American crashes, and observed trends in the increase of alcohol-related crashes in counties with tribal lands, the problem may be even more serious than indicated by the data.
- Speeding. Speeding as a contributing factor to crashes had increased, and South Dakota was among the highest 10 states for speed-related fatalities per 100 million VMT.
- Young drivers. Involvement in a motor vehicle crash was the leading cause of death among individuals 15–20 years old.

This report identifies data deficiencies that will need to be considered by this project (Task 5) and focus areas that the Task 6 methodology development may need to support. The report's model for correcting for underreported crashes could be considered for incorporation into the Task 6 methodology (but see also the 2007 report below on underreporting of crashes on Indian reservations).

Updating South Dakota Crash Frequencies and Crash Reduction Factors (2004)

This report, prepared internally by the SDDOT, evaluated all RSI projects completed between 1994 and 2000 and calculated accident reduction factors (ARFs) and severity reduction ratios (SRRs) based on those projects, along with benefit/cost ratios based on the project outcomes. Only two treatments ("cold plastic pavement markings" and "install signal with pavement markings") had the minimum 10 intersection examples that would allow South Dakota–specific ARFs and SRRs to be adopted. It was recommended that South Dakota continue to use external ARFs and SRRs for other treatment types until a given treatment type had been applied to at least 10 intersections and updated ARFs and SRRs calculated. The two sets of South Dakota–specific values can be considered for incorporation into the Task 6 methodology.

The report notes that SDDOT's Office of Local Government Assistance uses ARFs in its process for determining future RSI projects.

Improving Motor Vehicle Crash Reporting on Nine South Dakota Indian Reservations (2007)

This report, prepared by ICF International, Inc. for the SDDOT, evaluated the state of crash reporting on South Dakota's Indian reservations and provided recommendations for improving the process. Crash data are collected by tribal law enforcement officers and Bureau of Indian Affairs (BIA) officers, but procedures vary from tribe to tribe and only 52 of the 737 crash reports collected were in a form that could be input to the state's Accident Record System. If it is assumed that the 737 crash reports account for all of the reportable crashes on Indian reservations, then 64% of crashes that occur on Indian reservations do not appear in the state's records or in statistics derived from those records. This hampers the state's efforts to target roadway improvements and enforcement and education efforts, and causes the tribes to lose out on federal safety improvement funding that would help improve roadway safety on reservations.

A meeting with tribal law enforcement officers identified three possible solutions to improved crash reporting: (1) better training of tribal law enforcement officers on the reporting forms used by South Dakota, (2) software solutions for internal tribal data processing, and (3) an improved political climate between the tribes and the state. An additional recommendation that came out of the study was that the

SDDOT "should motivate crash reporting by actively facilitating the identification of rural hazards on tribal lands and by funding improvements."

The data on underreporting of tribal crashes could be considered for incorporation into the Task 6 methodology. However, if the report's recommendations are being implemented and crash reporting has improved, then the underreporting factor stated in the report may no longer be valid.

Identification of Abnormal Accident Patterns at Intersections (1999)

This report, prepared internally by the SDDOT, developed average, 90th-percentile, and 95th-percentile values of accidents at 14 different intersection types. Four intersection types had less than 30 examples across the state and, therefore, data from all intersections of that type were used to develop the percentile values. A sampling method was used to develop percentile values for the other ten intersection types. For each intersection type, percentile values are provided for collision type, severity, light condition, surface condition, season of year, day of week, hour of day, and alcohol/drug involvement. It was recommended that these values be updated every 3 years.

Current percentile values could be considered for incorporation into the Task 6 methodology, for use in identifying abnormal accident patterns.

Identification of Methods for Truck Crash Reduction (1999)

This report was prepared by the University of South Dakota for the SDDOT. Consistent with national trends, trucks are more likely to be involved in fatal accidents than motor vehicles as a whole. Areas of interest identified by the report included:

- Sites on Interstate highways where multiple truck crashes have occurred have typically been around entry and exit points (including rest area entries and exits), where the truck is generally going straight and another vehicle fails to yield to the truck.
- Trucks with gross vehicle weights (GVWs) of 80,000–120,000 lb constituted less than 10% of the total truck population, but were involved in nearly half of all truck-related crashes, and had a fatality rate 2.7 times that of trucks with GVWs in the 40,000–80,000 lb range.
- The Interstate system is highly used by trucks and experiences the most truck crashes of any roadway type.
- The data were not able to identify any particular trucking companies that were statistically more likely to be involved in a crash.

At the time of the report, the South Dakota Motor Vehicle Traffic Accident File did not contain certain fields that would allow contributing factors to truck crashes to be identified. A separate database, SAFETYNET, did contain the data of interest for the same crashes, but the two databases lacked a common key that could be used to link crash data from one database to the other. Therefore, a key focus of the research was to develop a "probabilistic linkage software tool" that could be used to link the two databases. A similar approach could be considered during the Task 6 methodology development, if it turns out that it would be useful to link multiple databases that lack a common key.

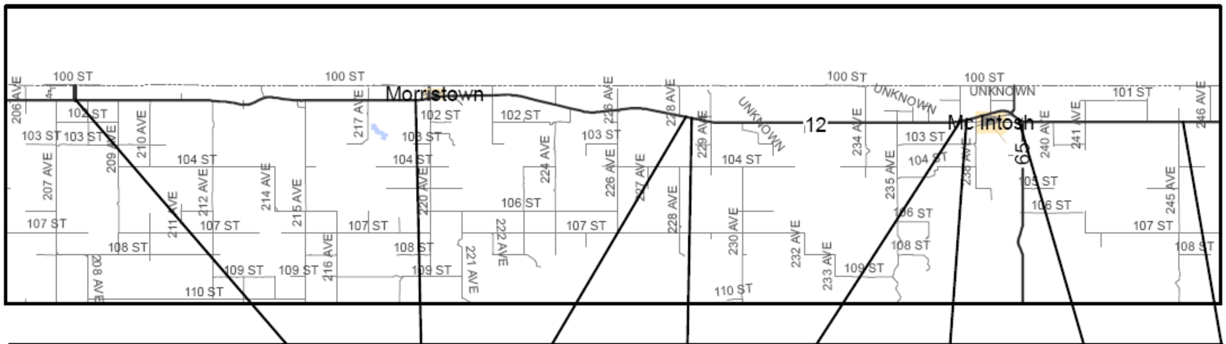
Highway Needs and Project Analysis Report (2009)

This report is prepared annually by the SDDOT Division of Planning/Engineering. Data from the state's pavement management system is accessed using GIS software, allowing (1) the division of highways into segments, (2) the calculation of benefit/cost ratios for pavement improvement projects within each segment, and (3) the prioritization of pavement improvements, based on the benefit/cost ratio. The information is presented as a series of straight-line charts for each highway, showing segment boundaries and the relevant data for each segment. An example is shown below.

HIGHWAY 012
Begin MRM = 101.68
End MRM = 132.45

RURAL

HIGHWAY 012
Begin MRM = 101.68
End MRM = 132.45



IDENTIFICATION							
Federal Aid System	NHS-NI	NHS-NI	NHS-NI	NHS-NI	NHS-NI	NHS-NI	NHS-NI
Funding Category	MAJA	MAJA	MAJA	MAJA	MAJA	MAJA	MAJA
Functional Classification	R-PA	R-PA	R-PA	R-PA	R-PA	R-PA	R-PA
Direction							
Beginning MRM	101.68	112.00	121.00	121.00	130.00	130.00	132.45
MRM Displacement	0.000	0.714	0.591	0.768	0.587	0.750	0.000
Segment Length	10.996	8.858	0.177	8.646	0.163	1.849	5.335
Year Built	1962	1950	1950	1983	1954	1954	1964
Year Last Improved	2005	2006	2006	2000	2000	2006	2006
Year Last Sealed	2008			2004	2004		
ROADWAY CONDITIONS							
Surface Condition Index	4.62	4.76	4.86	4.55	4.50	4.76	4.86
Roughness Index	4.92 (08)	5.00 (08)	5.00 (08)	4.60 (08)	4.76 (08)	4.97 (08)	4.99 (08)
ASPHALT INDEX VALUES							
Transverse Cracking	4.51 (08)	4.68 (08)	4.80 (08)	4.55 (08)	4.50 (08)	4.78 (08)	4.80 (08)
Fatigue Cracking	4.93 (08)	4.97 (08)	5.00 (08)	4.92 (08)	4.60 (08)	4.98 (08)	4.99 (08)

The state's pavement management system could serve as a model for this project's methodology to prioritize safety improvements, to be developed during Task 6.

APPENDIX B: PEER STATES DOTS INTERVIEWS MEETING NOTES

Iowa DOT

Date: 01/28/10 (Thursday)

Attendees: Tom Welch, Michael Pawlovich, Beth Wemple and Chriss Ruiz

Below are some general discussion points regarding the Iowa DOT prioritization process for safety improvements as well as roadway and crash data.

Safety Prioritization Approach

- The existing prioritization process combines a systematic approach with a high crash location method. Iowa DOT first selects particular system strategies (systematic approach) and then implements them at specific locations based on crashes (high crash location).
- The return on investment is much higher if the Department invests on rural rather than urban locations. Therefore, most of the state safety efforts are towards rural areas (i.e. severe crash locations), while the urban intersection improvements are capped.
- The "5% Most Severe Safety Needs Report" and the current rural/urban distribution help to better distribute the funds.
- Tom W. recommended implementing an educational program in South Dakota, if needed, to effectively manage the funding and get "upper management" bought in to the concept of systematic programming. He also emphasized that a systematic approach with some sort of prioritization to further narrow down the implementation of system strategies would be a good option for South Dakota.
- The federal government does not tell the states how to spend the HSIP funding; however, each state is responsible for submitting a "5% Most Severe Safety Needs Report" and an annual HSIP Report (i.e. funding allocation), which are reviewed and compared.
- Some states have generated documents stating that they would like to use a portion of safety funding to conduct other projects by justifying that safety is properly being controlled.

Roadway and Crash Data

- The Iowa DOT has approximately 10 years of state roadway traffic volume data. Some segment volumes are collected and some estimated, and turning movement counts at special intersections are collected as requested.
- The crash data is managed by the Motor Vehicle Department. Iowa developed TRACS which allows in the field coding. This is being utilized throughout the state. Officers use this system to report crashes, and the information goes directly into a data set. Only 20% of the data is coded manually. The average waiting period for the crash data is about two weeks. Iowa also has citizen's crash reporting.
- Michael P. uses data more than three months. This relates to the waiting time of a possible fatality.
- The data is GIS related and further associated with a tool that can conduct analysis. Iowa DOT does not use SafeyAnalyst since they feel their tools are effectively serving the purpose and SafeyAnalyst will require additional data.

The following paragraphs summarize some general information obtained from material provided by Iowa DOT prior to the phone conversation.

Iowa Department of Transportation, FFY 2009 High Risk Rural Roads Annual Report

The document states that Iowa DOT has traffic and crash data for state and local roads. The methodology to identify high risk rural roads (HRRR) is described as first selecting rural major collectors, rural minor collectors and rural local routes with crash rates above the statewide averages for fatal and major injury crashes. The top 15% segments for each roadway type is identified based on crash rate per 100M VMT and crashes per mile. This information together with a benefit-cost ratio analysis is used to determine the funding distribution for HRRR projects. The Iowa DOT proposes to evaluate the effectiveness of the countermeasures by comparing 5-year crash data before and after implementation.

Iowa Department of Transportation, 2009 5 Percent Most Severe Safety Needs Report

This document states that based on fatal and major injury crashes for years 2001 through 2007, Iowa's most severe safety needs relate to crashes involving: intersections, single-vehicle run-off-road, vehicles crossing medians on freeways, unbelted drivers and passengers, impaired drivers, and speeding. This information is used to determine the 5% most severe safety needs for each of these areas.

Optimizing Safety Program Investments in Iowa Presentation, Thomas M. Welch, P.E.

