DEVELOPING A METHODOLOGY FOR IMPLEMENTING SAFETY IMPROVEMENTS ON LOW-VOLUME ROADS IN MONTANA

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Final Report

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THE STATE OF MONTANA
DEPARTMENT OF TRANSPORTATION

in cooperation with
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FEDERAL HIGHWAY ADMINISTRATION

September 2021

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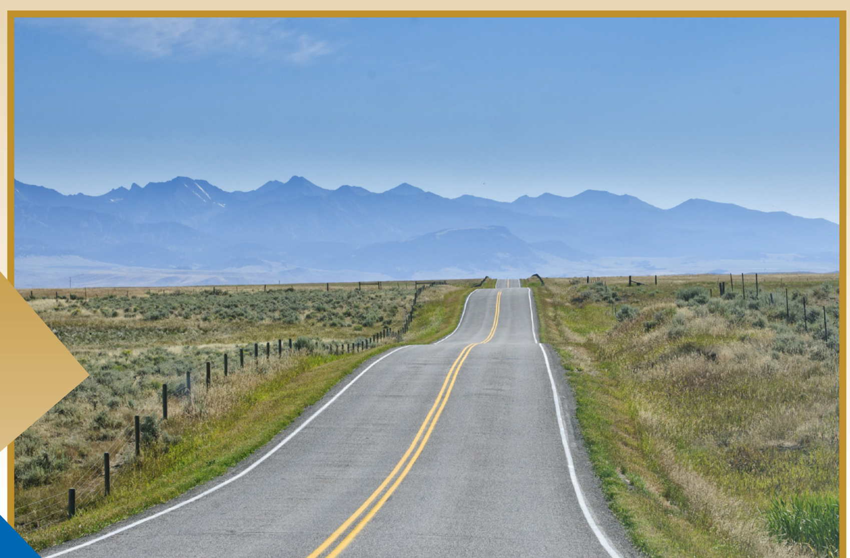

RESEARCH PROGRAMS

MDT

Developing a Methodology for Implementing Safety Improvements on Low-Volume Roads in Montana

Final Report

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16. Abstract

Rural low-volume roads (LVRs) are an integral part of the highway system as they provide connectivity to rural areas. Low traffic volumes and the random and sporadic nature of crash occurrence over LVR networks pose challenges in using the conventional crash-based network screening methods. Therefore, the objective of this research project is to develop an effective and practical network screening method for Montana LVRs. To that end, six tasks were successfully completed in this project including literature review, developing method assessment criteria, state of practice survey, assessment of network screening methods, developing network screening method for Montana LVRs, and the economic analysis of the new network screening methodology. Methods and findings from each task are detailed in this report along with a set of recommendations for safety management on LVRs and the implementation of the new proposed network screening methodology.

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EXECUTIVE SUMMARY

Rural low-volume roads (LVRs) are an integral part of the highway system as they provide connectivity to rural areas. These roads are typically two-lane, two-way highway facilities with lower functional classification, and many of them are unpaved roads serving remote rural areas. Although only 19 percent of people in the U.S. live in rural areas and 30 percent of the vehicle miles traveled occur in rural areas, almost half of crash deaths occur there (NHTSA, 2018). This highlights the need for incorporating LVRs into states' safety improvement programs to ensure progress toward vision zero objectives.

Network screening is an important step in any safety improvement program which helps to identify and rank sites for consideration of safety treatments. Low traffic volumes and the random and sporadic nature of crash occurrence over LVR networks pose challenges in using the conventional crash-based network screening methods. Therefore, the objective of this research is to develop an effective and practical network screening method for Montana LVRs. To that end, multiple tasks were successfully carried out which culminated with the development of the proposed network screening methodology.

A state-of-the-art review was carried out first where information about risk factors associated with LVRs and existing network screening methods were reviewed and summarized. Various research articles, research reports, agency websites and government publications were used in the literature review task.

The next task in the project aimed at developing assessment criteria for assessing the different network screening methods identified in the previous task. Eight assessment criteria were developed, namely, sensitivity to level of risk, sensitivity to economic effectiveness, precision, previous performance record, ease of understanding, ease of implementation, data requirements, and resource requirements.

The third task of the project involved a state-of-practice survey to collect information about safety management practices for LVRs across the country. An online survey was designed and distributed to all 50 state departments of transportation. Thirty-two states responded to the survey resulting in a response rate of 64 percent. The survey involved questions on various aspects of safety management on LVRs including those that are owned and operated by local government agencies.

The fourth task of the project was the assessment of different network screening methods identified in the first and third tasks of the project, using the criteria developed in the second task. Weights were assigned for different assessment criteria using pairwise comparisons. Further, a scoring scheme was developed for each of the assessment criteria. Using the scoring scheme and criteria weights, the network screening methods were evaluated for the degree they met the assessment criteria.

The next task in the project involved developing a network screening method for Montana LVRs that satisfies three major requirements: 1) method does not rely on crash history alone in network screening, 2) method requires minimal information that can easily be acquired, and 3) method can be implemented by staff with limited technical background. The proposed method involved assigning a score to each site based on roadway characteristics, the observed number of crashes, and traffic exposure over the analysis period. Separate scoring schemes were developed for roadway segments and intersections.

An economic analysis for implementing the proposed methodology was carried out next. Benefit-cost analysis was used to assess the potential economic benefits of the new method. Benefit-cost ratios for three different scenarios were calculated. Crash reduction for all crash severities, fatal and serious injury crashes only, and all crashes except property-damage-only crashes were considered in the analysis. The benefit-cost ratios for the three scenarios varied between 16 and 23.

This report discusses in some detail the work performed on all project tasks and culminates with a summary of findings and recommendations.

1. INTRODUCTION

Low-volume roads (LVRs) are an integral part of the highway system primarily serving local traffic in rural areas. These roads usually have two lanes one in each direction of travel and many of them are unpaved roads in remote rural areas. Further, some of the LVRs are outside the jurisdiction of state highway departments as they are owned and operated by local government agencies such as counties, townships, and tribal governments.

Recent statistics show that about 50 percent of fatal crashes occurred on rural roads, even though only 19 percent of the US population reside in rural areas (NHTSA, 2018). This statistic highlights the importance of traffic safety on rural roads, including LVRs. While LVRs are unique in the type and volume of traffic served, they also pose unique challenges for highway departments particularly those related to safety management programs. Specifically, on roadways with higher traffic volumes, the more frequent occurrence of crashes allows for the direct identification of high crash locations using historical data. However, on LVRs, crash occurrence, particularly fatal and serious injury crashes, is less frequent. This makes it difficult to identify trends and treat sites that are in greatest need of safety improvement based on historical data. Geometric and traffic data, as well as other data sets may be used to help identify potential treatment sites. Therefore, an approach for identifying treatment sites that have the greatest potential to reduce fatal and serious injury crashes on LVRs is necessary. The expectation is that such an approach would improve safety on LVRs, both those operated by the Montana Department of Transportation as well as those operated by local government transportation agencies by reducing the number and severity of highway crashes.

The objective of the current project is to develop a methodology for identifying locations for safety improvement on LVRs that would lead to a reduction in fatal and serious injury crashes occurring on these roads. The prospective methodology would facilitate the implementation of safety improvement programs on LVRs despite the challenges discussed earlier.

Six major project tasks were completed for this project. This final report consists of eight chapters, one chapter for each of the six project tasks, one chapter for introduction and another chapter for conclusions and recommendations. The chapters are:

1. Introduction
2. State of the Art Review
3. Criteria for Site Identification and Prioritization
4. State of Practice Survey
5. Assessment of Existing Methodologies
6. Developing a Methodology for Selecting Safety Improvement Sites on Low-Volume Roads
7. Assessing Benefits of Proposed Method
8. Conclusions and Recommendations

The following chapters will discuss in detail each of these tasks and the findings and results produced in each effort.

2. STATE OF THE ART REVIEW

One of the important steps of any traffic safety programs is screening the network to identify candidate locations for safety improvements. Over the years, various screening methods have been developed. Methods using historical crash data (crash frequency, severity, and rates) at individual sites are the older and most widely used. However, newer screening methods are using different variables (such as roadway and traffic characteristics) to identify candidate safety improvement sites on a given network. Methods in the two groups vary in complexity from the simple to the more sophisticated methods (using mathematical models for example). The purpose of this chapter is to present the results of the literature review task, summarizing the state of knowledge in network screening for candidate safety improvement sites, with an emphasis on low-volume rural roads.

2.1. Challenges of Screening Sites for Low-Volume Rural Roads

In 2018, about 50 percent of fatal crashes occurred on rural roads, even though only 19 percent of the US population reside in rural areas (NHTSA, 2018). This statistic highlights the importance of improving safety on rural roads, including those with low traffic volumes. While no uniform definition exists for low-volume roads (LVRs), an average daily traffic (ADT) of a thousand vehicles per day (1000 vpd) has been used more often (Ewan et al., 2016; FHWA, 2009; Gross et al., 2011) and will be used in this project as well.

Most highway departments have limited budgets to implement safety improvement projects on a regular basis. As such it is important to use an effective screening method to identify potential sites for further consideration. The conventional approach for screening sites for safety improvements is to use crash history, that is crash frequencies, rates, and/or crash severities. While this conventional approach may work for higher-volume roads, it may not be effective for LVRs. Specifically, should crash frequency be used as the sole ranking criterion, sites along LVRs are unlikely to rank high on the list because low volumes normally result in a few sporadic crashes over the analysis period. On the contrary, when crash rate is used as the sole ranking criterion, low volumes are expected to result in higher crash rates even with only a few crashes taking place on these roads. Consequently, those sites may rank high on the list even though few crashes occurring at these sites may not be related to roadway characteristics but on the driver behavior (for example distraction, DUI, speeding, etc.). Therefore, techniques based entirely on historical crash data may not be effective in screening sites for safety improvements on LVRs.

2.2. Risk Factors for Low Volume Roads

For this research, a risk factor is defined as any attribute or characteristic of a particular roadway that increases the likelihood of crash occurrence. These attributes or characteristics may be related to roadway, traffic, and/or environmental factors. Roadway factors primarily involve roadside features, cross-section elements, and alignment. Factors related to traffic involve percentage of trucks or motorcycles, running speeds, driver characteristics (such as age, experience, and local versus tourist), and presence of non-motorized modes. Finally, environmental factors include weather conditions that may compromise the safety of driving conditions (heavy fog, ice or snow, hydroplaning). Because safety improvement projects are most commonly related to roadway factors, the three main characteristics of roadways (roadside features, cross-section elements, and alignment) will be the focus of this review.

2.2.1. Roadside Features

Roadside features include side slopes, ditches, and presence of fixed objects (trees, utility poles, culvert openings, bridge piers, etc.) within proximity of the roadway.

Bendigeri et al. (2011) identified potential risk factors that are likely to increase roadside tree crashes on different road classes in South Carolina. The study found that approximately 48 percent of tree crashes in the state occurred on secondary routes and that drivers under the age of 36 were involved in over 57 percent of those crashes. The study also found that 48 of the 51 study sites that had experienced a crash did not meet clear zone requirements. Specifically, critical side slopes and non-traversable ditches reduced effective clear zone distances.

A study by Ewan et al. (2016) quantified the relationship between crash occurrence and geometric and roadside features along rural LVRs in Oregon. Descriptive statistics, crash rate analysis, regression and correlation analyses were used. The relationship of crash occurrence with lane width, shoulder width, grade, side slope, roadside fixed objects, and horizontal and vertical curves have been quantified. The study found that an increase in the side slope rating, fixed object rating and driveway density all had strong correlations to high crash rates.