The presentation lists the following Iowa DOT safety programs:

Statewide Programs

- Federal Hazard Elimination Program
- Highway Safety Management System (SMS)
- Data-Driven Highway Safety Program
- Safety Conscious Planning
- 3R Roadway Safety Audits

Local Assistance Programs

- State Traffic Safety Improvement Programs (TSIP)
- Traffic Engineering Assistance Program (TEAP)
- Safety Data Products
    - Crash Data Analysis Tools
    - Iowa Traffic Safety Data Services (ITSDS)
- Traffic & Safety Engineering Forum
- Small town signing program

Minnesota DOT

Date: 02/02/10 (Tuesday)

Attendees: Dave Engstrom, Julie Whitcher, Bradley Estochen, Beth Wemple, and Chriss Ruiz

Below are some general discussion points regarding the Minnesota DOT prioritization process for safety improvements, roadway and crash data availability and some suggestions for South Dakota consideration.

Safety Prioritization Approach

- The current prioritization process mostly focuses on a systematic approach with a reactive piece. Before 2006 each district used to manage how they spent their money and the prioritization was based only on a reactive approach. Now, each district is required to submit projects to the central office for approval. For rural areas the prioritization is mostly based on a systematic method (only up to 30% high crash location based), and on urban areas on a high crash location approach.
- Now that their office has control of the money, they can better decide on the distribution as far as which projects to implement.
- To help the locals generate projects the DOT developed a program to help each county identify high crash location versus systematic applications for particular locations.
- The 5% report is based on a reactive approach and a cluster analysis. For local facilities if any project is on the list they receive extra points.
- HSIP funding is the biggest source but there are others.
- SafetyAnalyst is about 90% implemented for the state highway system only.

Roadway and Crash Data

- On local roadways good crash data is available but traffic volumes are only available at some locations. There is no detailed data on roadway characteristics; however they are trying to improve by collecting data as needed. For example, if it is known that one type of curve should be prioritized over another, then data can be collected for that particular curve type.
- Minnesota does not have much crash data on tribal lands; however, they were able to implement rumble strips on one occasion. The tribes are able to submit projects for funding, but they have not done so.

Suggestions

- Identify key areas based on fatal and serious injuries considering behavioral and engineering characteristics and develop countermeasures.
- Recognize gaps in the data and start filling them as needed.
- Look into the benefit cost of implementing improvements system-wide versus at particular locations.

Missouri DOT

Date: 02/01/10 (Monday)

Attendees: Michael Curtit, John Miller, Beth Wemple, and Chriss Ruiz

Below are some general discussion points regarding the Missouri DOT prioritization process for safety improvements as well as roadway and crash data.

Safety Prioritization Approach

- Missouri uses both a high crash location and systematic methods to prioritize safety improvements. However, the high crash location approach is mostly being used because of the 5% requirement.

  High Crash Location approach

  - Two lists are developed for high severity locations. For state and local intersections, the list is developed by weighting fatal crashes with one value and serious injuries with another. For segments, a range list is developed by studying two-mile corridors at a time with some overlap. Both lists are used for the 5% report.

  Systematic

  - The information in the SHSP is used to develop strategies addressing the top crash issues in Missouri. The systematic method is used to implement policies essentially more than treatments. For example, considering that run-off-the road crashes are listed as the second crash type issue in the SHSP, a policy was implemented to install rumble strips and signs on major roads whenever there is any type of roadway improvement (i.e. resurfacing or rebuilt). This was integrated into the design manual, and implementation became a part of the design process.
  - Some strategies are implemented system-wide, while some only involve a sub-area.
- Approximately 75% of the fatalities occur on the state system. SHSP funding is spent on the state roadways. By law, state money needs to be spent on state roads.
- There is a 50/50 split of the funding between urban and rural locations as established by the commissioner. Funds are distributed to each district.
- Missouri DOT noted that the money that does not get used for construction is redirected for alcohol enforcement and then some portion goes towards safety improvements.
- The state has put a lot of effort into having the districts move towards a systematic approach and is trying to keep the counties involved by setting up committees.
- Missouri DOT is looking into purchasing SafetyAnalyst
- The department recommended South Dakota use performance measures and gain the support of senior managers as needed.

Roadway and Crash Data

- Crash data is directly entered by the highway patrol into a transportation management system. The data is geographically represented.
- Traffic volume data is available for all state roadways. HPMS sampling is conducted on local facilities

Montana DOT

Date: 01/29/10 (Friday)

Attendees: Pierre Jomini, Beth Wemple and Chriss Ruiz

Below are some general discussion points regarding the Montana DOT prioritization process for safety improvements, roadway and crash data availability and some suggestions for South Dakota consideration.

Safety Prioritization Approach

- The existing prioritization process involves both high crash location and systematic approaches. However the system largely emphasizes high crash location analysis. In terms of the systematic approach, Montana DOT has implemented rumble-strips on interstates locations that have experienced high run-off-road crashes. The high crash location approach looks into selecting locations based on crash frequency (segments above a given threshold get identified). The state has identified 10+ miles of high frequency corridors by weighting the corridors based on fatal and serious-injury crashes.
- Regression to the mean is not taken into account.
- HSIP funding distribution is based on a benefit-cost evaluation.
- Montana does not have roadway data characteristics in a computerized format. This may be one of their next steps.

Roadway and Crash Data

- Montana DOT has traffic volume data on the state system, but the local data is limited.
- Currently, the crash data is by mile-marker on major facilities, link coded in cities, and by sections in rural areas outside the cities. However, they are trying to transition into a GIS-based system for all locations.
- There are about 7 Indian reservations in Montana, and obtaining crash data has been difficult because of privacy issues. However, Pierre noted that the state has been having some success by implementing “reciprocal agreements” between the highway patrol and the tribes that allow them to investigate crashes. It should be noted that in Montana fatal crashes are investigated no matter the location.

Suggestions

Pierre provided the following recommendations for the consideration of South Dakota:

- Start at a small scale and evaluate the value of the improvements.
- Conduct system-wide analysis focusing on those locations that are most affected.
- Try to identify corridors with high severity crashes.
- Try to incorporate safety into other projects. One suggestion was to review design projects to identify potential safety treatments.

Washington State DOT

Date: 02/01/10 (Monday)

Attendees: Matthew Enders, Beth Wemple, and Chriss Ruiz.

Below are some general discussion points regarding the Washington State DOT prioritization process for safety improvements as well as roadway and crash data.

Safety Prioritization Approach

- WSDOT uses both the high crash location and systematic methods to prioritize safety improvements.

  High Crash Location approach

  - For state highways, WSDOT used to look into and weight all crashes, but switched the focus to fatal and serious-injuries last year. The current procedure is based on a linear analysis (crash frequency), 0.1-mile increments, and 5 years of data.
  - For local roadways, the fatal and serious-injury crashes get plotted using GIS to develop concentration areas.

  Systematic

  - For state roadways, system-wide low cost improvements get implemented. Some examples are centerline rumble-strips, cable median, guardrail updates. WSDOT is also looking into what issues exists with passing lanes.
  - For local roadways, an analysis of fatal and serious-injuries on High Risk Rural Roads identified run-off-road crashes as the most frequent problem. The top 10 locations of each county are ranked and money gets assigned to the counties based on this.
- WSDOT is currently working into removing the issue of regression to the mean.
- The majority of the money goes to local roadways. In fact, as dictated by the legislator, 1/3 goes to the state system, which includes about 7,000 miles of roads, and 2/3 goes to local system, which includes about 57,000 miles of roads.
- Most of the funding is allocated to urban locations based on the current high crash location procedure. However, the systematic approach is taking care of the rural needs at some level.
- Interstate safety money goes primary to rural areas. WSDOT was able separate a portion of the pavement funding for safety. Some of this money is being used for research to identify the needs of rural areas.

Roadway and Crash Data

- The crash data is geo-coded for all state facilities and for some local roadways. However, the state is working on getting a linear reference system for all public roads.
- No traffic volume data is available for the local system.
- WSDOT is looking into SafetyAnalyst for state facilities, but have some problems with traffic volumes on local cross-streets.
- A roadway inventory catalog is being developed. Fixed objects are being registered to identify clear zones.

- As far as data collection on tribal lands, WSDOT is working with the tribes to get crash reports that do not include personal information. Also, Washington State has Traffic Safety Commissions (about 20 to 25) that discuss funding distribution and needs for specific areas, and are currently trying to create one for tribes.

APPENDIX C: SOUTH DAKOTA PRIORITIZATION PROCEDURE MEETING NOTES

Date: 01/05/09 (Tuesday)

Attendees: Sonia Downs, Cliff Reuer, Beth Wemple and Chriss Ruiz

The existing prioritization process for safety improvements is based on both a reactive (old style) approach and a proactive (systematic) approach. The steps follow under each approach are summarized below:

Reactive Approach – Roadway Safety Improvement Program (RSI)

- The reactive approach is used for rural intersections and segments on all public roads (state and non-state roadways).
- The first step is to select intersections and segments with a crash frequency above 5 or more crashes in last three-years and within 100 feet of an intersection. This involves plotting the crashes onto a map and relating all crashes within a 100 ft radius of an intersection to the intersection and all others to the segments.
- Those locations above the threshold are further analyzed as follows:
    - Look for trends
    - Conduct Crash Magic software analysis
    - Develop accident rates for those locations in which AADT is available, and compared these values with the three-year statewide average.
- An “inspection team” involving representatives from traffic operations, roadway design, safety, law enforcement and the city evaluates and prioritizes the locations first screened based on countermeasures selected and a cost-benefit analysis.
- The team also asks the cities and highway patrols to provide a list of locations in need of safety improvements. Of those locations, a few get selected and compared with the 5% report, which is generated base on crash frequency.
- The final decision is mostly based on the cost-benefit analysis, which follows the Benefit-To-Cost Ratio Method described in the Highway Safety Improvement Program Manual FHWA-SA-09-029.

Sonia and Cliff will send information on benefit-cost procedure and statewide average costs calculation.

Proactive (Systematic) Approach

- Use the SHSP to select a crash type or severity to prioritize. Currently focused on fatal run-off-the-road crashes.
- Arc Map/Arc View is used to identify those locations experiencing focus crash type.
- For those locations identified, the accident rate is computed and compared with the statewide average. It is notable that some of these sites have crash rates so low that they would not even be ranked via the state’s RSI program
- Based on this approach rumble strips policy was revised to include rumble strips as part of all resurfacing projects whre sufficient shoulder width is available.
- After run-off crashes, the department looks into other crash types and in particular into alcohol and non-buckled up related crashes
- Signing and durable pavement marking are being implemented throughout the state.

Next Steps

- The state would like to find out if the procedures currently being used are the most current procedures when compared to other states. They would like us to contact North Dakota, Montana, Iowa, Michigan, Minnesota, and Wyoming.
- Cliff and Sonia recommended that we contact Dave Huft to obtain information from an ongoing study about transportation data availability on local government roads.

Cliff's will send contact information of other states DOTs.

APPENDIX D: SOUTH DAKOTA ROADWAY DATA SUMMARY AND MEETING NOTES

Roadway Data Summary

Roadway Segment Data

Format: Geodatabase

Data available: A summary of the data available in comparison to HSM requirements is provided in the table below. A list of some additional data available is also provided.

Data Need	Highway Safety Manual	SDDOT Data Available?
Roadway Segment Data		
Area type (urban/rural)	✓	Yes
Segment length	✓	Yes
Number of lanes	✓	Yes
Median type (divided/undivided)	✓	Yes (1)
Number of driveways	✓	No
Segment volume (AADT)	✓	ADT
Shoulder type and width	✓	Yes
Passing lane presence	✓	No
Horizontal and vertical curvature	✓	(2)
Roadside hazard data	✓	No
On-street parking	✓	Yes (3)
Lighting	✓	No

✓ Required data (note that requirements for HSM methods vary by facility type)

Notes:
1. **Median type is only provided for the state highway system**. County data does not include this roadway characteristic.
2. Vertical curve data: design speed, grade type, k-value. Horizontal curve: curve degree, speed.
3. **Parking is only provided for County data**.

Additional data available (Most Relevant)

State Highway System:

- Functional classification
- Highway system classification (national highway system – non-interstate, surface transportation system – STP)
- Surface width/type
- Speed limit
- Curb and gutter
- City/County
- Rumble strip
- Freight roadway

- Truck ADT

Local System:

- Functional classification
- Surface width/type
- Speed limit
- Terrain

Intersection Data

The intersection data listed below is provided as part of the crash database.