Schrum et al. (2012) investigated LVRs in Kansas and Nebraska to identify common fixed objects and geometric features that have the potential for causing crashes. Features identified included culverts, bridges, driveways, trees, ditches, slopes, utility poles and public broadcast service routing stations. Infrequent obstacles, including road and advertising signs, mailboxes, tree stumps, bushes, rock walls, boulders and water bodies were also identified as presenting safety issues. The frequency of the impact and their possible treatments were identified by the Roadside Safety Analysis Program (RSAP).

Souleyrette et al. (2010) undertook a safety analysis of low-volume rural roads in Iowa. Results revealed that LVRs had a higher frequency of roadside crashes (for example, those involving culverts, ditches, embankments, trees and poles) compared to their higher volume counterparts. The study also found a higher frequency of crashes at bridges, railroad crossings, driveways and T or Y configuration intersections, but a comparatively lower frequency at four-legged intersections.

Another study in Texas (Peng et al., 2012) investigated the relationship of roadside features with single vehicle crashes on rural two-lane roads. The investigation found that shoulder width, lateral clearance and side slope conditions impart a significant effect on road departure crashes. The study found that an increase in shoulder width, lateral clearance and the use of flatter side slopes decreased the probability of injury crashes.

2.2.2. Cross Section Elements

Cross section elements of roadways include lane width, shoulder width, shoulder surface type, use of rumble strips, markings, and delineation.

A study by Gross et al. (2011) on low volume roads found that narrow lane widths (between 8 and 10.5 feet), narrow or unpaved shoulders, lack of turn lanes, and pavement edge drop-offs of greater than 2 inches, all raise safety concerns. These issues were identified during observations from Road Safety Audits and are not based on a statistical evaluation.

Gross and Jovanis (2007) investigated the safety effectiveness of lane and shoulder widths for rural, two lane highway segments in Pennsylvania, including low-volume segments (those with average daily traffic (ADT) of less than 500 vehicles per day). Matching case-control approach was used to investigate segment and crash data, with control segments used for safety comparisons. Conditional logistic regression was used to investigate the relationship between crashes and lane and shoulder widths. Results indicated that lane widths between 10 to 11.5 feet and greater than 13 feet were less safe than the lane width of 12 feet. However, lane widths less than 10 feet indicated a lower crash risk, which contradicts the findings of other studies. Shoulder widths of 0 to 3 feet were found to increase crash risk, with that risk dropping as width increased.

Ivan et al. (1999) identified differences in causality factors for single and multi-vehicle crashes on two-lane roads. Even though this work did not focus on low volume roads, study results provided insights about potential risk factors. The research found that single vehicle crash rates decreased with increased traffic, wider shoulder widths and longer sight distances. Multi-vehicle crash rates increased with the presence of signalized intersections.

Wang et al. (2013) compiled a review of the effects of road characteristics on safety. The review found that past evaluation of the relationship between speed and crashes produced mixed results, with some studies suggesting increased speeds reduced safety while other studies suggesting the opposite trend. Regarding road characteristics, the researchers stated that past work had found roads with narrow lanes (less than 11.5 feet) and sharp horizontal curves had decreased numbers of crashes. Similarly, increased shoulder width and pavement improvements had also been found to reduce crashes. While these findings were not focused for low-volume rural roads, they may provide information about potential risk factors on these roads.

A study in Virginia (Garber and Kassebaum, 2008) identified causal factors of crashes at high-risk locations on rural and urban two-lane roads. Major causal factors were identified using fault tree analysis. Generalized linear modeling (GLM) was used to develop models for prediction of crash occurrence at study sites. Annual average daily traffic (AADT) values for the routes examined ranged from 0 to over 10,000 vehicles per day (vpd). The investigation found that variables associated with crashes did not vary between rural and urban roads. The research found that grade, operational speed, lane width and passing zone presence were factors in run-off-the-road crashes. Lane width, average daily traffic (ADT), turn lane presence and operating speeds were associated with rear end crashes. Curvature, operating speed, grade, ADT and passing zone presence were factors in head-on crashes. ADT, passing zone presence, speed, curvature and lane width were associated with sideswipe crashes. Finally, grade, operational speed, ADT, curvature, lane width and passing zone presence were associated with crashes classified as “other”.

Mahgoub et al. (2011) identified a series of issues to examine when conducting field reviews of local roads (ADT less than 500 vpd). This was part of the process for developing a quantitative assessment tool for local roads. The issues identified included changes in land use, traffic, terrain, lane width, shoulder width, fixed objects, guardrail presence, pavement surface, signage adequacy and railroad crossing presence. These features were listed only for evaluation purposes with no specific quantification of the associated risks.

Fitzpatrick et al. (2001) identified characteristics of low-volume two lane road crashes in Texas. The study found that sites with higher crash rates had higher presence of vertical and horizontal curves, narrow lanes, narrow shoulders, higher driveway/access density or restrictive sight distances due to roadside development.

Stamatiadis et al (1999) examined the likelihood of crash involvement for young (< 35), middle age (35-64) and older (65+) drivers on low volume roads (AADT > 5000 vpd) in Kentucky and North Carolina. The roadway characteristics examined in this study were speed limits, lane widths, shoulder widths and AADT. Ratios were calculated to measure the relative crash propensity for the different driver groups. Results for single vehicle crashes indicated that for speed limits above 45 mph, all age groups were more likely to be involved in crashes. For lane widths of 8 to 9 feet, younger and middle age drivers were more likely to be involved in crashes, while only younger drivers were at risk for lane widths of 9 to 10 feet. Shoulder widths of 0 to 1 foot presented a risk to younger drivers, while widths of 1 to 5 feet were a risk for younger and middle age drivers. Finally, roads with an AADT of 0 to 1999 vpd were a risk to younger and middle age drivers. When examining two-vehicle crashes, both younger and older driver groups were at risk for all these same features, while middle age drivers were found to be less at risk.

A study on risk factors for LVRs in Oregon (Ewan et al., 2016) found that lane widths of less than 12 feet had a higher crash risk than roads with the standard 12 foot lanes. Also, roads with narrow or no shoulders exhibited higher crash rates compared to shoulder widths of 4 to 5 feet. A correlation analysis also revealed that wider lane and shoulder widths were associated with lower crash rates.

A study by Sun et al. (2007) investigated the impact of pavement edge line on narrow, low volume (86 – 1,855 vpd ADT) roads in Louisiana, by examining general crash trends. The study found that fatal run-off-the-road crashes comprised up to 75 percent of total fatal crashes on rural two-lane roads where pavement widths were less than 20 feet.

Wang et al. (2008) evaluated rural two-lane roads (no traffic volumes cited) in Washington State to identify causal factors in crashes. Crashes were shown to decrease as shoulder and pavement widths increased. No specific values associated with these risks were identified by this research.

2.2.3. Alignment

Horizontal and vertical alignments include such elements as horizontal curves, vertical curves, grades, and their associated sight distances.

Federal Highway Administration (FHWA) found that, compared to a tangent section of road, a horizontal curve with a radius of 500 feet was 200 percent more likely to have a crash, while a horizontal curve with a radius of 1,000 feet was 50 percent more likely to experience a crash (FHWA, 2009; Zegeer et al., 1990). Similarly, Harwood et al. (2000) found that when curve length and radius were both 100 feet, the crash rate was more than 28 times higher than that of a tangent section.

Findley et al. (2012) investigated the impacts of spatial relationships to horizontal curve safety on rural two-lane roads in North Carolina. The factors investigated included distance to adjacent curves, radius and length of adjacent curves. The research found that the distance between adjacent curves was significant in estimating crashes, with longer distances between curves being associated with a higher number of crashes.

Van Schalkwyk and Washington (2008) identified characteristic features of two-lane rural roads for crashes in the state of Washington. The rate of run-off-the-road crashes was found to be higher in mountainous terrain than for other terrain types. Segments with shoulder widths less than 5 feet had higher overall and severe injury crash rates, including on horizontal curves. Also, horizontal curves having a degree of curvature above 2 was found to be associated with higher crash rates. In addition, Knapp and Robinson (2012) reported that a critical radius of 800 feet or less contributes to higher fatal and injury crash rates (more than 3.86 crashes per million vehicle-miles traveled).

The previously cited study by Stamatiadis et al. (1999) investigated the safety effect of degree of curvature on drivers by age group. The study found that degrees of curvature from 0.4 to 8.4

were a risk to younger drivers; degrees from 8.5 to 19.4 were a risk to younger and middle age drivers, and degrees of 19.5 and more a risk to younger and older drivers. Wang et al. (2008) also found that the increase in degree of curvature increased crash risk. In addition, the study found that grade or the presence of a curb or roadside wall also increased crash risk. However, no specific values associated with these risks were cited in this study.

Schneider et al. (2009) examined the severity of crashes at horizontal and vertical curves on rural two-lane roads. The results found that driver injuries were more likely to be severe on curves with a radius between 500 and 2,800 feet compared to sharper low-speed curves and gradual high-speed curves. When examining parametric-specific elasticities to measure the impact of different parameters on the likelihood of injury outcomes, it was found that run-off-the-road injuries increased by 7.7 percent on horizontal curves with a radius greater than 2,800 feet and 18.9 percent for curves with a radius between 500 and 2,800 feet. The combination of horizontal and vertical curves increased the likelihood of fatal crashes by 560 percent on curves with a radius of 500 to 2,800 feet.

Ewan et al. (2016) found that for LVRs in Oregon, higher degrees of curvature were associated with higher crash risks than curves with smaller degrees of curvature. The study found that crashes are eight times more likely to occur on curves with degrees of curvature of 30 or higher compared with curves with degrees of curvature of less than 5.

In their investigation of the safety effects of horizontal curve and grade combinations on two-lane rural highways in Washington State, Bauer and Harwood (2013) found that short and sharp horizontal curves were associated with higher crash frequencies. Also, short horizontal curves at sharp crest and sag vertical curves had higher crash frequencies.

2.3. Network Screening Methods

An important step in the Highway Safety Improvement Program (HSIP) is screening the network for sites that are good candidates for safety improvement projects. The screening process follows certain criteria that are good indicators of safety performance (crash history) or the level of risk (risk factors). This section discusses network screening methods reported in literature or published online, as well as various methods for assessing or predicting the level of risk by assessing risk factors at a particular site. Screening methods are classified into three types: those that use crash history, those that use crash prediction models, and those that utilize a combination of crash history and prediction models.

2.3.1. Methods based on Historical Crash Experience

This section discusses network screening methods that use historical crash experience such as crash frequencies, severities, crash types, and/or crash rates (the latter require the use of traffic exposure data). The methods that exclusively utilize historic crash data are presented first, followed by those that utilize crash data in conjunction with other information (such as traffic or roadway characteristics).

2.3.1.1. Methods using Crash Data Alone

Crash Frequency/Density Method: Crash frequency methods use the number of crashes for each site in the network. These sites could be a spot location (for example intersection, bridge, highway-rail crossing, etc.) or a roadway segment. Crash frequency could also be established for specific crash types, such as run-off-the-road crashes, pedestrian-involved crashes, etc. The sites are then ranked in a descending order. When crash frequency at a location is greater than a pre-determined critical value, that location is considered a "high crash location." The critical frequency values are either calculated using average crash frequency at similar sites (and their standard deviations) or by choosing a considerably high number for that particular type of location (Pawlovich, 2007; Southeast Michigan Council of Governments [SEMCOG], 1997; National Cooperative Highway Research Program [NCHRP], 1986; NCHRP, 2000).

The crash density method is used to calculate the number of crashes per mile for roadway segments. A segment can be defined as the minimum length of roadway having consistent characteristics. Similarly, the segments are ranked in descending order and segments having a crash density greater than a pre-determined critical density are considered as "high crash locations." The critical density is calculated in a similar fashion as described in the frequency method (Pawlovich, 2007; SEMCOG, 1997; NCHRP, 1986; NCHRP, 2000).

An illustrative approach to the crash frequency/density method is the spot map method. The spot map method develops a map showing crashes on the network, thus identifying crash clusters at spot locations and on segments of the road network. The map is then used to identify those locations or segments having the greatest numbers of total crashes or total crashes of a specific type. This is a simple and easy method more suitable for small areas and areas having lower number of crashes (Pawlovich, 2007; SEMCOG, 1997). It only provides rough estimates of high crash locations and fails to provide a list of those locations.

Crash Severity Methods: Crash injury severity is also incorporated in network screening. One method for assessing crash injury severity utilizes the ratio of fatal crashes to total number of crashes in identifying sites for further consideration. Fatal crash rates, fatal plus injury crash rates, and total crash rates may also be used. Crash severity methods incorporate injury severity in a number of ways, including frequency/density of severe crashes, rate of severe crashes and ratio of severe crashes. In this method, severe crashes are assigned more weight than other crashes. Generally, the results for each site are compared to a system-wide average for similar roadways. This allows any agencies to devote more resources to locations with a greater potential for severe crashes.

The equivalent property damage only (EPDO) method and the relative severity index (RSI) are two types of crash severity methods. The EPDO method assigns a weight to fatal and injury crashes against a baseline of property-damage-only (PDO) crashes. The EPDO for a site (or segment) is calculated using the weights, frequency of fatal, injury and PDO crashes. The EPDO rate for a site is calculated using traffic exposure data (Pawlovich, 2007; SEMCOG, 1997; NCHRP, 1986; NCHRP, 2000). The RSI method incorporates the weighted average cost of crashes at the site or segment. The RSI is calculated using frequencies and estimated crash costs for fatal, injury and property damage crashes (Pawlovich, 2007; SEMCOG, 1997; NCHRP, 1986; NCHRP, 2000).

A combination of crash frequency and crash severity is sometimes used for network screenings. This method incorporates both concentration criteria and severity criteria. To meet the concentration criteria, the site crash frequency/density must exceed a pre-determined critical value. To meet the severity criteria, the EPDO rate for the site must also exceed a predetermined cut-off value. If both criteria are met, the site is considered a candidate for safety improvement measures. Critical rates for total crash frequencies, fatal crash frequencies, etc. are used to determine the cut-off values (Pawlovich, 2007).

2.3.1.2. Methods using crash data in conjunction with other data

The Crash Rate Method: The crash rate method incorporates traffic exposure with crash history in the network screening process. Crash rates are expressed for highway segments as the number of crashes per million vehicle miles traveled, and for spot locations as the number of crashes per million vehicles entering. Like the crash frequency methods, a critical crash rate must be established, with locations higher than the critical value classified as "high-crash locations." A common practice is to use a critical value that is twice as high as the system-wide mean crash rate (Pawlovich, 2007; SEMCOG, 1997). The crash rate method often uses total crashes in calculating rates, however, rates for specific crash type (single-vehicle crashes for example) and severity levels (fatal crashes for example) are also used.

The Frequency-Rate Method: The frequency-rate method combines the results from crash frequency-density methods and the crash rate method. In this method, the crash frequencies and densities, as well as crash rates are calculated for point locations and roadway segments. Critical values are established for crash frequencies or densities as well as for crash rates both for point locations and roadway segments independently. Consequently, locations having both frequency/density value and crash rate value greater than the pre-specified critical values are considered "high crash locations" (Pawlovich, 2007; SEMCOG, 1997; NCHRP, 1986; NCHRP, 2000).

The Quality Control Method: The quality control method uses similar principles as that of the frequency and rate methods. This method involves comparing crash frequencies/densities or rates with pre-determined values for sites of similar characteristics. There are two types of quality control: number quality control and rate quality control.

The number quality control compares the actual frequency/density for each site with the critical frequency/density. A test is applied to determine the statistical significance of a site's crash frequency/density when compared to the mean crash frequency/density for similar sites. The statistical test assumes crashes have a Poisson distribution, and uses a probability constant that adjusts the critical value as per the level of confidence requirements. The rate quality control method follows the same principle but uses crash rates instead of frequency/density. The final step of this method includes the calculation of a safety index. The safety index is the ratio of observed frequency/density or crash rate to the critical frequency/density or crash rate. The sites are then ranked by the safety index (Pawlovich, 2007; SEMCOG, 1997; NCHRP, 2000).

Deacon et al. (1975) developed an effective procedure for identifying hazardous rural highway locations based on crash statistics. The procedure utilized multiple indicators of crash experience which included the number of fatal crashes, the total number of crashes, the number of effective-property-damage-only crashes, and the crash rate. Critical levels of these four indicators are expected to vary from state to state depending on the nature of the local safety improvement program as well as local traffic and roadway conditions and prevailing attitudes toward highway safety. Critical crash rates are established using quality control procedures.

Index Methods: Index methods combine crash severity indices with other methods. There are three main index methods: the weighted rank method, the crash probability index method (CPI) and the Iowa method.

The weighted rank method (Pawlovich, 2007; SEMCOG, 1997; NCHRP, 2000) combines results from other methods. For example, ranks based on the crash frequency/density, crash rate and crash severity methods are generated. Then using a weighting factor, the combined rank based on the individual ranks are calculated.

The crash probability index (CPI) combines the results from the crash rate, crash frequency and casualty ratio (CR) methods. Casualty ratio is the ratio of fatal and all types of injury crashes to the total number of crashes at a given site or segment. This method reduces misleading results that arise from either high or low traffic volume at a site, while also incorporating the severity of the crashes. When any of the results exceed their critical values, penalty points are assigned. The CPI value for a site is the sum of all the penalty points. Sites with higher CPI values receive higher priority. The penalty points for each of the criteria (rate, frequency and CR) can be subjectively assigned based on how much importance an agency puts on each of the methods. The critical value for the rate and frequency is set using the same principle as that of crash rate and crash frequency/density methods. The critical value for CR can be determined by using the regional CR. The regional CR can also be in terms of facility and intersection type in conjunction with traffic exposure (AADT) (Pawlovich, 2007; SEMCOG, 1997). Both the weighted rank method and the CPI method allows retention of some of the benefits of the different methods while also minimizing the disadvantages of each method. For example, using the crash frequency and the crash rate together helps to address the inaccuracy of the crash frequency method that arises due to very low or high volumes.

In Iowa, a method like the weighted rank methods are used. Three rank lists are developed: frequency rank, severity rank and rate rank. The original Iowa method requires identification of sites with at least eight total crashes, four injury crashes and one fatality. The selected sites are first sorted by descending frequency of crashes (frequency rank). Then the locations are sorted by a severity rank. The severity ranks are developed using the principle of loss of value. Each crash severity (fatal, injury, property damage only, etc.) is assigned a monetary value.

The loss value at a site is calculated based on the frequency of each crash severity and the respective monetary value. Finally, using the traffic exposure data, crash rates are calculated, and the sites are ranked according to the crash rates. The three ranks are then combined to create a composite rank factor which is used to prioritize the sites in a descending order (Pawlovich, 2007; Estochen, 1999; Iowa Department of Transportation Office of Traffic and Safety [IDOT TAS], n.d.)

The newer Iowa method uses a similar approach with focus on intersections. Crashes on road segments within a certain proximity of an intersection are considered as intersection related crashes. The frequency and rate rankings are developed in the same way as the original method. The injury severity ranking is developed by multiplying the frequency of each injury severity by specific weights. A normalization process of the ranks is carried out for each of the methods. This helps to reduce the impact of very large numbers when the ranks are combined. This is done by dividing each of the frequency, rate and severity values by their respective maximum values. For example, the maximum crash frequency in the frequency-based ranking is 5000. Another site has a frequency of 3000. Therefore, the normalized value for the second site would come out as 3/5. Finally, a weighted sum of the ranks of the measures is calculated. The weights are assigned based on the importance the agency puts on the individual ranks (Pawlovich, 2007).

2.3.2. Predictive Methods

Network screening methods based on predicted crash numbers use mathematical models to "predict" future crash numbers for a particular site in a network. These models are developed based on the relationship between crash numbers and roadway, traffic and geometric factors. This section discusses a few prediction models developed for rural roads.

2.3.2.1. Methods using crash prediction models

Zhong et al (2011) developed crash prediction models for rural roads in Wyoming using both the negative binomial regression (NBR) and Poisson regression method. The model used historical crash rate (number of crashes per unit length), traffic volume, and speed. The study found that NBR fits the over dispersed data more accurately. The study showed statistically similar crash rates for both gravel and paved road surfaces. The study also correlated higher crash rates with high traffic volumes in conjunction with high speeds. However, only 36 effective observations were used for this investigation.

Using data from rural two-lane highways in Pennsylvania, Aguero-Valverdea et al (2016) developed a methodology using crash type for identifying sites with promise (SWiPs). Full Bayes multivariate crash frequency model with spatial correlation to estimate crash frequency according to crash types was used. AADT at a particular time and segment length was used to predict the number of crashes. The study also compared univariate model, univariate spatial model, a multivariate Poisson lognormal model (MVPLN), and a MVPLN spatial model and found that MVPLN spatial model had a better fit of the data.

Schultz et al. (2016) developed a crash prediction model using the following variables: average annual daily traffic (AADT), segment length, speed limit, number of lanes, percentage of trucks, VMT, and the interaction between speed limit and number of lanes. About 100,000 iterations were performed on each segment to obtain posterior predictive distributions of the number of crashes that is expected to occur. The actual number of crashes were compared to the posterior predictive distribution to assign a percentile to each segment. The percentile was determined by where the actual number of crashes fell on the predicted distribution and was assigned a number between 0 and 1. The higher the percentile, the greater chance the segment is a hot spot that needs to be analyzed for safety improvements.

A Canadian study (de Leur and Sayed, 2002) developed a road safety risk index (RSRI) utilizing concepts related to the traffic conflict observation technique and drive-through safety reviews. Well-defined and quantifiable characteristics of road features are studied and scored while completing a drive-through review. These scores are then combined to produce an overall road safety risk, by combining three components of risk: the exposure of road users to road features, the probability of becoming involved in a collision, and the resulting consequences should a collision occur.

Ewan et al. (2015) developed a risk index to identify locations along Oregon’s low-volume rural roads that deserve further consideration. The crash risk index was developed using three major elements: geometric features, crash history and traffic exposure. Weights, which show the contribution of geometric and roadside features, crash history, and traffic exposure elements in the overall crash risk index, are assigned to each of these elements.

The International Road Assessment Program (iRAP) (2009) developed a methodology for network screening and for prioritizing locations for safety investments. The methodology involved inspection of the desired road either by driving and recording potential risk factors along a highway or by using video log data routinely acquired by law enforcement and transportation agencies. The methodology introduced road protection score (RPS) which is a function of likelihood, severity, crash type, and type of road users. The RPS for a site is the sum of the individual RPS of different crash types. For example, car occupant RPS is the sum of run-off RPS, head-on RPS and intersection RPS. The likelihood factor is the connection of a certain risk factor with the likelihood of death due to a certain type of crash. The severity factor is determined from the speed and the presence of roadside objects. For example, steep embankments have a potential to increase the severity of roadside crashes. The crash-type calibration factors are based on the analysis of the fatality proportions associated with each crash type along generic type of roads. Finally, a star rating is provided for different ranges of RPS. The higher the rating, the better the safety score, with one star being the least performing score and 5 star being the highest performing score.