- ADT for intersecting roadways
- Number of intersection legs
- Traffic control type (for locations with crashes)
- Lighting (for locations with crashes)
- Median (for locations with crashes)

Roadway Data Meeting Notes

Date: 02/23/10 (Monday)

Attendees: Roger Brees, Beth Wemple, Chriss Ruiz, and Darryl dePencier

Initial Data Storage / GIS Questions

- Q: Does SDDOT have an enterprise level geodatabase that combines all roadway data?

  A: Yes it does. SDDOT uses a SQL based database to store all roadway attributes/geometry and look-up tables. The database uses dynamic segmentation to generate maps of any given attribute.

- Q: Is the dynamic segmentation based on the MRM system?

  A: No, the MRM system is a reference marker for data collection, but the database uses the "from" and "to" mile attributes as its linear referencing system in dynamic segmentation. Roger will provide a document describing the MRM system and its purpose.

- Q: Does SDDOT have any data on intersection characteristics beyond number of approaches and general ADT?

  A: No, SDDOT does not keep any data on intersection characteristics. Roger is not aware of any inventory of traffic signals or any other readily available source of data on intersection control.

- Q: How does SDDOT manage data updates?

  A: Updates are done annually and take about one month to complete. The typical update period is mid-November to mid-December. Updates are handled centrally.

- Q: Is there any integration between the collision database and the general roadway database?

  A: The roadway and crash databases are separate entities. The roadway database is an imported portion of the crash database. The crash database is supposed to be updated annually with the newest version of the roadway database, but the updates are sometimes less frequent.

General Discussion

- Local data is collected directly by planning districts. SDDOT has developed a collection manual to ensure that there are consistent collection standards across the state. Some areas have had consistent staff collecting the data throughout the years while other areas have very high turn-over. This has led to different experience levels across regions, but the general data standard is consistent.
- Roger reviewed the checklist provided by Chriss and confirmed that we are aware of all relevant data available and that what we have flagged as missing is in fact not available.
- *Roger will provide documents describing data collection and the MRM system as well as a sample of the local data which we did not find on their FTP site.*
- *Chriss will provide Roger with a KAI FTP location to upload data for us.*

APPENDIX E: SOUTH DAKOTA CRASH DATA SUMMARY AND MEETING NOTES

Crash Data Summary

Format: Geodatabase and .mdb (Microsoft Office Access)

Data available: The database includes crashes for both segments and intersections. The most relevant information is provided in three tables: accident table, person table, and vehicle table. The accident table is the only one that includes location information (geo-base), but the other two tables can be related to the accident table. The list provided below summarizes the most significant data included in these tables.

Accident Table:

- Location
- Time
- Date
- Accident Severity and Type
- Lighting conditions
- Roadway conditions
- Roadway information
    - Functional Classification
    - Highway Category
    - Shoulder Type
    - Access Control
    - Number of Lanes
    - One-way restriction
    - Divided or Undivided
    - Median Type
    - Speed Limit

Person Table:

- Age
- Sex
- Drug use/test
- Alcohol use/test

Vehicle Table:

- Vehicle maneuver
- Vehicle Direction
- Speed Limit
- Contributing Factors
- Vehicle damage
- Traffic Control Device Type

Data is available for years 2004 – 2008. Data prior to 2004 is in a different system and more arbitrary. Crash data is available for state and local system.

Additional Data for Intersections:

The file titled "IntersectionsGDB.mdb" includes all the intersections in South Dakota. The data included is location, intersecting roadway names, county, city, and state trunk designation.

The file titled "IntersectionAccidentRateGDB.mdb" includes the data listed below in addition to that provided in the "IntersectionsGDB.mdb". The data is based on the latest full three-year period of 2005, 2006 and 2007. However, no specific counts for each year are reported (it seems that they may have grouped all years into one total count).

Data available:

- Fatal accident count
- Incapacitating injury accident count
- Non-incapacitating injury accident count
- Property-damage-only accident count
- Injury accident count
- Total accident count
- Weighted accident points
- ADT or Average Daily Traffic for the intersection
- Standard accident rate
- Weighted accident rate (PDO – 1 rating, injury – 3 rating, and fatal – 12 rating)
- Five percent accident rate (severe accident (e.g. fatal and incapacitating) only)
- Intersection leg count

Limitations:

1. Only a limited number of intersections have ADT data (about 25%).
2. The number of intersection legs may be reflected incorrectly for some complex intersections.

This file also includes segment information for ADT (most locations show zero value) and roadway name.

Crash Data Meeting Notes

Date: 03/03/10 (Wednesday)

Attendees: Chuck Fergen, Beth Wemple, Chriss Ruiz, and Darryl DePencier

Initial Data Storage / GIS Questions

- Q: Is crash data for the entire state stored centrally?

  A: Yes it is. Data collection is handled at the regional level, but all data must be submitted to the Department of Public Safety for entry in the central database. Strict quality control measures are in place to ensure that all data is entered completely. Incomplete data is returned to regional staff for completion before uploading to the database.

- Q: How are updates to the database controlled?

  A: Only Department staff members are currently given access to the database. The state is in the process of implementing TRACS throughout the state to enable direct data entry to the database. Quality control measures will be in place ensuring that local agencies must not enter incomplete data.

- Q: Is roadway data uploaded from SDDOT annually?

  A: The roadway data should be refreshed annually and efforts are being made to ensure that happens, but up until this point, the updates have not been that frequent.

- Q: How do we ensure that “0” attributes are truly 0 and not no data?

  A: The quality control measures prohibit blank entries into the database. If a required value is not reported, the data is sent back to the region for completion. In cases where data is simply not available, -99 is used to signify no data.

- Q: Why does the crash database contain 2 legged intersections?

  A: Intersections are defined by the Department as any junction of two roads. L shaped intersections are therefore valid.

General Discussion

- Even though safety data is collected locally, there is very detailed guidance from the Department of Public Safety to ensure state-wide consistency in data quality and format. The only source of variation is the level of experience available. Some regions have higher turnover than others causing some regions to have more seasoned data collectors than others.
- The Department of Public Safety will provide a manual for safety data collection and database field definitions.

APPENDIX F: ALTERNATIVE METHODOLOGIES SAMPLE PROBLEMS

This appendix includes sample problem applications for a number of methodologies presented in Sections 5.4.3, 5.4.4 and 5.6.3. These sample problems were extracted from the Highway Safety Manual, Part B: Roadway Safety Management Process.

Network Screening Sample Problems

Excess Proportions of Specific Crash Types Sample Problem

A roadway agency is undertaking an effort to improve safety on their highway network. They are screening twenty intersections to identify sites with potential for reducing the crash frequency.

- Facts
  - All of the intersections have four approaches and are in rural areas;
  - 13 are signalized intersections and 7 are unsignalized (two-way stop controlled) intersections;
  - Three-years of detailed intersection crash data is shown in Exhibit 1.
- Data Needs
  - Crash data by type and location

Exhibit 1: Intersection Detailed Crash data Summary (3 Years)

Intersections	Total	Crash Severity			Crash Type							
		Fatal	Injury	PDO	Rear End	Sideswipe/ Overtaking	Right Angle	Ped	Bike	Head-On	Fixed Object	Other
1	22	0	6	16	11	4	4	0	0	0	1	2
2	35	2	23	10	4	2	21	0	2	5	0	1
3	23	0	13	10	11	5	2	1	0	0	4	0
4	13	0	5	8	7	2	3	0	0	0	1	0
5	15	0	4	11	9	4	2	0	0	0	0	0
6	9	0	2	7	3	2	3	0	0	0	1	0
7	34	1	17	16	19	7	5	0	0	0	3	0
8	9	0	2	7	4	3	1	0	0	0	0	1
9	37	0	22	15	14	4	17	2	0	0	0	0
10	17	0	7	10	9	4	2	0	0	0	1	1
11	38	1	19	18	6	5	23	0	0	4	0	0
12	32	0	15	17	12	2	14	1	0	2	0	1
13	6	0	2	4	3	1	2	0	0	0	0	0
14	10	0	5	5	5	1	1	1	0	0	1	1
15	17	1	4	12	9	4	1	0	0	0	1	2
16	21	0	11	10	8	4	7	0	0	0	1	1
17	13	1	5	7	6	2	2	0	0	1	0	2
18	19	0	8	11	8	7	3	0	0	0	0	1
19	11	1	5	5	5	4	0	1	0	0	0	1
20	8	0	3	5	2	3	2	0	0	0	1	0

Procedure

The sample intersections are to be screened for a high proportion of angle crashes. Prior to beginning the method, the 20 intersections are organized into two subcategories (i.e., reference populations): TWSC intersections, and signalized intersections.

For the sample situation the threshold proportion is selected to be 60 percent. The selection of a limiting probability can vary depending on the probabilities of each specific crash types exceeding a threshold proportion. For example, if many sites have high probability, the limiting probability can be correspondingly higher in order to limit the number of sites to a reasonable study size. In this example, a 60-percent limiting probability results in four sites that will be evaluated based on the Excess Proportions performance measure.

STEP 1 – Calculate Observed Proportions

A. Determine which collision type or crash severity to target and calculate observed proportion of target collision type or crash severity for each site.

B. Identify the frequency of the collision type or crash severity of interest and the total observed crashes of all types and severity during the study period at each site.

C. Calculate the observed proportion of the collision type or crash severity of interest for each site that has experienced two or more crashes of the target collision type or crash severity using Equation 1.

$$p_i = N_{observed,i} / N_{observed,i(TOTAL)} \qquad (1)$$

Where,

p_i = Observed proportion at site i

$N_{observed,i}$ = Number of observed target crashes at site i

$N_{observed,i(TOTAL)}$ = Total number of crashes at site i

Shown below is the calculation for right angle crashes for Intersection 7. The values used in the calculation are found in Exhibit 1.

$$p_i = 5/34 = 0.15$$

STEP 2 – Estimate a Threshold Proportion

Select the threshold proportion of crashes, p*i, for a specific collision type. A useful default starting point is the proportion of target crashes in the reference population under consideration. For example, if considering rear end crashes, it would be the observed rear-end crash frequency experienced at all sites in the reference population divided by the total observed crash frequency at all sites in the reference population. The proportion of a specific crash type in the entire population is calculated using Equation 2.

$$p^*_i = \sum N_{observed,i} / \sum N_{observed,i(TOTAL)} \qquad (2)$$

Where,

p^*_i = Threshold proportion

$\sum N_{observed,i}$ = Sum of observed target crash frequency within the population

$\sum N_{observed,i(TOTAL)}$ = Sum of total observed crash frequency within the population

Exhibit 2: Estimated Threshold Proportion of Angle Collisions

Below is the calculation for threshold proportion of angle collisions for TWSC intersections.

$$p*_i = 33/150 = 0.22$$

Exhibit 2 summarizes the threshold proportions for the reference populations.

Reference Population	Angle Crashes	Total Crashes	Observed Threshold Proportion ($p*_i$)
TWSC	33	150	0.22
Traffic Signals	82	239	0.34

STEP 3 – Calculate Sample Variance

Calculate the sample variance (s^2) for each subcategory. The sample variance is different from population variance. In general, the population variance of a finite population of size N is given by

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(x_i - \mu)^2$$

where

$$\mu = \frac{1}{N}\sum_{i=1}^{N} x_i$$

is the population mean.

In many practical situations, the true variance of a population is not known a priori and must be computed somehow. When dealing with extremely large populations, it is not possible to count every object in the population.

A common task is to estimate the variance of a population from a sample. For this method, be sure to calculate the sample variance using Equation 3:

$$Var(N) = \left(\frac{1}{n_{sites} - 1}\right) \times \left[\sum_{i=1}^{n}\left(\frac{N_{observed,i}^{\;2} - N_{observed,i}}{N_{observed,i\ (TOTAL)}^{\;2} - N_{observed,i\ (TOTAL)}}\right) - \left(\frac{1}{n_{sites}}\right) \times \left(\sum_{i=1}^{n} \frac{N_{observed,i}}{N_{observed,i\ (TOTAL)}}\right)^2\right] \quad (3)$$

for $N_{observed,i} \geq 2$

Where,

Var(N) = Variance

n_{sites} = Total number of sites being analyzed

$N_{observed,i}$ = Observed target crashes for a site i

$N_{observed,i(TOTAL)}$ = Total number of crashes for a site i

Exhibit 3: Sample Variance Calculation

Exhibit 3 summarizes the calculations for the two-way stop-controlled subcategory. TWSC sites 15 and 19 were removed from the variance calculation because less than two angle crashes were reported over the study period.

TWSC	Angle Crashes $(N_{Observed,i})$	$(N_{Observed,i})^2$	Total Crashes $(N_{Observed,i(TOTAL)})$	$(N_{Observed,i(TOTAL)})^2$	N	TWSC Variance
2	21	441	35	1225	5	0.037
7	5	25	34	1156		
3	2	4	23	529		
10	2	4	17	289		
17	2	4	13	169		

STEP 4 – Calculate Alpha and Beta Parameters

Calculate the sample mean proportion of target crashes by type or severity for all sites under consideration using Equation 4:

$$\overline{p^*_i} = \frac{\sum p_i}{n_{sites}} \;, N_{observed,\ i} \geq 2 \qquad (4)$$

Where,

n_{sites} = Total number of sites being analyzed;

$\overline{p^*_i}$ = Mean proportion of target crash types; and

p_i = Observed proportion.

Calculate Alpha (α) and Beta (β) for each subcategory using Equations 5 and 6.

$$\alpha = \frac{\overline{p^*_i}^2 - \overline{p^*_i}^3 - s^2(\overline{p^*_i})}{s^2} \qquad (5)$$

$$\beta = \frac{\alpha}{\overline{p^*_i}} - \alpha \qquad (6)$$

Where,

$\overline{p^*_i}$ = Mean proportion of target crash types

Below is the calculation for the two-way stop-controlled subcategory. The numerical values shown in the equations below are summarized in Exhibit 4

$$\alpha = \frac{0.22^2 - 0.22^3 - 0.037 \times 0.22}{0.037} = 0.80$$

$$\beta = \left(0.80 / 0.22\right) - 0.80 = 2.84$$

Exhibit 4 summarizes the alpha and beta calculations for the TWSC intersections.

SUBCATEGORIES	s^2	p^*_i	α	β
TWSC	0.037	0.22	0.80	2.84

Exhibit 4: Alpha and Beta Calculations

STEP 5 – Calculate the Probability

Using a "betadist" spreadsheet function, calculate the probability that the observed proportion exceeds the threshold proportion for each intersection as shown in Equation 7.

$$P\left(p_i > p^*_i \,/\, N_{observed,i}, N_{observed,i(TOTAL)}\right) = 1 - betadist\left(p^*_i, \alpha + N_{observed,i}, \beta + N_{observed,i(TOTAL)} - N_{observed,i}\right) \quad (7)$$

Where:

p^*_i = Threshold proportion

p_i = Observed proportion

$N_{observed,i}$ = Observed target crashes for a site i

$N_{observed,i(TOTAL)}$ = Total number of crashes for a site i

Exhibit 5: Probability Calculations

Below is the probability calculation for Intersection 7.

$$P\left(p_i > p^*_i | N_{Observed,i}, N_{Observed,i\ (TOTAL)}\right) = 1\text{-}betadist\left(0.22, 0.80 + 5, 2.84 + 34 - 5\right)$$

Exhibit 5 summarizes the probability calculation for Intersection 7.

TWSC	RIGHT ANGLE CRASHES $(N_{Observed,\ i})$	TOTAL CRASHES $(N_{Observed,I(TOTAL)})$	p_i	p^*_i	α	β	PROBABILITY
7	5	34	0.15	0.22	0.80	2.84	0.13

For Intersection 7, the resulting probability is interpreted as "There is a 13% chance that the long-term expected proportion of right angle crashes at Intersection 7 is actually greater than the long-term expected proportion for TWSC intersections." Therefore, in this case, with such a small probability there is limited need of additional study of Intersection 7 with regards to right angle crashes.

STEP 6 – Calculate the Excess Proportion

Calculate the difference between the true observed proportion and the threshold proportion for each site using Equation 8:

$$p_{DIFF} = p_i - p^*_i \quad (8)$$

Where,

p^*_i = Threshold proportion

p_i = Observed proportion

STEP 7 – Rank Locations

Rank locations in descending order by the value of P_{DIFF}. The greater the difference between the observed and threshold proportion, the greater the likelihood that the site will benefit from a countermeasure targeted at the collision type under consideration.

Exhibit 6: Ranking Based on Excess Proportion

The four intersections that met the limiting probability of 60-percent are ranked in Exhibit 6 below.

Intersections	Probability	Observed Proportion p_i	Threshold Proportion p^*_i	Excess Proportion $p_{DIFF} = p_i - p^*_i$
2	1.00	0.60	0.22	0.38
11	0.99	0.61	0.34	0.27
9	0.81	0.46	0.34	0.12
12	0.71	0.44	0.34	0.10

Sliding Window Sample Problem

A roadway agency is undertaking an effort to improve safety on its highway network. There are ten roadway segments from which the agency wants to identify sites that will be studied in more detail because they show a potential for reducing the average crash frequency.

The agency chooses to apply the sliding window method using the RSI performance measure to analyze each roadway segment.

- Facts
    - The roadway segments comprise:
        - 1.2 miles of rural undivided two-lane roadway
        - 2.1 miles are undivided urban/suburban arterial with four lanes
    - 0.6 miles of divided urban/suburban two-lane roadway
    - Segment characteristics and a three-year summary of crash data are in Exhibit 7.
    - Three-years of detailed roadway segment crash data is shown in Exhibit 9.
- Assumptions
    - The roadway agency has accepted the FHWA crash costs by severity and type as shown in Exhibit 7.

Exhibit 7: Relative Severity Index Crash Costs

Crash Type	RSI Crash Costs
Rear End - Non-Intersection	$30,100
Sideswipe/Overtaking	$34,000
Angle - Non-Intersection	$56,100
Pedestrian/Bike Non-Intersection	$287,900
Head-On - Non-Intersection	$375,100
Roll-Over	$239,700
Fixed Object	$94,700
Other/Undefined	$55,100

Source: Crash Cost Estimates by Maximum Police-Reported Injury Severity within Selected Crash Geometries, FHWA - HRT - 05-051, October 2005.

Exhibit 8 and Exhibit 9 summarize the roadway segment characteristics and crash data.

Exhibit 8: Roadway Segment Characteristics

Segments	Cross-Section (Number of Lanes)	Segment Length (Miles)	AADT	Undivided/ Divided	Crash Data		
					Total Year 1	Total Year 2	Total Year 3
1	2	0.80	9,000	U	16	15	14
2	2	0.40	15,000	U	12	14	10
3	4	0.50	20,000	D	6	9	5
4	4	0.50	19,200	D	7	5	1
5	4	0.35	22,000	D	18	16	15
6	4	0.30	25,000	D	14	12	10
7	4	0.45	26,000	D	12	11	13
8	2	0.20	10,000	U	2	1	3
9	2	0.25	14,000	U	3	2	1
10	2	0.15	15,000	U	1	2	1

Exhibit 9: Roadway Segment Detail Crash Data Summary (3 Years)

Segment	Total	Crash Severity			Crash Type							
		Fatal	Injury	PDO	Rear-End	Angle	Head-On	Sideswipe	Pedestrian	Fixed Object	Roll-Over	Other
1	45	3	17	25	0	0	6	5	0	15	19	0
2	36	0	5	31	0	1	3	3	3	14	10	2
3	20	0	9	11	1	0	5	5	0	5	3	1
4	13	0	5	8	3	0	1	2	0	4	0	3
5	49	0	9	40	1	1	21	12	2	5	5	2
6	36	0	5	31	4	0	11	10	0	5	4	2
7	36	0	6	30	2	0	13	11	0	4	3	3
8	6	0	1	5	2	0	0	1	0	1	0	2
9	6	0	1	5	1	0	0	1	0	2	0	2
10	4	0	0	4	2	0	0	0	0	1	0	1

`The following assumptions are used to apply the sliding window analysis technique in the roadway segment sample problems:

- Segment 1 extends from mile point 1.2 to 2.0
- The length of window in the sliding window analysis is 0.3 miles
- The window slides in increments of 0.1 miles

The name of the window subsegments and the limits of each subsegment are summarized in Exhibit 10.

Exhibit 10: Segment 1 Sliding Window Parameters

Window Subsegments	Beginning Limit (Mile Point)	Ending Limit (Mile Point)
1a	1.2	1.5
1b	1.3	1.6
1c	1.4	1.7
1d	1.5	1.8
1e	1.6	1.9
1f	1.7	2.0

The windows shown above in Exhibit 10 are the windows used to evaluate Segment 1 throughout the roadway segment sample problems. Therefore, whenever window subsegment 1a is referenced it is the portion of Segment 1 that extends from mile point 1.2 to 1.5 and so forth.

Exhibit 11 summarizes the crash data for each window subsegment within Segment 1. This data will be used throughout the roadway segment sample problems to illustrate how to apply each screening method.

Exhibit 11: Segment 1 Crash Data per Sliding Window Subsegments

Window Subsegments	Total	Crash Severity			Crash Type			
		Fatal	Injury	PDO	Head-On	Sideswipe	Fixed Object	Roll - Over
1a	8	0	3	5	0	0	3	5
1b	8	0	4	4	1	1	3	3
1c	7	0	3	4	3	1	0	3
1d	11	2	3	6	1	2	5	3
1e	4	0	0	4	0	0	1	3
1f	7	1	4	2	1	1	3	2

When the sliding window approach is applied to a method, each segment is ranked based on the highest value found on that segment.

Procedure

STEP 1 – Calculate RSI Crash Costs per Crash Type

For each window subsegment, multiply the average crash frequency for each crash type by its respective RSI per crash type.

Exhibit 12: Crash type Summary for Segment 1 Window Subsegments

Exhibit 11summarizes the observed average crash frequency by crash type for each window subsegment over the last three-years and the corresponding RSI crash costs for each crash type.

WINDOW SUBSEGMENTS	HEAD-ON	SIDE-SWIPE	FIXED OBJECT	ROLL – OVER	TOTAL
OBSERVED AVERAGE CRASH FREQUENCY					
1a	0	0	3	5	8
1b	1	1	3	3	8
1c	3	1	0	3	7
1d	1	2	5	3	11
1e	0	0	1	3	4
1f	1	1	3	2	7
RSI CRASH COSTS PER CRASH TYPE					
1a	$0	$0	$284,100	$1,198,500	$1,482,600
1b	$375,100	$34,000	$284,100	$719,100	$1,412,300
1c	$1,125,300	$34,000	$0	$719,100	$1,878,400
1d	$375,100	$68,000	$473,500	$719,100	$1,635,700
1e	$0	$0	$94,700	$719,100	$813,800
1f	$375,100	$34,000	$284,100	$479,400	$1,172,600

Table Notes:
1. Crash types that were not reported to have occurred on Roadway Segment 1 were omitted from the table. The RSI costs for these crash types are zero.
2. The values in this table are the result of multiplying the average crash frequency for each crash type by the corresponding RSI cost.

The calculation for Window Subsegment 1d is shown below.

$$\text{Total RSI Cost} = (1 \times \$375{,}100) + (2 \times \$34{,}000) + (5 \times \$94{,}700) + (3 \times \$239{,}700) = \$1{,}635{,}700$$

STEP 2 – Calculate Average RSI Cost per Subsegment

Sum the RSI costs for all crash types and divide by the total average crash frequency for the specific window subsegment as shown in Equation 9. The result is an Average RSI cost for each window subsegment.

$$\textit{Average RSI Cost per Subsegment} = \textit{Total RSI Cost} / N_{observed,i(TOTAL)} \quad (9)$$

Where,

$N_{observed,i(TOTAL)}$ = Total observed crashes at site, i

Exhibit 13: Average RSI Cost per Window Subsegment

The calculation for Window Subsegment 1d is shown below.

$$Average\ RS\ I\ Cost\ = \$1{,}635{,}700 / 11 = \$148{,}700$$

Exhibit 13 summarizes the Average RSI Crash Cost calculation for each window subsegment within Segment 1.