2.3.2.2. Methods using surrogate safety measures

According to a FHWA study (Gettman et al., 2008), surrogate safety measures are "measures other than actual crash frequencies" that are helpful to assess safety needs without waiting for a statistically significant number of crashes to occur. Many methods for identifying candidate sites for safety improvements using surrogate safety measures have been proposed and/or used. This section discusses a few of these methods.

Speed and speed variation are identified as potential surrogate measures by many studies (Lee et al., 2002; Lee et al., 2006; Kwon et al., 2011). Studies have linked higher speeds with higher crash rates (Nilsson, 2004; Finch et al., 1994; Baruya, 1998). Studies also found that speed is a major determinant of crash severity (Aarts and van Schagen, 2006). Speed and speed variations are also used by many studies to determine crash potential (Stipanica and Miranda-Moreno, 2015). Siddiqui and Al-Kaisy (2017) has also used speed and speed variation as part of their investigation in assessing safety effects of a variable speed limit system.

A study in New Zealand (Harris et al., 2015) developed a method to identify curves on rural highways with higher level of risk using speed. Using the Austroads (the Australian transportation agency) operating speed model, the methodology calculated speeds along road sections based on the geometric features of the road. The method then compared the calculated speed with the horizontal curve radius to assess the design limitations of the curve. A new geographic information systems (GIS) model was developed. The model identified the curves, predicted the operating speeds along road corridors and assessed curve risk using approach speeds and radius. However, the operating speed prediction was based only on the observations of passenger car drivers and therefore, the results of the speed prediction could only refer to the predicted speed of passenger cars.

Stipancica et al. (2018) examined whether vehicle braking and accelerating maneuvers could be used as surrogate safety measure. GPS data was collected from smartphones of people who regularly drive to explore their braking and acceleration as potential surrogate measures through correlation with historical collision frequency and severity across different facility types. Data collection was done in Quebec City, Canada in 2014. The sample for this study contained over 4000 drivers and 21,000 trips. Hard braking and accelerating events were extracted and compared to historical crash data using Spearman's correlation coefficient and pairwise Kolmogorov-Smirnov tests. Both braking and accelerating showed positive correlation with crash frequency on highway segments, and stronger correlations were found at intersections. Locations with more braking and accelerating also tended to have more collisions. Though this study did not propose an identification and screening method for these maneuvers, the proposed surrogate measures can potentially be utilized for identification of candidate sites for safety improvements at the network level.

2.3.3. Methods using Crash History and Prediction Methods

The previous section presented methods that used predicted number of crashes for network screening purposes. However, should reliable crash data be available for highway network in question, it is possible to use crash history along with prediction models in assessing safety performance for all segments and intersections within the network. Methods that share this approach are briefly discussed in this section.

2.3.3.1. Empirical Bayes method

One example of the methods using crash history and crash prediction in assessing safety performance is the well-known empirical Bayes (EB) method. This method determines the expected number of crashes using the actual number of crashes (crash history) along with the predicted number of crashes using safety performance functions (crash prediction models). The Highway Safety Manual (HSM) recommends the use of empirical Bayes method in assessing safety performance at sites for which the observed crash frequency is available (AASHTO, 2010). The HSM prediction models, like the models explained in section 4.2.1, are mathematical models developed using data from a large number of similar sites. These models use traffic exposure as the main variable and are referred to as safety performance functions (SPFs). These models were developed using data from sites with specific geometric features, traffic control, etc. For sites with different geometric features and/or traffic control, adjustment to the predicted crash numbers are required. Adjustment factors used for this purpose are called the crash modification factors (CMFs). A calibration factor may also be used to account for regional and local variations.

2.3.3.2. Other methods

A study in Kentucky (Hummer et al., 1999) compared the collision-based method and an inventory-based method to identify candidate locations for safety improvements on rural roads. At that time, Tennessee DOT used the collision-based methods to identify those locations (the traditional hotspot identification methods). For the inventory-based methods, a seven-step process was developed. Three of the seven steps involve identifying sites for further consideration. Those three steps are: selection of suitable segments of highways on which the analysis is to be performed, breaking down those segments into distinct locations (such as bridges, curves, straight segments, etc.) and applying crash prediction models to calculate the predicted number of crashes for the segments. Then using both results, sites that are good candidates for safety improvement projects were ranked. To identify the effectiveness of each method, a survey was designed and sent to safety experts. As a part of the questionnaire, photographs of the sites were included. The experts were asked to rank those sites and their results were compared with the results of the two methods. The comparison indicated that both methods have the potential to perform equally well in identifying candidate safety improvement sites, and the study recommended using the inventory method to compliment the collision-based method.

Ossenbruggen (1987) developed a probability-based method to identify hazardous sections. The expected number of crashes for a spot was identified using an equation connecting the average daily traffic (ADT) and the probability of a harmful event taking place. The probability is calculated using two main variables; the probability of an individual being killed in a single motor vehicle trip and the mean number of trips made by an individual in a lifetime. The expected numbers of fatal and injury crashes are calculated by their respective equations. Sites with expected number of crashes less than the actual number of fatal and injury crashes, are identified as hazardous.

Tarko et al (2004) proposed two crash screening methods for ranking hazardous locations. One of the methods is based on the difference between expected and true crash numbers and the other is based on crash cost. The two proposed methods are index of crash frequency and index of crash cost.

The index of crash frequency (ICF) measures the difference between the estimates of the expected crashes and the typical numbers of crashes. The difference is then divided by the standard deviation of the difference estimate. Locations having an ICF value greater than 2 are considered as high crash locations. The higher the ICF value, the higher the chance of the location having higher number of crashes. This is so because it compares a location to a typical location of the same type having the same exposure.

This study did not use the empirical Bayes method, as the aim was to identify sites that had "anomalies in crash frequencies that might indicate a need for road improvements". The study also stated that the index method has already been used in Indiana for several years.

The second method compares the total cost of reported crashes with the typical cost. For this method, crashes are divided into two main categories, namely, injury or fatality crashes and property damage- only crashes. The authors claim that this method "incorporates crash severity through average crash costs" (Tarko et al., 2004).

2.3.4. Non-Mathematical Models of Network Screening

Lack of accurate and reliable crash data makes it difficult to use some of the aforementioned methods to identify locations for safety improvement projects. In these cases, the presence of certain risk factors can be used. These often use simple sets of criteria in assessing the level of risk at a particular site and in ranking the sites.

One available resource from FHWA is the Systemic Safety Project Selection tool. This network screening and prioritization process uses site-specific crash information (including type and severity), considers common factors contributing to the focus crash type, traffic volumes and geometric features of the road (FHWA, 2013). A particular focus is placed on the severity of crashes. Risk factors are determined based on the analysis of crash and roadway data. Roadway and traffic attributes shown to have a correlation to a particular crash type are known as risk factors. Locations having one or more of these risk factors are scored with “1” or an asterisk. After reviewing the locations, the risk factors are reassessed for their usefulness in identification of safety improvement locations in the whole system. Any risk factor that is present in every location of the network is discarded. Finally, the locations are ranked based on the presence of risk factors. Higher number of risk factors indicate higher potential for a particular crash type and therefore has higher priority. Kentucky (KYTC, 2012), Minnesota (MnDOT, 2014), New York (Richard et al., 2013) and Thurston County in Washington (The Thurston County Public Works Department, 2013) have all reported using the systematic safety project tool.

Both the Minnesota County Roadway Safety Plan (CRSP) and North Dakota Department of Transportation employ a star approach to identify at-risk locations. The approach identifies risk factors for the network and any site having the identified risk factors receives a star. If any site has more than a pre-determined number of stars, it is identified as an at-risk site.

2.4. Summary

This chapter presented the results of the literature review project task. The review focused on the different methods and approaches for identifying at-risk sites that are good candidates for safety improvements as well as the methods for assessing the level of risk at individual locations. More emphasis was placed on rural and LVRs and on network screening applications. The review included methods published in reports, studies and websites that have been either applied in practice or proposed by researchers.

The review is divided mainly into two parts: risk factors and network screening methods. Risk factors discussed in this chapter are those associated with roadway characteristics that are believed to affect safety performance in relation to roadside features, cross-section elements, and alignment design. The screening methods are further classified in this chapter into three major sections: methods using historical crash data, predictive methods, and methods using historical crash data and prediction models in combination.

3. CRITERIA FOR SITE IDENTIFICATION AND PRIORITIZATION

In the United States, traffic safety is a priority for state departments of transportation (DOTs) given the large number of crashes and fatalities on the highway system. DOTs allocate considerable resources to implement safety improvements. As available funding is usually limited, safety improvement projects should target sites on the network that result in the most safety benefits. To this end, highway safety programs involve the process of network screening for sites with less than a satisfactory safety record. Identified sites would represent good candidates for further consideration in developing and prioritizing safety projects. Several methods have been used in practice for the preliminary screening of the network for sites that are good candidates for safety improvement projects. Most of these methods have advantages and disadvantages in terms of data needs and the way screening results correspond to actual safety benefits at candidate locations. This task discusses some of the important criteria that will be used in assessing the merits (or lack thereof) of different network screening methods. The criteria discussed in this chapter are also important in guiding the development of Montana-specific methodology of network screening for the purpose of selecting safety improvement sites on rural low-volume roads (LVRs).

3.1. Criteria for Suitable Network Screening Methods

This section discusses the most important criteria that should be considered in assessing the suitability of a network screening method for identifying candidate safety improvement project sites. While some criteria may be more important than others, a comparison across these criteria is beyond the scope of this task.

3.1.1. Sensitivity to Level of Risk

This criterion accounts for the level of risk present at any given site on a roadway network. For this project, the level of risk is defined as the likelihood of a crash occurring at a given location. It is well-known that the major determinants of the level of risk are the geometric and roadside features. Geometric features include cross section elements such as number of lanes, lane width, shoulder width, etc. and highway alignment (examples include horizontal and vertical curves, grades, sight distance, etc.). Roadside features, on the other hand, primarily involve side slopes and the presence of fixed objects within proximity of the highway. These physical roadway properties are often referred to as “risk factors” in the traffic safety professional community. It is important to mention that the level of risk is also affected by traffic and environmental conditions due to their impact on risk factors. Factors related to traffic involve percentage of trucks or motorcycles, running speeds, driver characteristics (like age, experience, local versus tourist, etc.), and presence of non-motorized modes. Regarding environmental conditions, factors such as the presence of ice and snow on a pavement surface will increase the level of risk by reducing the tire-pavement traction. Similarly, heavy fog, and rainfall may restrict the sight distance and raise safety concerns when available sight distance is less than that required for a safe stopping maneuver. According to this criterion, network screening methods that are more sensitive to level of risk, (i.e. those that account for risk factors), would score high compared to other methods that do not incorporate risk factors.

3.1.2. Sensitivity to Economic Effectiveness

Economic effectiveness, often used in the form of benefit-cost ratio, is a major consideration for most highway departments when selecting sites for safety improvement projects. The rationale is clear and straightforward, a site that is expected to yield higher monetary return on safety investment is likely to receive safety funds. Following this principle, sites with higher crash frequencies and more severe crashes are generally associated with higher returns on safety investments. This also highlights the fact that roadways with high traffic exposure are often associated with higher crash frequencies, and therefore higher benefit-cost ratios. Besides traffic exposure, higher crash frequencies may also be related to the level of risk (or risk factors) at a particular site. However, the relationship between crash frequencies and risk factors may not be evident using crash data alone when traffic exposure is very low (for example rural LVRs). According to this criterion, network screening methods using crash frequency and severity would score higher than other methods that do not account for crash frequency or severity.

3.1.3. Precision

The precision criterion is used to assess whether a network screening method can respond to small and subtle changes of any factor related to the level of risk or crash occurrence at a particular site. Using a less precise screening method might lead to discarding potential at-risk sites, as the method may not be able to accurately assess the risk due to differences in magnitude of a risk-related feature. On the other hand, less precise methods usually tend to be fast, easy, and inexpensive to implement (i.e. doesn’t require much data or staff time). In the context of assessing risk, precision can be stratified into three levels: presence of a feature (e.g. a segment with a horizontal curve), a range of values for a feature (e.g. a segment with a horizontal curve with radius between 300 and 500 feet) and an exact value for that feature (e.g. segment with a horizontal curve with a radius of 360 feet). As an example, consider a situation where screening is completed on two similar roadway sites. The two sites are located on horizontal curves, have the same traffic volume, the same cross section, and the same roadside features. However, the radius of the horizontal curve at one site is much smaller than that at the other. Consequently, a screening method that screens sites based on the presence of certain risk-related features (in this case horizontal curvature), will yield the same score for both sites. However, sharper horizontal curves tend to impart greater risk. Therefore, a screening method that has the potential to identify this difference in the level of risk at the two sites is better able to identify the site with the sharper curve as being associated with higher risk. Consequently, a more precise network screening method receives a better score under this criterion.

3.1.4. Previous Performance Record

This criterion allows the scoring of network screening methods based on previous record of their performance. Only when a screening method is applied, a full understanding of the strengths and limitations of that method is achieved. The track record of a method being used in practice by more highway departments is often associated with the practicality of the method and the level of satisfaction of users. Hence, the application of a method in practice and the number of these agencies using a method is an indicator of the practicality of the method and its merits. This criterion is also important as it provides a scoring opportunity of the methods based on user feedback.

Using this criterion, a proposed network screening method that has not been used in practice would score low compared to other methods that have found use in practice. By the same token, a method that was only used by a single agency may not score as high as other methods that have been used by a larger number of transportation agencies.

3.1.5. Ease of Understanding

This criterion is to assess how intuitive or easy to comprehend the prospective network screening method is to the practitioner. Since the intent of this project is to develop a screening method that can easily be applied on local and LVRs, ease of understanding by practitioners at both state and local government agencies is essential. This criterion is also important because many local government agencies (counties, townships, etc.) may not have technical experts on-staff. Therefore, an easy-to-understand method will help facilitate implementation and use.

Under this criterion, sophisticated methods that require more extensive technical backgrounds (statistics for example) would score lower than other simpler methods which only require limited skills and/or expertise.

3.1.6. Ease of Implementation

This criterion would assess whether a network screening method is easy to implement and is closely related to the practicality of using a particular method. The ease of implementation considers factors such as the availability and accessibility of data and whether specially trained personnel are required. Certain methods may require special training such as those outlined in the Highway Safety Manual (HSM) (AASHTO 2010), special software (for example the iRAP program), or detailed roadway information that is not readily accessible by agency personnel. For example, the International Road Assessment Program methodology (iRAP, 2019) is not as easy to implement as some of the other conventional methods. Part of the iRAP method requires a road audit with sophisticated equipment and trained personnel for investigation. The data required is not readily available and therefore requires an extensive road audit. Similarly, prediction methods based on surrogate measures like conflict analysis require high precision video data, complex algorithms, and trained personnel to implement. According to this criterion, network screening methods that are more difficult to implement would receive lower scores.

3.1.7. Data Requirements

This criterion would assess the type, amount and precision of data required for a network screening method. Data types can be classified into three broad categories: crash data, traffic data and roadway data. Some methods may require information from only one category, while other methods may require information from all three categories. Further, within each data category, one or more information pieces may be required. For example, one method may only require information about crash frequency, while another method may require crash frequency, severity, and type. Data precision is another consideration in assessing data needs. For example, one method may require information about the presence of a certain feature (for instance horizontal curve, shoulder, grade, etc.) whereas another method may require the exact value of that feature (for instance curve radius, shoulder width, percent grade, etc.). Under this criterion, a network screening method requiring large amounts of information from multiple data categories with high precision would score low when compared to other methods that require less information from fewer data categories, with lower precision.

3.1.8. Resource Requirements

This criterion accounts for the resources needed when implementing a prospective network screening method. Resources primarily involve agency personnel and staff who are involved in applying the proposed method as well as other costs involved in acquiring the data, including staff time. Network screening methods which require fewer resources for implementation would score higher than resource-intensive methods under this criterion.

4. STATE OF THE PRACTICE SURVEY

The task presented in this chapter aims at understanding the state of practice in the United States regarding identifying sites for safety improvements on low-volume roads (LVRs). An online survey was developed in this task which was then finalized and sent to all state department of transportation (DOTs) seeking information on different aspects of safety management programs on LVRs, with emphasis on identifying sites for safety improvement projects.

This chapter begins with a summary of the methodology and a description of the survey tool. The remainder of the chapter discusses the results of the questionnaire. A summary of the findings is presented at the end of the chapter.

4.1. Methodology

The survey questionnaire consists of two major parts. The first part contains seven questions about identifying sites for LVRs that are owned and operated by the state's DOT. These questions address issues such as the use of specific network screening methods, use of cost effectiveness in the process, access to various types of data, and the level of agency's satisfaction with the site selection process. In this regard, "network screening is the process of identifying sites for further investigation and potential treatment" (Srinivasan et al., 2016). The second part of the questionnaire consists of ten questions and focuses on site identification for non-state-owned local roads. The questions in this section address issues such as the leadership of safety programs for non-state-owned LVRs, local agency involvement and its level, safety fund allocation for non-state-owned local roads, site identification methods, and other relevant aspects.

The survey used for this study was created and managed using Qualtrics software. The survey was sent via email to safety personnel at state DOTs in all the 50 states. Thirty-two (32) DOTs responded to the survey resulting in a response rate of 64 percent. The responding states are shown in red on the map in **Figure 1.** One responding agency submitted the survey without completing the questionnaire, and as such, this response was excluded from further consideration and analysis. A copy of the questionnaire is provided in **APPENDIX A** at the end of the report.

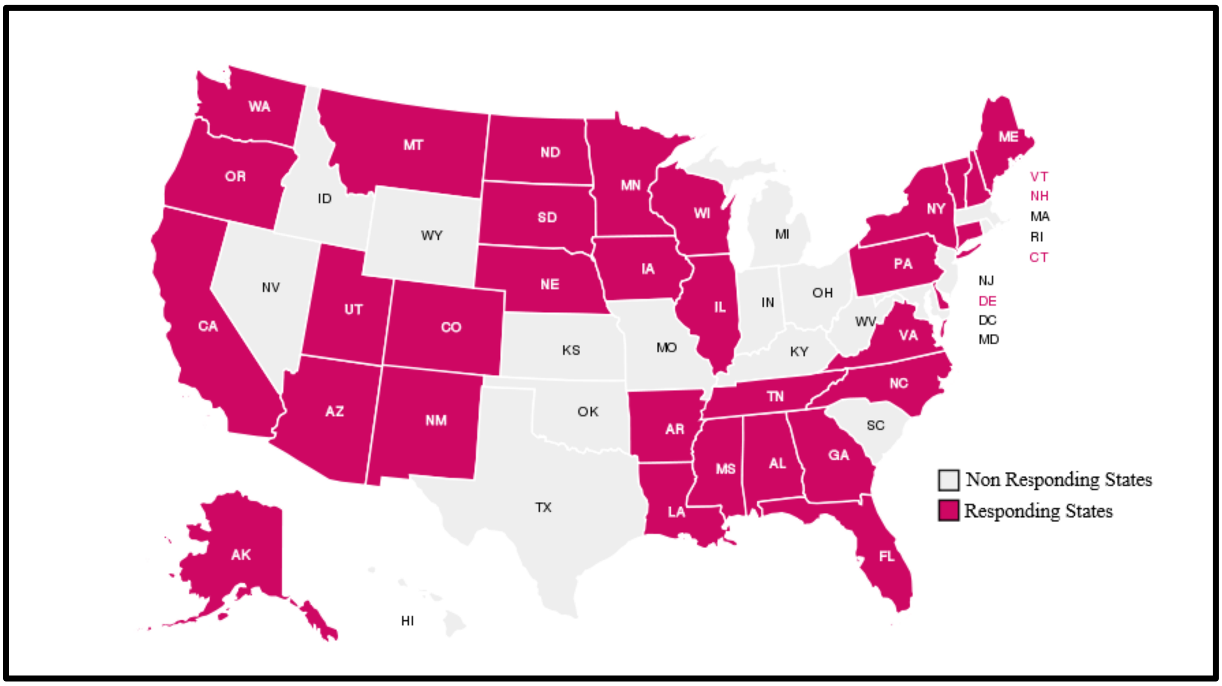

Figure 1: Map Showing the Survey Responding States

4.2. Results

4.2.1. Safety Improvement Programs for State-Owned Low-Volume Roads

As discussed earlier, the survey was divided into two parts. The first part consisted of questions that focused specifically on state-owned local roads. The results from the analysis of these responses are discussed in the following paragraphs.

The purpose of this survey was to understand how safety projects on LVRs are addressed by the different states. Before inquiring about the different methods of how safety concerns on LVRs are addressed, a question about the percentage of LVRs in each state was asked. The question asked about the percentage of roadways in the state that have a volume of less than 1000 vpd. The responses to this question are illustrated in **Figure 2**.

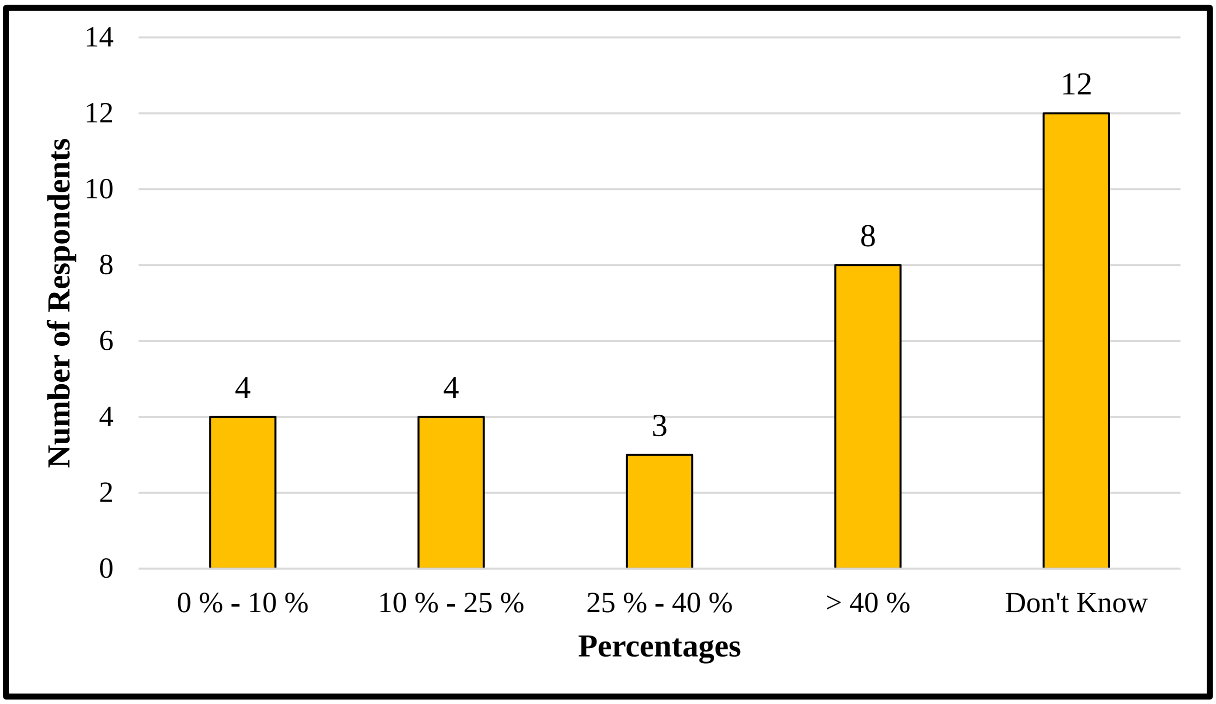

Figure 2: Percentage of Low-Volume Roads in State Highway Network

Eight out of 31 states (around 25 percent) reported that more than 40 percent of their roads are LVRs, that is, have an annual average daily traffic (AADT) of less than 1000 vehicles per day. Four out of 31 (about 13 percent) respondents reported a percentage between 10 and 25, and a similar number of states reported a percentage less than 10. Only three out of 31 states (less than 10 percent) reported a percentage between 25 and 40. It is important to note that 12 out of 31 respondents (around 38 percent) did not report a percentage due to lack of information. This might be because most states do not classify their roads based on daily volumes. Another possible reason is that many of the LVRs are in remote rural areas and therefore traffic counts on these roads may not be readily available.