Exhibit 13: Average RSI Crash Cost per Window Subsegment

WINDOW SUBSEGMENT	TOTAL NUMBER OF CRASHES	TOTAL RSI VALUE	AVERAGE RSI VALUE
1a	8	$1,482,600	$185,300
1b	8	$1,412,300	$176,500
1c	7	$1,878,400	$268,300
1d	11	$1,635,700	$148,700
1e	4	$813,800	$203,500
1f	7	$1,172,600	$167,500

STEP 3 – Calculate Average RSI Cost for the Population

Calculate the average RSI cost for the entire reference population (i.e category under consideration) by summing the total RSI costs for each site and dividing by the total average crash frequency within the population. In this sample problem, the population consists of Segment 1 and Segment 2. Preferably, there are more than two segments within a population; however, for the purpose of illustrating the concept and maintaining brevity this set of example problems only has two segments within the population.

The average RSI cost for the population ($\overline{RSI_P}$) is calculated using Equation 10.

$$\overline{RSI_P} = \frac{\sum_{i=1}^{n} RSI_i}{\sum_{i=1}^{n} N_{observed,i}} \quad (10)$$

Where,

$\overline{RSI_P}$ = Average RSI cost for the population

RSI_i = RSI cost per site in the population

$N_{observed,i}$ = Number of observed crashes in the population

Exhibit 14 summarizes the information needed to calculate the average RSI cost for the population.

Exhibit 14: Average RSI Cost for Two-Lane Undivided Rural Highway Population

Roadway Segments	Angle	Head-On	Side-swipe	Pedestrian	Fixed Object	Roll-Over	Other	Total
Average Crash Frequency Over Three-years								
1	0	6	5	0	15	19	0	45
2	1	3	3	3	14	10	2	36
RSI Crash Costs per Crash Type								
1	$0	$2,250,600	$170,000	$0	$1,420,500	$4,554,300	$0	$8,395,400
2	$56,100	$1,125,300	$102,000	$863,700	$1,325,800	$2,397,000	$110,000	$5,979,900

Below is the average RSI cost calculation for the Rural Two-Lane Highway population. This can be used as a threshold for comparison of RSI cost of individual sub-segments within a segment.

$$\overline{RSI_P} = \frac{\sum_{i=1}^{n} RSI_i}{\sum_{i=1}^{n} N_{observed,i}} = \frac{\$8{,}395{,}400 + \$5{,}979{,}900}{45 + 36} = \$177{,}500$$

STEP 4 – Rank Locations and Compare

Steps 1 and 2 are repeated for each roadway segment and Step 3 is repeated for each population. The roadway segments are ranked using the highest average RSI cost calculated for each roadway segment. For example, Segment 1 would be ranked using the highest average RSI cost shown in Exhibit 13 from Window Subsegment 1c ($268,300). The highest average RSI cost for each roadway segment is also compared to the average RSI cost for the entire population. This comparison indicates whether or not the roadway segment's average RSI cost is above or below the average value for similar locations.

Prioritization Method

Incremental Benefit-Cost Analysis

Exhibit 15 summarizes the crash reduction, monetary benefits and costs for the safety improvement projects being considered.

Exhibit 15: Project Facts

Location	Estimated Average Reduction in Crash Frequency	Present Value of Crash Reduction	Cost Estimate
Intersection 2	47	$33,437,850	$695,000
Intersection 7	6	$1,200,000	$200,000
Intersection 11	7	$1,400,000	$230,000
Intersection 12	9	$1,800,000	$100,000
Segment 1	18	$3,517,400	$250,000
Segment 2	16	$2,936,700	$225,000
Segment 5	458	$7,829,600	$3,500,000
Segment 6	110	$6,500,000	$2,750,000
Segment 7	120	$7,000,000	$3,100,000

STEP 1 – Calculate the BCR

Calculate the BCR for each project using Equation 11.

$$BCR = \frac{PVB}{PVC} \qquad (11)$$

Where,

BCR = Benefit cost ratio

PVB = Present value of project benefits

PVC = Present value of project costs

STEP 2 – Organize Projects by Project Cost

The incremental analysis is applied to pairs of projects ordered by project cost [for projects with BCR greater than 1.0], as shown in Exhibit 16.

Exhibit 16: Cost of Improvement Ranking

PROJECT	COST OF IMPROVEMENT
Intersection 12	$100,000
Intersection 7	$200,000
Segment 2	$225,000
Intersection 11	$230,000
Segment 1	$250,000
Intersection 2	$695,000
Segment 6	$2,750,000
Segment 7	$3,100,000
Segment 5	$3,500,000

STEP 3 – Calculate Incremental BCR

Equation 12 is applied to a series of project pairs ordered by cost. If the incremental BCR is greater than 1.0, the higher-cost project is preferred to the lower-cost project. If the incremental BCR is a positive value less than 1.0, or is zero or negative, the lower-cost project is preferred to the higher-cost project. The computations then proceed comparing the preferred project from the first comparison to the project with the next highest cost. The preferred alternative from the final comparison is assigned the highest priority. The project with the second-highest priority is then determined by applying the same computational procedure but omitting the highest priority project.

$$Incremental\ BCR = (PV_{benefits\ 2} - PV_{benefits\ 1}) / (PV_{costs\ 2} - PV_{costs\ 1}) \qquad (12)$$

Where,

$PV_{benefits\ 1}$ = Present value of benefits for lower-cost project

$PV_{benefits\ 2}$ = Present value of benefits for higher-cost project

$PV_{costs\ 1}$ = Present value of cost for lower-cost project

$PV_{costs\ 2}$ = Present value of cost for higher-cost project

Exhibit 17 illustrates the sequence of incremental benefit-cost comparisons needed to assign priority to the projects.

Exhibit 17: Incremental BCR Analysis

Comparison	Project	$PV_{benefits}$	PV_{costs}	Incremental BCR	Preferred Project
1	Intersection 12	$1,800,000	$100,000	-6	Intersection 12
	Intersection 7	$1,200,000	$200,000		
2	Intersection 12	$1,800,000	$100,000	9	Segment 2
	Segment 2	$2,936,700	$225,000		
3	Segment 2	$2,936,700	$225,000	-307	Segment 2
	Intersection 11	$1,400,000	$230,000		
4	Segment 2	$2,936,700	$225,000	23	Segment 1
	Segment 1	$3,517,400	$250,000		
5	Segment 1	$3,517,400	$250,000	67	Intersection 2
	Intersection 2	$33,437,850	$695,000		
6	Intersection 2	$33,437,850	$695,000	-13	Intersection 2
	Segment 6	$6,500,000	$2,750,000		
7	Intersection 2	$33,437,850	$695,000	-11	Intersection 2
	Segment 7	$7,000,000	$3,100,000		
8	Intersection 2	$33,437,850	$695,000	-9	Intersection 2
	Segment 5	$7,829,600	$3,500,000		

As shown by the comparisons in Exhibit 17, the improvement project for Intersection 2 receives the highest priority. In order to assign priorities to the remaining projects, another series of incremental calculations is performed, each time omitting the projects previously prioritized. Based on multiple iterations of this method, the projects were ranked as shown in Exhibit 18.

Exhibit 18: Ranking Results of Incremental BCR Analysis

Rank	Project
1	Intersection 2
2	Segment 5
3	Segment 7
4	Segment 6
5	Segment 1
6	Segment 2
7	Intersection 12
8	Intersection 11
9	Intersection 7

APPENDIX G: CRASH ANALYSIS TOOL USER GUIDE

This guide includes the instructions and background that are required to use and understand the Crash Analysis Tool that has been developed and customized for use by the South Dakota Department of Transportation. The guide is divided into the following sections:

- Advance preparation needed for tool use;
- Accessing the tool;
- Loading the appropriate inputs;
- Viewing and interpreting results;

The calculations conducted by the tool are based on the methodologies described in Appendix F in the August 23, 2010 Report entitled "Methods to Identify Needed Highway Safety Improvements in South Dakota."

System Requirements

To run this tool, the PC must have a licensed installation of ESRI's ArcGIS software at the ArcView 9.3 level or higher. The PC must also have the Visual Basic for Applications Core component installed. This is provided with all ESRI software, but is not commonly part of the default installation. A network administrator can add this component to computers that will run the Crash Analysis Tool.

Data Input Requirements

The following GIS layers are required to run the tool:

- Crash records as a GIS point layer. Intersection and segment crashes should be separated into individual layers. If crash records are separated into different tables by year, the tables should be merged into one;
- Intersection ranges or buffers as a GIS polygon layer. This layer will define a buffer range around each intersection that will determine which intersection a crash belongs to. This layer was prepared by Kittelson & Associates using South Dakota's aggregated intersection points at the base. The default buffer size is 100' for urban intersections and 250' for rural intersections. New buffers can be created using an ArcGIS add-on called ET GeoWizards;
- State roadways as a GIS polyline layer. The tool is configured to accept the current SDDOT roadway data;
- Subdivision geometry as a GIS polygon layer. The tool can limit analysis to particular areas. The layer must include a "Name" column to allow the tool to distinguish the divisions. Tool testing was performed using the county shapefile that was provided by SDDOT.

These layers do not need to be updated on any regular basis; however the more current they are the more current the data. The South Dakota Department of Transportation already possesses and maintains the data listed above. If there are changes to locations of intersections, a new buffer layer can be generated using an ArcGIS plug in called ET GeoWizards. The tool should be saved to a location on the PC with no spaces or special characters in the file path. An example of a good location would be C:\Safety\June2010\. A poor location would be C:\Documents and Settings\User\Safety Analysis – June 2010\.

All of the above layers should be loaded into the "GIS Data Inputs" folder included with the tool.

Accessing the Tool

The tool is accessed by opening the "SafetyAnalysis.mxd" file that was provided. This will launch an ArcMap session on your machine. Add all of the layers that are saved in the "GIS Data Inputs" folder.

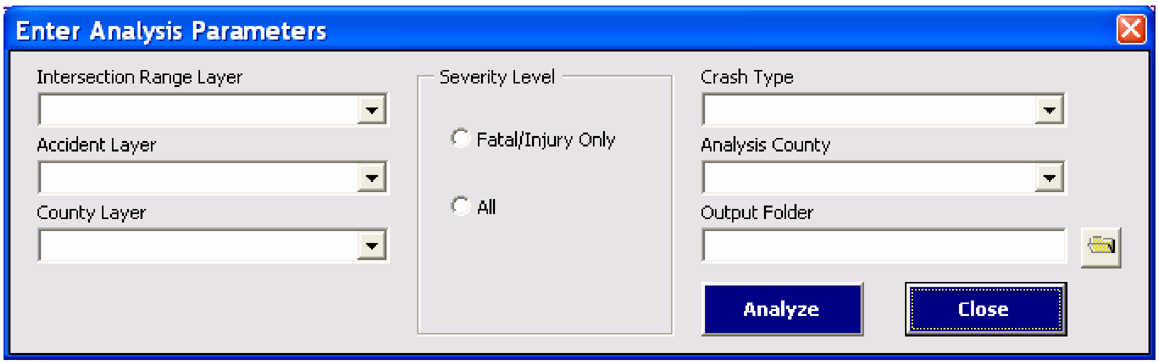
There will also be an undocked "Crash Analysis Toolbar" with two buttons; one for Intersection Analysis, one for Segment Analysis.

If the tool bar buttons say "Missing," then the computer is missing the Visual Basic for Applications Core component. Install that component from the ArcGIS installation discs and then reopen the project.

Loading the Appropriate Inputs

Intersection and segment analyses require different inputs and parameters. Exhibit 1 displays the input window for intersection safety analysis.

Exhibit 1: Intersection Safety Analysis Input Window



- Intersection Range Layer – select the polygon file that contains the intersection buffers to be used in this analysis;
- Accident Layer – select the point file that contains the intersection related accidents for all years that are to be analyzed;
- County Layer – select the polygon file that contains state counties or other geographical division for the analysis. The layer's attribute table must contain a populated "Name" field;
- Severity Level – this toggle will either filter out property-damage-only crashes, analyzing only fatal and injury crashes, or will analyze all crashes. In many cases, the fatal and injury crash filter will significantly reduce the sample size, leading to a higher likelihood of Type I statistical error, or that the result table will contain "false positives" due to the rare and random nature of automobile crashes. There are five levels of severity in the South Dakota Crash Database. 1 – Fatal, 2 – Incapacitating Injury, 3 – Non-Incapacitating Injury, 4 – Possible Injury and 5 – Property-Damage-Only. The Fatal/Injury-Only toggle will filter out crash level's 4 and 5;
- Crash Type – Select one from the following list of crash types that are available in the drop down window.
  - Left-Turn Angle
  - Right-Turn Angle
  - Head-On
  - Rear End
  - Fixed Object in Road
  - Fixed Object off Road
  - Overturn on Road
  - Overturn off Road
  - Sideswipe Overtake
  - Sideswipe Opposite Direction
  - Angle, Intersection
  - Angle, No Intersection
  - Bicycle
  - Pedestrian
  - Animal
  - Parked Vehicle

- Analysis County – Select a geographical division to analyze. If the entire state is needed, select "All." This can be done with any set of division polygons that contain a "Name" field;
- Output Folder – This defines the location to store the files generated by the tool. There is an "Outputs" folder supplied with the tool, but the outputs can be put in any path location that does not include spaces or special characters.