Moving on to understand how states manage safety projects for LVRs, the survey inquired whether the agency has a different method for selecting safety improvement sites on LVRs than that used for other state-owned roads. This information is important because traditional methods for site identification on higher-volume roads (non LVRs) may not work well on LVRs.

More than 80 percent of the respondents (25 out of 31) reported having a different method for their local roads, while only about 19 percent of the respondents (6 out of 31) reported using the same method/process. This shows that most of the responding DOTs use separate and different methods for LVRs.

The next question in the survey asked DOTs about the different safety improvement site identification methods. **Figure 3** shows the number of times different methods were reported being used for site identification on state-owned local roads. Results show that crash severity is the most often reported method (21 times), followed by the FHWA systemic approach (15 times), and the combination of the crash frequencies and crash rates (15 times). The FHWA systemic approach to safety involves widely implemented improvements based on high-risk roadway features correlated with specific severe crash types [2]. Crash rate method alone is the least used method (8 times). Eleven states reported using different methods and their responses are summarized in **APPENDIX B** at the end of this report. As shown in this appendix, around seven responses are related to the use of predictive methods outlined in the Highway Safety Manual (HSM).

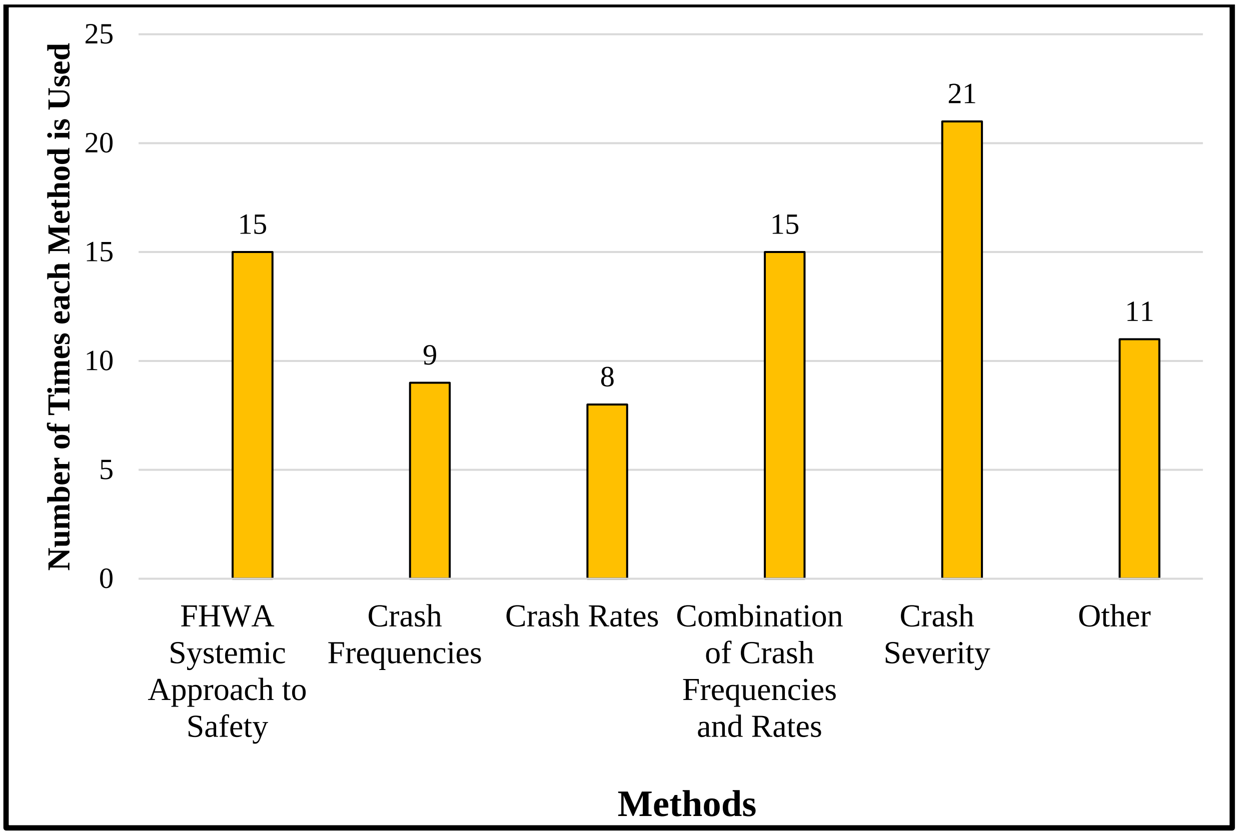

Figure 3: Frequency of Use of Different Site Identification Methods

Many of the respondents reported using the traditional network screening methods along with the FHWA systemic approach for site identification on state-owned local roads. Specifically, 15 out of 31 responding DOTs (48 percent) reported using the FHWA systemic approach in combination with one or more of other network screening methods.

The following question in the survey asked DOTs about how cost effectiveness is used for safety improvement site identification. **Table 1** summarizes the responses to this question.

Table 1: Use of Cost Effectiveness in Safety Management on State-Owned Low-volume Roads

How Cost Effectiveness is Used	Number of Responses
Rank safety improvement sites at the network level	6
Compare alternative safety countermeasures at specific sites	7
Both ranking sites and comparing alternatives	17
Not used	1

Seventeen out of 31 responding agencies (55 percent) reported using cost effectiveness for both ranking sites at the network level as well as for comparing different site-specific safety improvement alternatives. Only 7 DOTs (22 percent) use cost effectiveness for site-specific comparative analyses and another 6 DOTs (19 percent) use it for ranking sites at the network level (network screening).

To indirectly gather information on the level of challenges (or difficulties) in managing safety on LVRs, DOTs were asked about their level of satisfaction with the methods they reported using on state-owned LVRs. The question used a scale of 1 to 10, with 1 being "not satisfied" and 10 being "extremely satisfied." The responses to this question are summarized in **Table 2** and vary in a range from 4 to 10. Eighteen out of 31 DOTs (about 58 percent) reported a satisfaction level of 8 or higher, indicating a high level of satisfaction with their LVRs methods. Five out of 31 DOTs (around 16 percent) reported a score of 7, indicating DOTs are somewhat satisfied with the methods used. The remaining eight DOTs (around 26 percent) scored 6 or less on the scale, which reflects a lower level of satisfaction with the methods used. The responses reveal that most of the responding DOTs (around 74 percent) are satisfied with their methods of identifying safety improvement sites on LVRs.

Table 2: Department of Transportation's Level of Satisfaction with State-Owned LVR Methods

Level of Satisfaction	Number of responding departments
1	0
2	0
3	0
4	1
5	2
6	5
7	5
8	14
9	3
10	1

To examine any possible association between the level of satisfaction of DOTs and the methods used by DOTs in identifying safety improvement sites, the number of states with a level of satisfaction of 7 or greater were found for three different identification method categories: using network screening, using FHWA systemic approach and network screening, and using HSM-related methods (that is, prediction models using safety performance functions (SPFs) or empirical Bayes (EB)). The results of this analysis are summarized in **Table 3**. The level of satisfaction is the lowest for states using only network screening methods. The use of FHWA systemic approach in conjunction with network screening methods is shown to improve the level of satisfaction. Finally, all states that reported using HSM-related methods have a level of satisfaction of 7 or greater.

Table 3: Association of Level of Satisfaction with Site Identification Method Used

	Number of States	With Level of Satisfaction > 7	Percent
Number of States using only Network Screening Methods	16	10	63%
Number of States using FHWA Systemic Approach with Network Screening Approach	15	13	87%
Number of States using HSM-Related Methods	7	7	100%

To effectively manage safety on LVRs, access to crash, traffic, roadway, and roadside data is critical. Therefore, a question about the type of data that is readily available to safety personnel at the network level was included in the survey. The responses are summarized in **Table 4**.

Seven out of 31 DOTs (around 22 percent) reported having access to all data, that is crash, traffic, roadway, and roadside data (for example side slope, fixed objects, driveway density, etc.). Fourteen DOTs (around 45 percent) reported having access to all data except roadside features. The remaining 9 DOTs don't have access to roadway or roadside data: 7 DOTs have access to crash and traffic data and two DOTs have access to crash data only. These numbers show that around two thirds of the responding agencies have access to most of the data needed to analyze safety at the network level.

Table 4: Access to Different Data Types

Combination of Different Data Types	Number of States with Data Access
Detailed Crash Data	2
Crash & Traffic	7
Crash, Traffic & Roadway	14
All	7
Crash, Roadway & Roadside	1

4.2.2. Safety Improvement Programs for Non-State-Owned Low-Volume Roads

The second part of the survey focused on safety programs and practices for non-state-owned local roads. The findings from the responses to this part of the questionnaire are discussed in the following section.

To understand how safety on non-state-owned local roads are managed by DOTs, the survey asked DOTs whether the Highway Safety Improvement Program (HSIP) leader for non-state-owned roadways is different from the individual leading the program for state-owned roadways. Around 90 percent (28 out of 31) of responding DOTs do not have a separate HSIP leader for non-state-owned local roads. The remaining 10 percent (3 departments) confirmed that different leaders are assigned to safety programs for state-owned and non-state-owned local roads.

For more effective safety improvement programs on LVRs, input from local government DOTs is important. To understand the extent of local involvement of local DOTs, a question was included in the survey. Approximately 90 percent of the respondents (28 out of 31) reported involving local government DOTs in the site identification process, while only about 10 percent of respondents (3 out of 31) reported no involvement of local government DOTs in the process. These numbers suggest that most programs rely on input from local government DOTs in identifying safety improvement sites on local roads.

To gain a better understanding of how DOTs manage safety on non-state-owned local roads, DOTs were asked about the way DOTs allocate funds for safety improvements on these roads. Specifically, a question regarding the process for determining how much funding is allocated to safety projects on non-state-owned local roads was included in the survey. Most of the responses were descriptive responses and the results are codified and summarized in **Figure 4**.

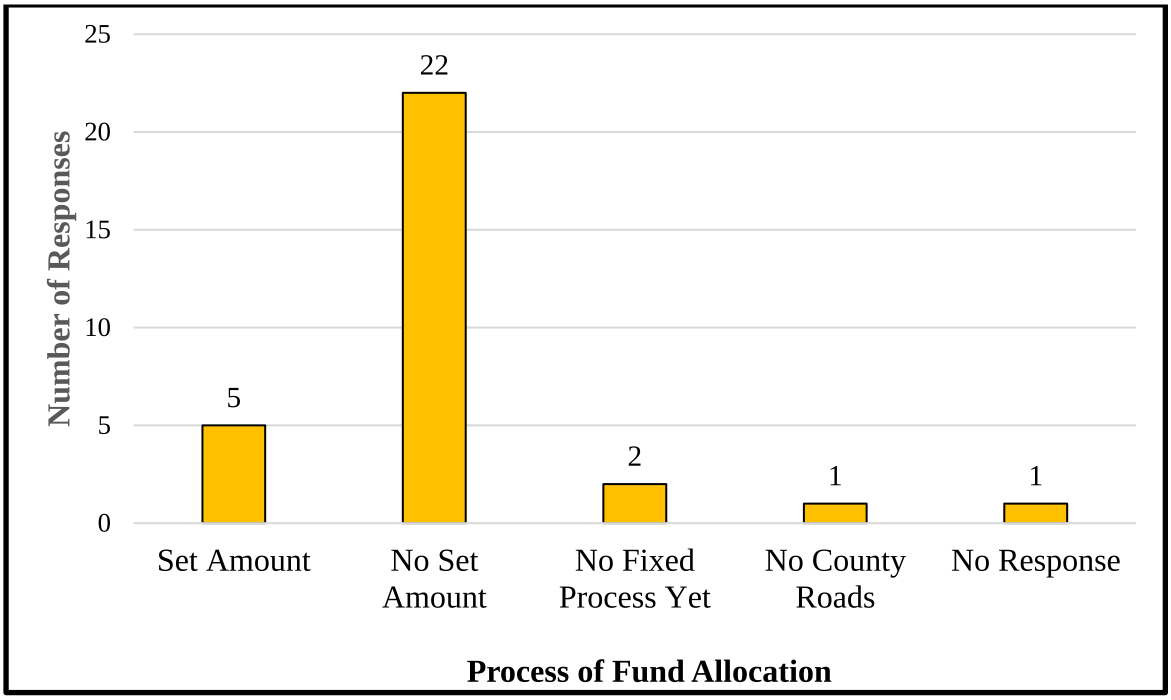

Figure 4: Number of States Using Different Fund Allocation Methods

Figure 4 clearly shows that only five states (around 16 percent) have a process where they set aside a specific amount of safety funds for these roads. Most respondents (24 out of 31) indicated that they do not use a set amount of funds or do not have an established process for allocating funds to non-state-owned local roads. North Carolina reported not having any significant number of non-state-owned local roads, and therefore, does not have separate fund allocation for them.

One of the most important aspects of any safety program is site identification. Therefore, a question about how safety improvement sites are identified on non-state-owned local roads was included in the survey. The frequency of using different identification methods is illustrated in **Figure 5**. In answering this question, respondents could choose more than one method in their answers. Fifteen departments reported that they include non-state-owned local roads in their statewide hotspot network screening. Another 13 DOTs indicated they perform network screening within local jurisdictions. Further, crash experience at sporadic specific sites, and perception of risk at individual sites by law enforcement or the public were reported in 21, 17, and 8 responses respectively. About 8 of the responding states reported using methods other than those included in this question. Those different methods as reported by the DOTs are provided in **APPENDIX C** of this report.

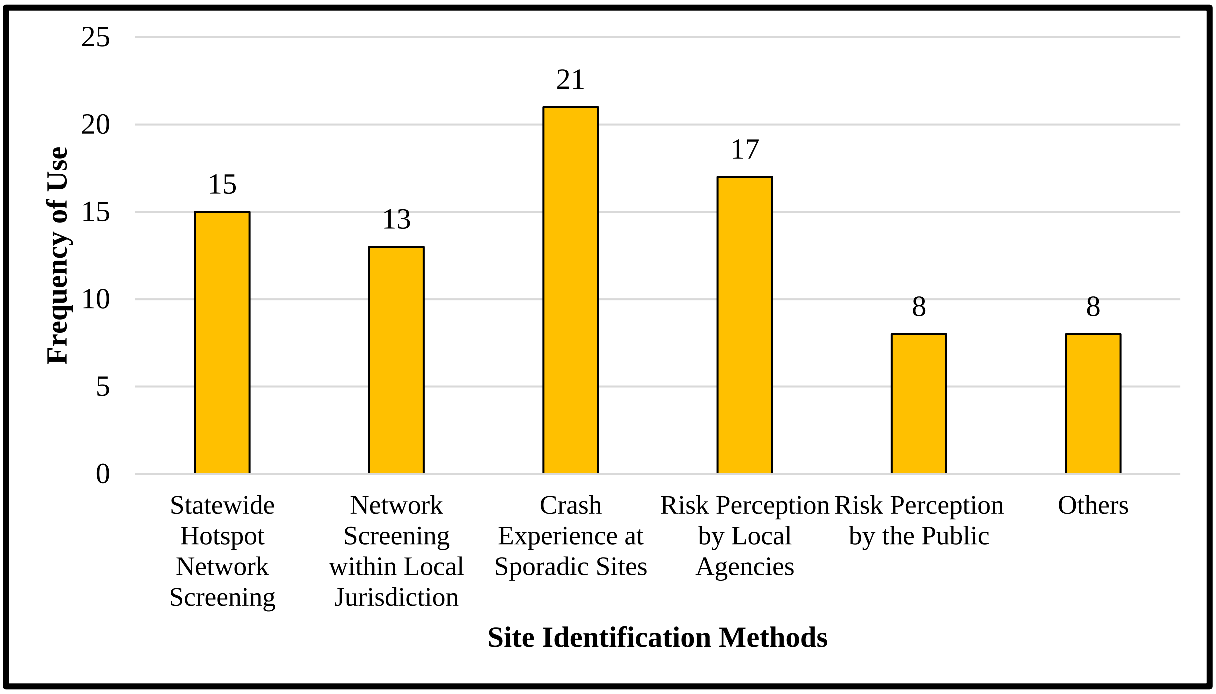

Figure 5: Frequency of Different Site Identification Methods for Non-State-Owned Local Roads

For any data-driven safety analysis, access to crash, roadway, and traffic data is critical. To understand how the different DOTs, handle non-state-owned local roads, a question about which entity conducts traffic and roadway data collection for non-state-owned local roads was included. The summary of the responses is provided in **Table 5**.

Table 5: Entities Conducting Roadway and Traffic Data Collection for Non-State-Owned Local Roads

State DOT	3
Local Agency	9
Both	16
Others	3

As shown in **Table 5**, around half of the responding DOTs reported that both the state DOT and the local DOTs conduct the traffic and roadway data collection needed for safety improvement sites. Nine responding DOTs indicated that local DOTs are responsible for collecting traffic and roadway data, while only three DOTs indicated that data collection is undertaken by the state DOT.

To understand the selection process of safety improvement sites on non-state-owned local roads, a question about the criteria used for justifying the selection of safety improvement sites was included in the survey. **Figure 6** shows the frequency of the different criteria used in agency responses. In answering this question, DOTs can select more than one criterion from the list of criteria provided. Consistent with expectations, cost effectiveness is the criterion most frequently used in selecting safety improvement sites (reported by 24 DOTs). Crash severity was reported in 12 responses while the combination of crash frequency and rate was reported in 10 responses. Crash frequency and crash rate alone were reported in 8 and 5 responses, respectively.

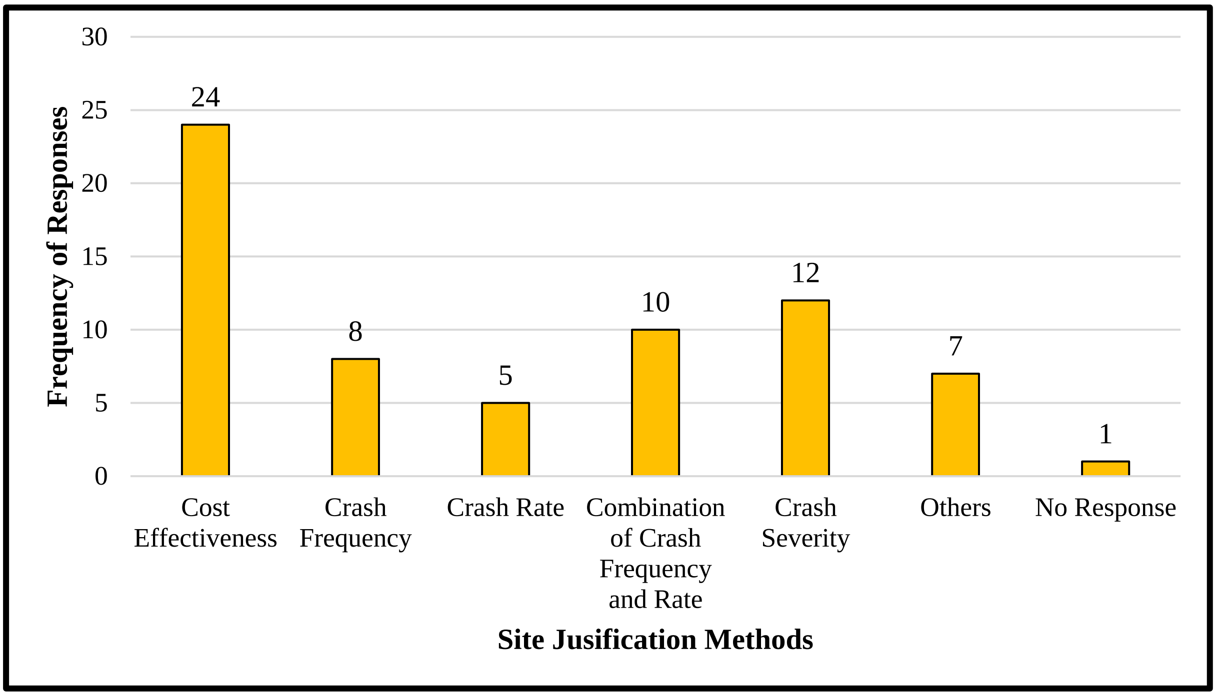

Figure 6: Frequency of Different Site Justification Methods for Non-State-Owned Local Roads

Another question in the survey asked DOTs whether the selection of safety improvement sites on non-state-owned local roads is performed separately from that of state-owned roadways. About 55 percent (17 out of 31) of the responding DOTs select safety improvement sites on non-state-owned local roads together with state-owned local roads, while the remaining 45 percent (14 out of 31) of the responding DOTs select them separately.

The FHWA systemic approach to safety evaluates risk across an entire roadway system and implements low-cost safety countermeasures throughout the roadway network. Given the lower crash densities on local and LVRs and the associated difficulty in using crash data alone for identifying safety improvement sites, systemic safety improvements become even more important in managing safety on LVRs. To understand the extent of its application on non-state-owned local roads, highway DOTs were asked about the percentage of safety improvement funds allocated to systemic improvements. The responses are shown in **Figure 7** below.