Exhibit 2 shows the input window for segment safety analysis.

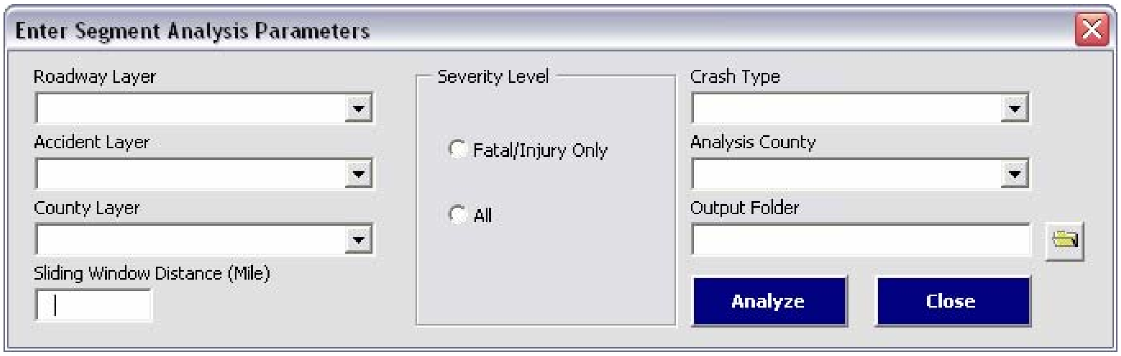


Exhibit 2: Segment Safety Analysis Input Window

- Roadway Layer – Select the file containing the roadway segments to be analyzed. This file must contain a coded functional classification field using state functional classification codes;
- Accident Layer – select the point file that contains the non-intersection related accidents for all years that are to be analyzed;
- County Layer – select the polygon file that contains state counties or other geographical division that you would like to base the analysis on. The layer must contain a populated "Name" field;
- Sliding Window Distance – enter a distance in miles that a sliding window analysis will cover along the roadway segment. Sliding window analyses are described in Section 5.4.4 of the research report. An initial distance of 1 mile is suggested. If the sample size is too small, it may be difficult to capture a statistically relevant number of crashes. It may be necessary to increase the sliding window size. It can be made very large (e.g. 1000 miles) to disable this function altogether. The sliding window will advance by ¼ of its length for each iteration.Severity Level – this toggle will either filter out property-damage-only crashes, analyzing only fatal and injury crashes, or will analyze all crashes. In many cases, the fatal and injury crash filter will significantly reduce the sample size, leading to a higher likelihood of Type I statistical error, or that the result table will contain "false positives" due to the rare and random nature of automobile crashes. There are five levels of severity in the South Dakota Crash Database. 1 – Fatal, 2 – Incapacitating Injury, 3 – Non-Incapacitating Injury, 4 – Possible Injury and 5 – Property-damage-only. The fatal/injury-only toggle will filter out crash levels 4 and 5;
- Crash Type – Select one from the following list of crash types that are available in the drop down window.

- Left-Turn Angle
- Right-Turn Angle
- Head-On
- Rear End
- Fixed Object in Road
- Fixed Object off Road
- Overturn on Road
- Overturn off Road
- Sideswipe Overtake
- Sideswipe Opposite Direction
- Angle, Intersection
- Angle, No Intersection
- Bicycle
- Pedestrian
- Animal
- Parked Vehicle

- Analysis County – Select a geographical division to analyze. If the entire state is needed, select "All." This can be done with any set of division polygons that contain a "Name" field;
- Output Folder – This defines the location to store the files generated by the tool. There is an "Outputs" folder supplied with the tool, but the outputs can be put in any path location that does not include spaces or special characters.

Viewing and Interpreting Results

Output Tables

An output layer will be created for each reference population using the analysis parameters. For example, an intersection safety analysis for left-turn angle crashes will produce a layer for urban signalized, urban unsignalized, rural signalized and rural unsignalized intersections. The layer name will specify the crash type, the reference population and the number of intersections where the crash type proportion exceeded the population threshold for that crash type.

The layer includes all of the source data for that intersection or segment. It also includes fields that contain a count of the number of valid crashes for that feature, the number of crashes of the specific crash type, the probability that the result table will contain "false positives" due to the rare and random nature of automobile crashes, and the proportional difference in the matching crashes for the feature and the reference population as a whole [In some cases with small sample sizes, the Highway Safety Manual methodology cannot calculate a valid probability. In those cases, the probability field will not be generated and the proportional difference field must be used on its own].

As with all shapefiles, the portion with the extension .dbf can be opened in Microsoft Excel for easy manipulation. The tables can also be sorted and summarized in ArcGIS-based on any roadway or intersection characteristics available in the source data. Additionally, all GIS mapping functionality is available to visualize the spatial relationship between sites with high proportions of the requested crash type. Data fields generated by the tool are described in Table 1.

Table 1: Field Definitions

Field	Data Type	Description
SUM_Join_C	Double precision number	Number of crashes assigned to the site for the input crash years.
SUM_CType	Double precision number	Number of crashes of the selected crash type at each site.
Prob	Double precision number	The statistical probability that the selected crash type is over-represented at each site.(1)
P_{DIFF}	Double precision number	The excess proportion of the selected crash type at each site over the proportion of the selected crash type for the entire population.

(1) In cases where the sample size is very small, a statistical anomaly may prohibit the calculation of a probability factor. This anomaly occurs when a combination of high variance and a low number of sites with 2 or more of the selected crash site are found. The "Prob" field will not be generated in those cases and a message will inform the user that "Due to an insufficient sample size, a valid probability could not be calculated. Please consider the excess proportion or pDIFF value to be less reliable in this case."

APPENDIX H: DESCRIPTIVE STATISTICS FOR QUALITATIVE ANALYSIS EXAMPLE

(Fixed Object Off Road Crash Type/Pennington County, Rural Facility)

This appendix is a summary of the mean P_{DIFF} as compared to the number of sites (N) with the particular roadway geometric characteristics for fixed object off the road crash types. The variables shown in the following tables are described as follows:

- Surface width (SURFAC_WI)
- Surface type – material type of driving lanes (SURFACE_TY)
- Surface condition (SURFACE_CO)
- Number of through driving lanes (LANES)
- Curb and shoulder configuration (i.e. on right and left, none, right only, left only) (CURB_SHLDR)
- Shoulder type – predominant material type of the shoulder (SHOULDER_T)
- Shoulder width (SHOULDER W)
- Posted Speed Limit (SPEED_LIMI)
- Parking on the roadway (i.e. sides or center))PARKING)
- Terrain adjacent to the roadway (TERRAIN)
- Rideability – quality of travel across a road segment (RIDEABILT)

SURFACE WI (feet)	Mean P_{DIFF}	N	Std. Deviation
22	0.65	1	.
24	0.33	9	0.25
26	0.31	2	0.00
28	0.35	2	0.42
32	0.65	2	0.00
Total	0.39	16	0.25

SURFACE TY	Mean P_{DIFF}	N	Std. Deviation
Gravel or Crushed Rock (5)	0.65	1	.
Mixed Bituminous (8)	0.37	15	0.25
Total	0.39	16	0.25

SURFACE_CO	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.65	1	.
Good (2)	0.37	15	0.248
Total	0.39	16	0.249

LANES	Mean P_{DIFF}	N	Std. Deviation
2	0.39	16	0.25
Total	0.39	16	0.25

CURB_SHLDR	Mean P_{DIFF}	N	Std. Deviation
Shoulder on the left and shoulder on the right (5)	0.42	4	0.29
Neither on the left and neither on the right (9)	0.38	12	0.25
Total	0.39	16	0.25

SHOULDER_T	Mean P_{DIFF}	N	Std. Deviation
No Shoulders (0)	0.38	12	0.25
Asphalt (4)	0.42	4	0.29
Total	0.39	16	0.25

SHOULDER_W (feet)	Mean P_{DIFF}	N	Std. Deviation
0	0.38	12	0.25
2	0.65	2	0.00
4	0.18	2	0.18
Total	0.39	16	0.25

SPEED_LIMI (mph)	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.54	3	0.20
35	0.51	3	0.25
40	0.15	1	.
50	0.29	8	0.25
55	0.65	1	.
Total	0.39	16	0.25

PARKING	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.37	15	0.25
No Parking Spaces (1)	0.65	1	.
Total	0.39	16	0.25

TERRAIN	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.65	1	.
Rolling (2)	0.37	15	0.25
Total	0.39	16	0.25

RIDEABILIT	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.65	1	.
Good (2)	0.37	15	0.25
Total	0.39	16	0.25

APPENDIX I: SPSS OUTPUT FOR STATEWIDE ANOVA ANALYSIS

(Fixed Off Object Off The Road Crash Type/Statewide – Rural Facility)

Descriptive Statistics

The tables presented in this section of the appendix show the descriptive statistics of the mean P_{DIFF} as compared to the number of sites for each roadway geometric characteristic used in the ANOVA analysis. Statewide data for object off the road crash type in a rural facility was used as described in Section 5.5.4. The variables shown in the following tables and graphs are described as follows:

- Surface width (SURFAC_WI)
- Surface condition (SURFACE_CO)
- Number of through driving lanes (LANES)
- Curb and shoulder configuration (i.e. on right and left, none, right only, left only) (CURB_SHLDR)
- Shoulder type – predominant material type of the shoulder (SHOULDER_T)
- Shoulder width (SHOULDER W)
- Posted Speed Limit (SPEED_LIMI)
- Terrain adjacent to the roadway (TERRAIN)
- Rideability – quality of travel across a road segment (RIDEABILT)

P_{DIFF} * SURFACE_WI

SURFACE_WI (feet)	Mean P_{DIFF}	N	Std. Deviation
20	0.54	4	0.32
22	0.55	8	0.23
24	0.44	77	0.26
25	0.43	3	0.34
26	0.44	13	0.21
28	0.60	7	0.26
32	0.64	3	0.28
36	0.21	1	.
Total	0.46	116	0.26

P_{DIFF} * SURFACE_CO

SURFACE_CO	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.47	6	0.31
Excellent (1)	0.49	17	0.22
Good (2)	0.46	75	0.27
Fair (3)	0.44	15	0.25
Poor (4)	0.39	3	0.14
Total	0.46	116	0.26

P_{DIFF} * CURB_SHLDR

CURB_SHLDR	Mean P_{DIFF}	N	Std. Deviation
Shoulder on the left and shoulder on the right (5)	0.46	44	0.26
Neither on the left and shoulder on the right (8)	0.47	1	.
Neither on the left and neither on the right (9)	0.46	71	0.26
Total	0.46	116	0.26

P_{DIFF} * SHOULDER_T

SHOULDER_T	Mean P_{DIFF}	N	Std. Deviation
No Shoulders (0)	0.46	71	0.26
Earth (1)	0.47	1	.
Gravel or Crushed Stone (2)	0.45	11	0.26
Blotter (3)	0.09	1	.
Asphalt (4)	0.48	32	0.26
Total	0.46	116	0.26

P_{DIFF} * SHOULDER_W

SHOULDER_W (feet)	Mean P_{DIFF}	N	Std. Deviation
0	0.46	71	0.26
1	0.46	14	0.26
2	0.45	17	0.27
3	0.34	2	0.18
4	0.38	3	0.15
5	0.81	2	.
6	0.49	5	0.33
8	0.44	2	0.042
Total	0.46	116	0.26

P_{DIFF} * SPEED_LIMI

SPEED_LIMI (mph)	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.51	28	0.25
25	0.66	2	0.21
35	0.53	9	0.30
40	0.42	3	0.09
45	0.52	9	0.25
50	0.40	10	0.25
55	0.43	51	0.26
65	0.39	4	0.33
Total	0.46	116	0.26

P_{DIFF} * TERRAIN

TERRAIN	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.47	6	0.31
Level (1)	0.45	70	0.26
Rolling (2)	0.46	35	0.26
Mountainous (3)	0.62	5	0.17
Total	0.46	116	0.26

P_{DIFF} * RIDEABILIT

RIDEABILIT	Mean P_{DIFF}	N	Std. Deviation
Not Attributed (0)	0.47	6	0.31
Excellent (1)	0.51	14	0.18
Good (2)	0.46	82	0.27
Fair (3)	0.46	14	0.24
Total	0.46	116	0.26

ANOVA

The following table presents the ANOVA test results conducted for the data presented earlier in this appendix. The first column (Source) lists the independent variables (geometric characteristics) – all in caps – used to test their effect on the dependent variable (P_{DIFF}). In the same column, "corrected model" represents the overall significance of the model. Assuming a 95% significance level, the values shown in the last column of the table (Sig) should have a value lower or equal to 0.05 (5%) in order to the independent variables and the "corrected model" have a statistically significant effect on the dependent variable. As shown in the table below, none of the studied roadway geometric characteristics had a significant influence on the P_{DIFF} for object off the road crash type in statewide rural facilities. The other columns (Type III Sum of Squares, df, Mean Square, F) are part of the ANOVA calculation steps that result in the last column (Sig) values.

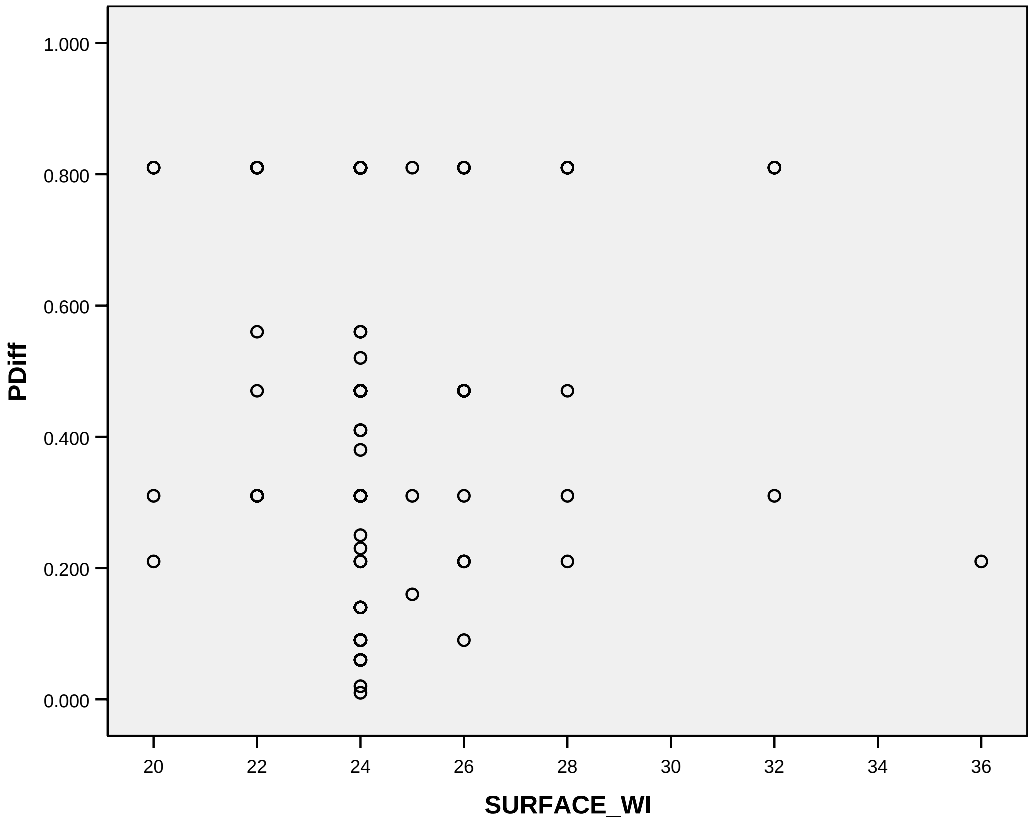
Tests of Between Subject Effects

Dependent Variable: P_{DIFF}

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	1.502(a)	33	.046	.610	.943
Intercept	.298	1	.298	3.984	.049
SURFACE_WI	.220	7	.031	.422	.886
SURFACE_CO	.130	3	.043	.582	.628
CURB_SHLDR	.036	1	.036	.479	.491
SHOULDER_T	.122	3	.041	.546	.653
SHOULDER_W	.393	6	.065	.876	.516
SPEED_LIMI	.255	7	.036	.488	.841
TERRAIN	.132	2	.066	.887	.416
RIDEABILIT	.102	2	.051	.684	.507
Error	6.123	82	.075		
Total	32.568	116			
Corrected Total	7.626	115			
R Squared = .197 (Adjusted R Squared = -.126)					

Graphs – Scatter Plots

The following scatter plot graphs provide a visual confirmation of the ANOVA results. For each of the studied geometric characteristic different levels (i.e. surface width – 20 ft, 22 ft, 24ft,…etc), the associated P_{DIFF} was plotted. This specific type of plot indicates if any possible trend –linear, exponential, logarithmic, etc - in the data exists. The random spread of data points in each of the following graphs indicates the lack of trends with the associated P_{DIFF} values.



1.000
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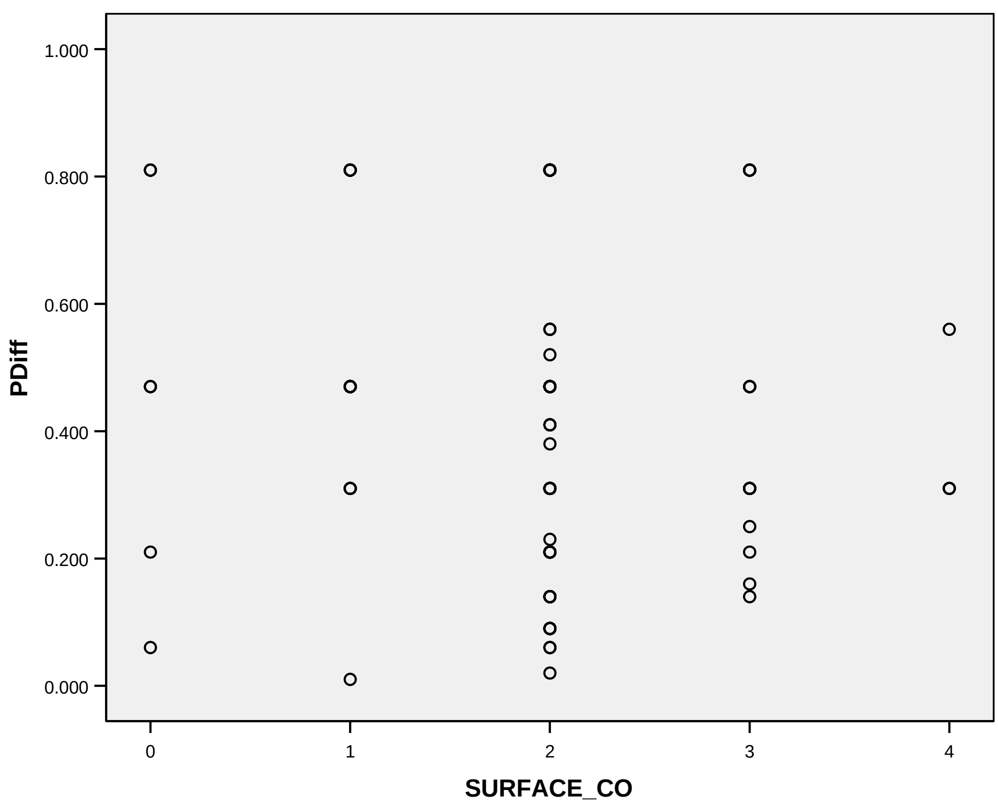
SURFACE_WI



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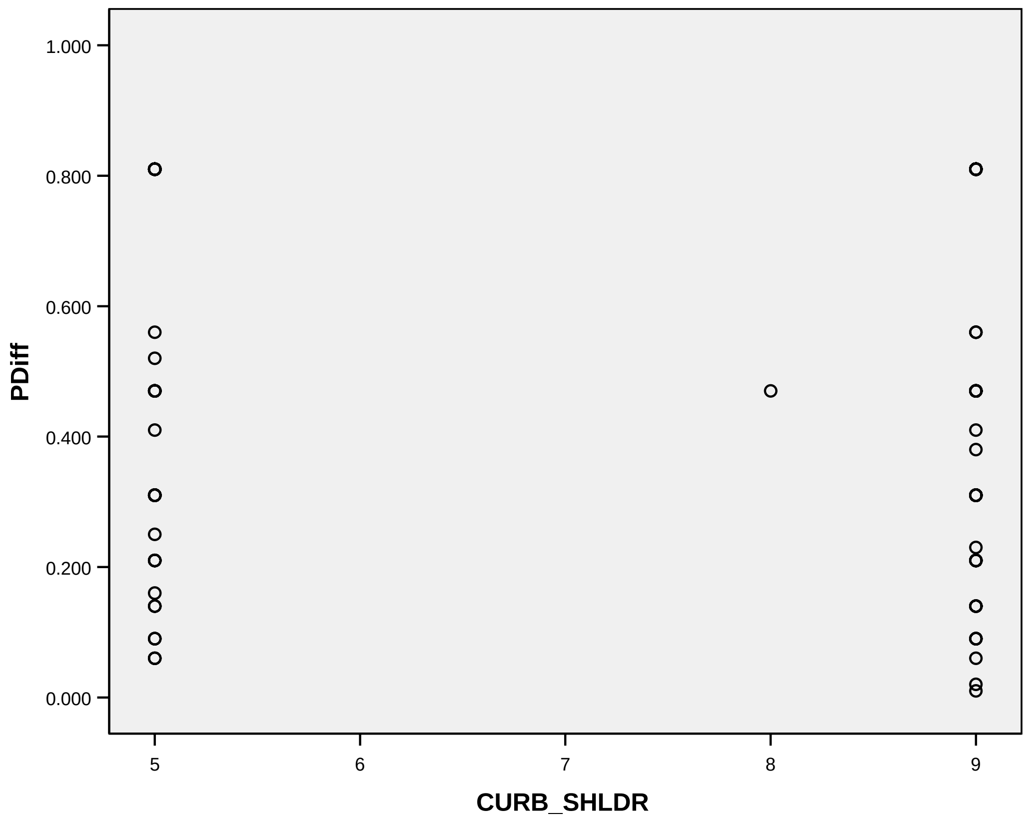
SURFACE_CO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PDiff
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8
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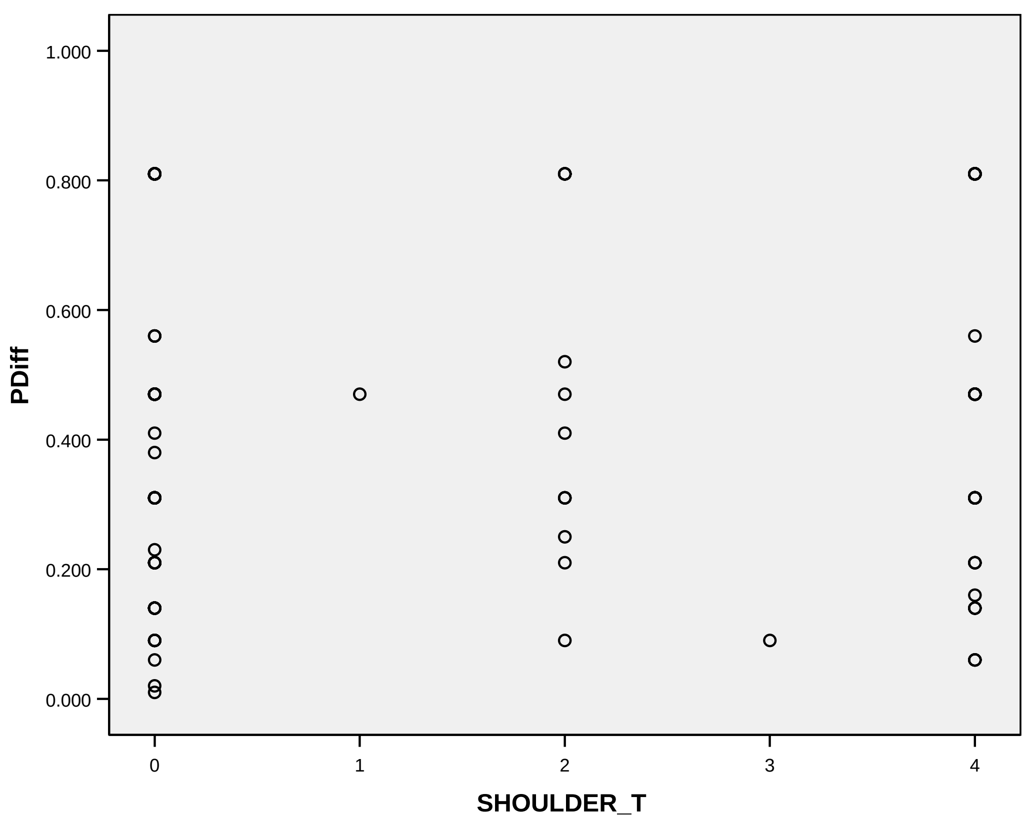
CURB_SHLDR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PDiff
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1
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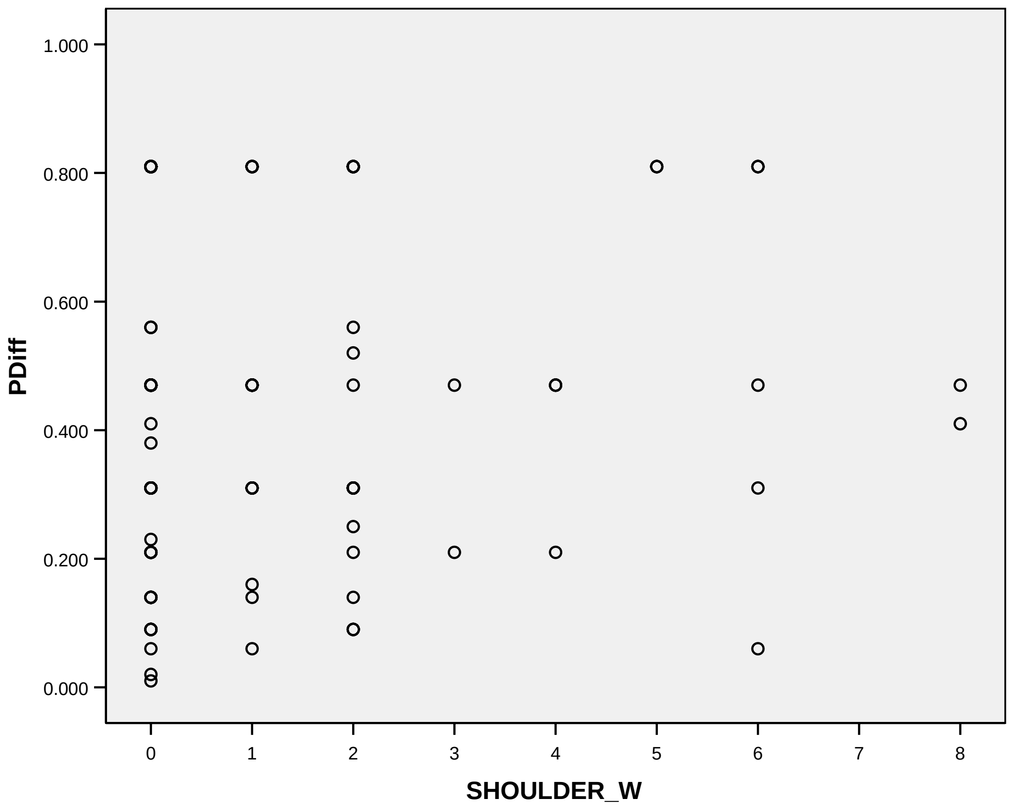
3
4
SHOULDER_T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PDiff
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7
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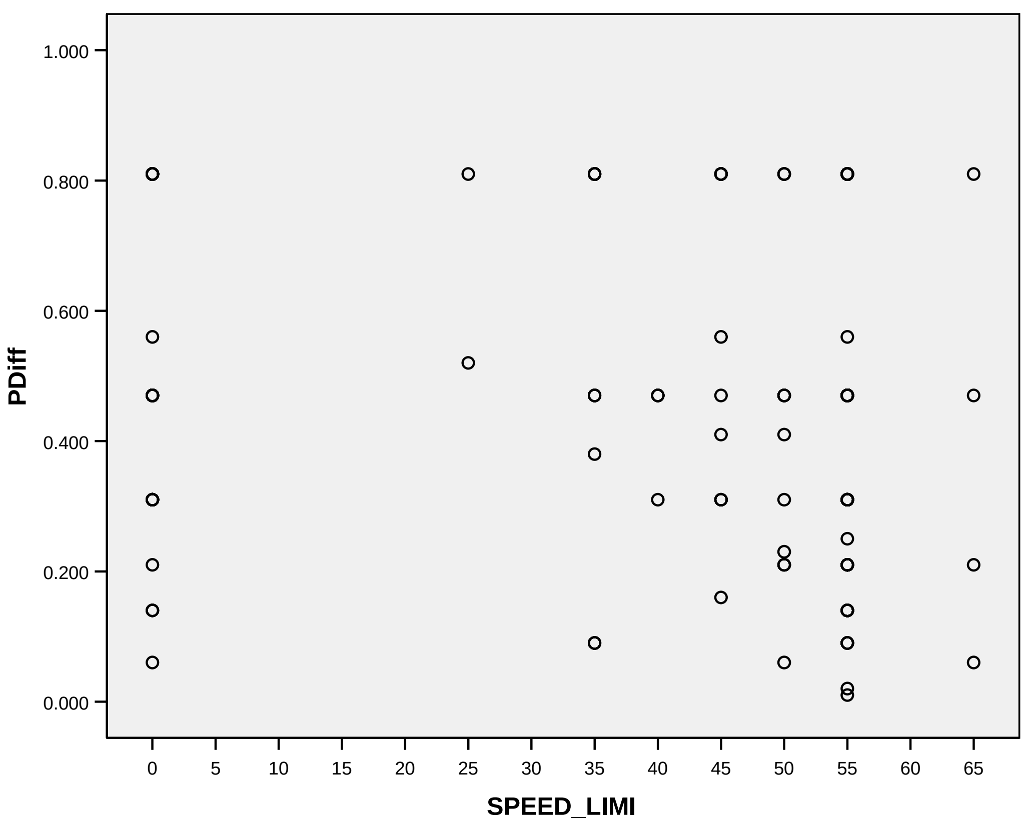
SHOULDER_W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PDiff
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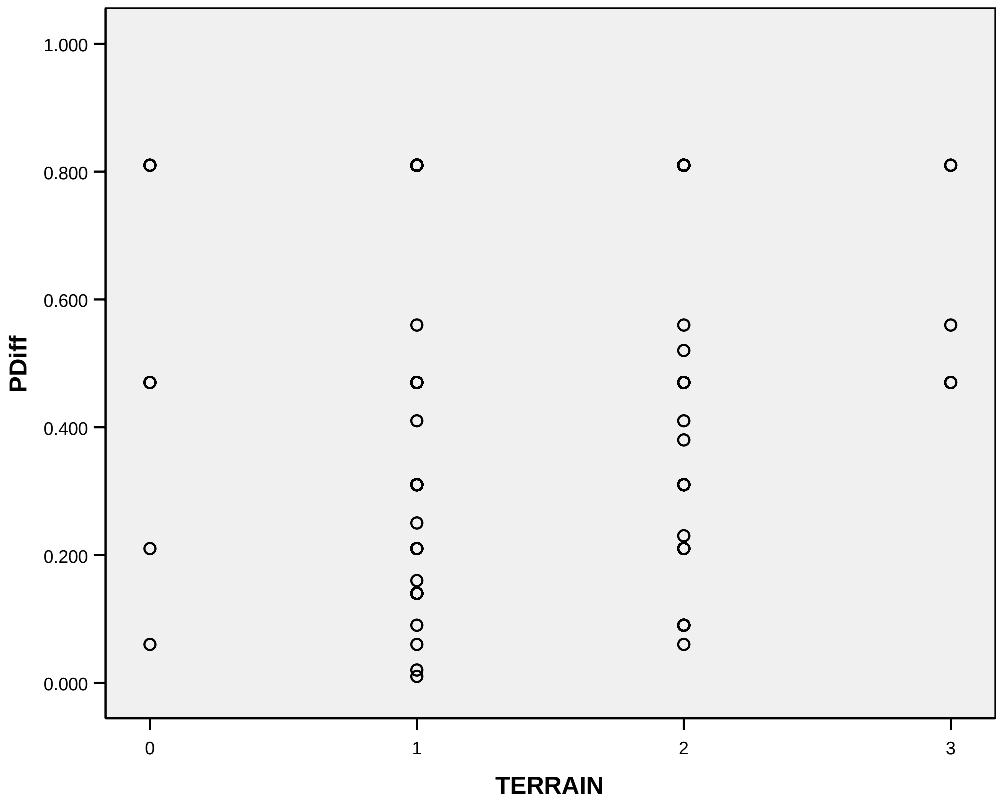
55
60
65
SPEED_LIMI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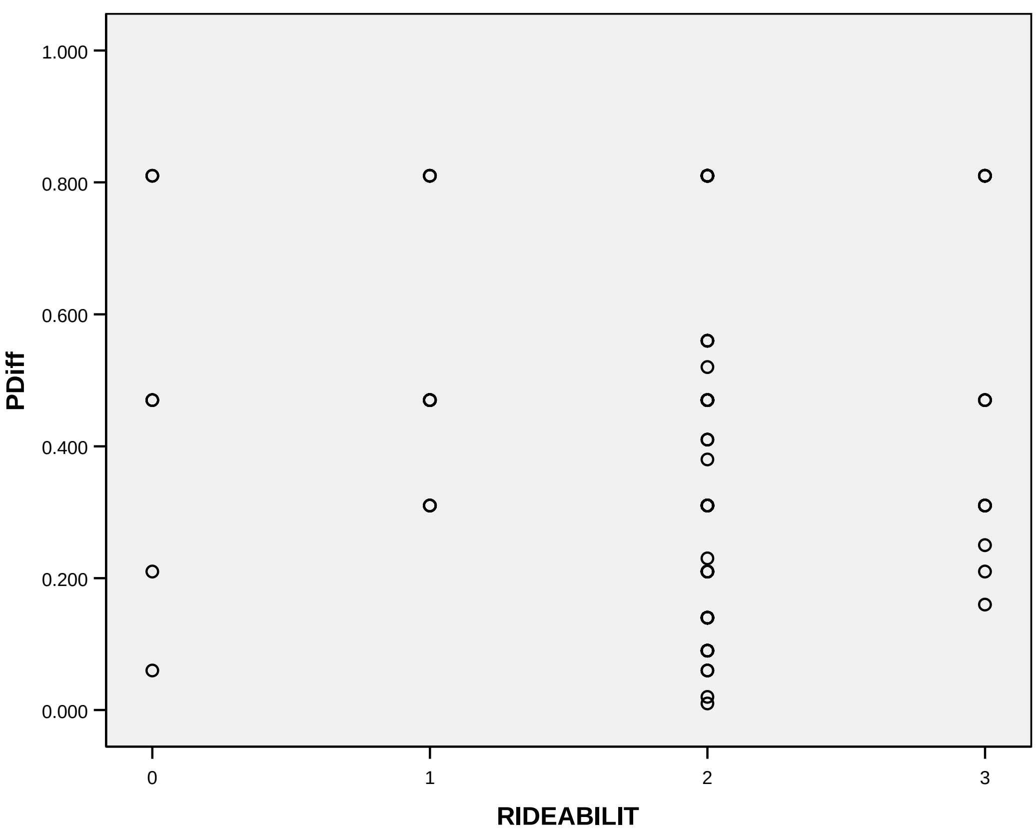
0.800
0.600
0.400
0.200
0.000
PDiff
0
1
2
3
TERRAIN


1.000
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0.600
0.400
0.200
0.000
PDiff
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1
2
3
RIDEABILIT