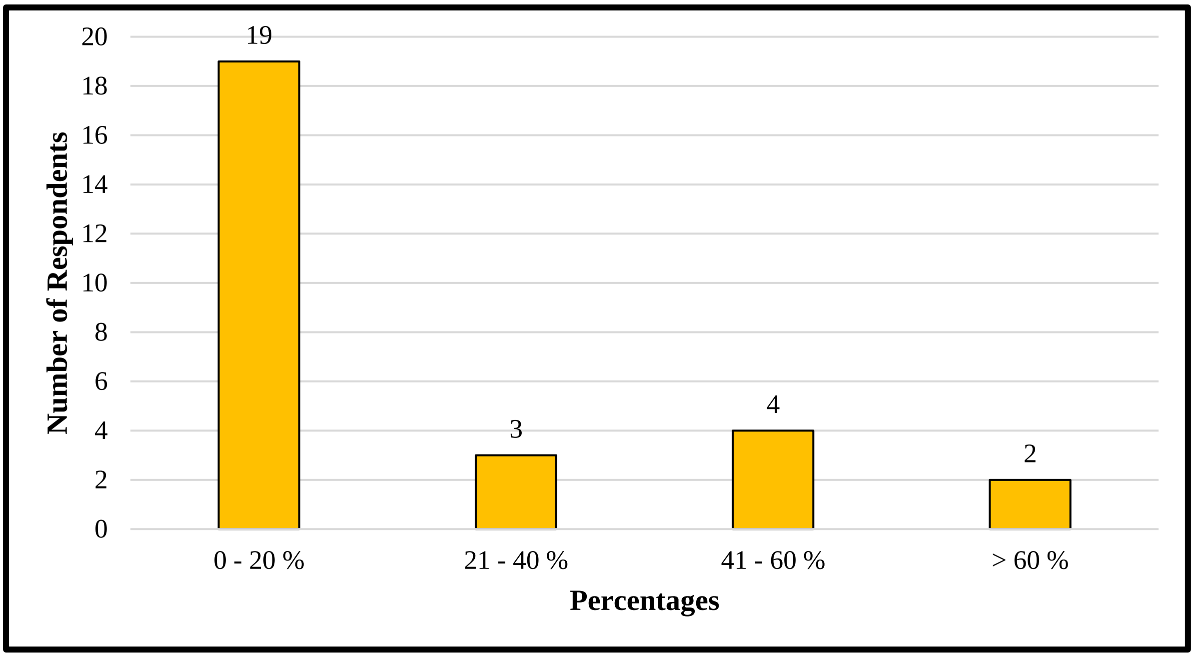

Figure 7: Safety Funds for Systemic Improvements for Non-State-Owned Local Roads

More than two thirds of the responding DOTs (19 out of 28) reported allocating less than 20 percent of the funds for systemic improvements, while only about 7 percent (2 out of 28) of the responding DOTs reported allocating more than 60 percent. The remaining seven DOTs (25 percent) reported allocating 20 to 60 percent of total safety improvement funds to systemic improvements. Three DOTs did not answer this question.

Many of the non-state-owned low-volume local roads in Montana are unpaved, and therefore, a question was included in the survey on whether DOTs include unpaved roads in their safety improvement programs. About 61 percent (19 out of 31) of the responding DOTs do not include non-state-owned unpaved roads in their programs while the remaining 39 percent (12 out of 31) of the DOTs include them.

4.3. Summary and Key Findings

A state of practice survey was conducted to learn about state agency practices in managing safety on low-volume local roads. The survey was sent to safety personnel in all 50 states and 32 of the states responded to the survey. This chapter presented and discussed the results obtained from the survey. The major findings of the survey are:

- About 80 percent of the responding DOTs have a separate method for selecting sites on LVRs from the method used for conventional roads.
- Crash severity is the most frequently used criterion for identification of potential safety improvement sites on LVRs.
- Around 48 percent of the responding DOTs reported using the FHWA systemic approach in combination with one or more of other network screening criteria.
- More than half of the responding DOTs (55 percent) reported using cost effectiveness both in ranking sites at the network level as well as in comparing specific safety improvements at individual sites.
- Around 90 percent of the responding DOTs have the same personnel leading the safety improvement program for state-owned and non-state-owned local roads.
- Around two thirds of the responding DOTs reported having access to crash, traffic, and roadway data for state-owned LVRs. However, only one third of those DOTs (7 states) reported having access to roadside data as well.
- Around 90 percent of the responding DOTs involve local DOTs (counties, townships, etc.) in identifying safety improvement sites on non-state-owned local roads.
- Most of the responding DOTs (70 percent) reported not allocating a set amount of funds for safety projects on non-state-owned local roads.
- Crash experience at sporadic sites was the most frequently reported method for identifying safety improvement sites on non-state-owned local roads.
- Roadway and traffic data for non-state-owned local roads are collected by both the state and the local agency, as reported by 52 percent of the responding DOTs.
- Cost effectiveness was the most frequently reported criterion in justifying safety improvement projects on non-state-owned local roads.

- More than half of the responding DOT (55 percent) reported using one process for identifying safety improvement sites on state-owned and non-state-owned local roads.
- More than two thirds of the responding DOTs allocate less than 20 percent of total safety funds to systemic improvements on non-state-owned local roads.
- Unpaved roads are not involved in safety improvement programs on non-state-owned local roads for 61 percent of the responding DOTs.

5. ASSESSMENT OF EXISTING METHODOLOGIES

This chapter summarizes the results of the fifth task of the project, which is intended to assess the various network screening methods that are reported in the existing literature or included in the results of the practice survey conducted in the previous task. The chapter starts with discussing the assessment methodology developed in this task, and then moves to discuss assessment results from applying the proposed methodology on the various network screening approaches. Finally, the chapter concludes with a summary of the evaluation methodology and a highlight of major findings.

5.1. Assessment of Screening Methods

The assessment methodology developed and used in this task aims at removing much of the subjectivity of the assessment criteria by following a systematic quantitative approach in expressing the level of a method meeting certain criteria. The method consists of three key elements: developing a scoring scheme for criteria, assigning weights to criteria, and preparing the final assessment matrix. Each of these elements is discussed in detail in the following sections.

5.1.1. Developing a Scoring Scheme for Assessment Criteria

In this step, numerical scores were assigned to the evaluation criteria based on the level a particular method meets those criteria. The scoring scheme developed is shown in **Table 6**. A four-level score (1 to 4) was assigned to level of risk representing sites lacking risk factors, those with traffic properties, geometric properties, and those with both traffic and geometric properties involving risk in an ascending order. Cost effectiveness was assigned three levels (1 to 3) with the lowest level for methods overlooking frequency and severity of crashes, middle level for methods considering either frequency or severity of crashes, and the higher level for methods considering both crash frequency and severity in screening the network. Precision was assigned three levels: presence of a feature, a range of values for a feature, and an exact value for that feature with scores increasing with the level of precision. Previous performance record was assigned four levels based on three factors: 1) whether the method was used by agencies, 2) the number of agencies using the method, and 3) any reported evaluation or validation of the respective method. Methods that are proposed in the literature but have not moved yet into practice are assigned the lowest level. Methods that have been used by one or two highway departments, but no validation is reported are assigned level 2. Level 3 is assigned for methods used by one or two agencies with reported validation, or methods that are used by three or more agencies without a reported validation. The highest level (level 4) is assigned for methods that are used by three or more agencies with validation or evaluation of the method reported in the literature. Ease of understanding is assigned only two levels: level 1 for complicated methods that may be difficult to understand and level 2 for methods that are intuitive and easy to understand. Ease of implementation is assigned three levels, with the lowest level (level 1) representing methods that are difficult to implement, highest level (level 3) for methods that are easy to implement, and the middle level (level 2) for methods that fall in between the previous two categories. Finally, the resource requirements criterion is assigned two levels, level 1 for methods requiring significant resources and level 2 for methods requiring average resources. While Task 3 treated "data requirements" and "resource requirements" as two separate evaluation criteria, it was decided to combine these two criteria under "resource requirements" in the assessment due to the large overlap between the two criteria.

Table 6: Scoring Scheme for Evaluation Criteria

Criteria	Scores	Score Categories	
Level of Risk	1-4	No risk factors	1
		Risk - Traffic properties	2
		Risk - Geometric properties	3
		Risk - Traffic & geometric properties	4
Economic Effectiveness	1-3	No frequency, no severity	1
		Only frequency	2
		Only severity	2
		Crash frequency and severity	3
Precision	1-3	Existence of attributes	1
		Range of values of attributes	2
		Exact values of attributes	3
Previous Performance Record	1-4	Proposed methods	1
		Used by 1 or 2 agencies without any validation	2
		Used by 1 or 2 agencies with validation	3
		Used by 3 or more agencies without validation	3
		Used by 3 or more agencies with validation	4
Ease of Understanding	1-2	Difficult to understand	1
		Easy to understand	2
Ease of Implementation	1-3	Difficult to implement	1
		Somewhat easy to implement	2
		Easy to implement	3
Resource Requirements	1-2	Significant resources	1
		Average resources	2

5.1.2. Assigning Weights to Assessment Criteria

As it is logical to think that different criteria bear different significance in assessing the merits of screening methods, it was important to develop a quantitative approach where relative weights are assigned to the assessment criteria. This has proven to be a challenging step, yet it could be the most important step in the process. The procedure outlined in this section is intended to quantify a process that is inherently subjective. To simplify comparisons across multiple criteria, the problem was reduced to conducting a large number of pairwise comparisons between pairs of variables using a matrix covering all pair combinations, as shown in **Table 7**. In this table, green cells are for relative weights assigned to criteria in the column headings, while blue cells are for weights assigned to criteria shown in the row headings. In pair-wise comparisons, weights are assigned to the two variables based on their relative importance (the total weight 10 is split between the two variables, with a minimum weight of 1 and a maximum weight of 9). The weights assigned to each criterion while comparing to all other criteria are then summed to find the total weight which is an indicator of the level of significance of that criterion. Lastly, the total weight is normalized by dividing by the highest possible weight (63 is the highest possible weight for the matrix shown in **Table 7**) and converted to a suitable scale (a scale of 0-10 is used for this assessment).

Table 7: Table Showing the Process of Assigning Weights to Criteria

	Level of Risk	Cost Effectiveness	Precision	Previous Performance	Ease of Understanding	Ease of Implementation	Resource Requirements	Total Weight	Normalized Weight (out of 10)
Level of Risk									
Cost Effectiveness									
Precision									
Previous Performance Record									
Ease of Understanding									
Ease of Implementation									
Resource Requirements									
Total Weight									
Normalized Weight									

Note: Green cells show weights assigned to column criteria while blue cells show weights assigned to row criteria

While the process outlined above largely simplifies the problem at hand (comparison across multiple criteria), pair-wise comparisons could still be difficult and may yield inconsistent results in the absence of any guiding rules. These guiding rules regarding the significance of different criteria are important for accurate and consistent evaluation results. It should be noted that, the guiding rules should reflect, to a large extent, the priorities and perspective of the agency. In this assessment, the researchers developed the following set of rules to guide the pairwise comparisons in the assessment process.

1. Cost effectiveness is the most important among all other criteria investigated in this project and described earlier as most state DOTs use cost effectiveness in selecting and justifying safety improvement projects.

2. The inherent level of risk to any specific site in the network is the second most important criterion after cost effectiveness and above all other criteria.

3. Previous performance record is more important than other criteria, namely, precision, ease of implementation, ease of understanding and resource requirements.

Using these guiding principles and conducting the respective pairwise comparisons, the overall weights assigned to different criteria are shown in **Table 8**. The minimum and maximum weights are found to be 4.1 and 8.7 on a scale of 10.

Table 8: Pairwise Comparison Results and the Relative Weights Assigned to Criteria

	Level of Risk		Cost Effectiveness		Precision		Previous Performance Record		Ease of Understanding		Ease of Implementation		Resource Requirements		Total Weight	Normalized Weight (out of 10)
Level of Risk		5		6		2		3		2		2		2	**48**	**7.6**
	5		4		8		7		8		8		8			
Cost Effectiveness		4		5		1		2		1		1		1	**55**	**8.7**
	6		5		9		8		9		9		9			
Precision		8		9		5		7		5		5		5	**26**	**4.1**
	2		1		5		3		5		5		5			
Previous Performance Record		7		8		3		5		3		3		3	**38**	**6.0**
	3		2		7		5		7		7		7			
Ease of Understanding		8		9		5		7		5		5		5	**26**	**4.1**
	2		1		5		3		5		5		5			
Ease of Implementation		8		9		5		7		5		5		5	**26**	**4.1**
	2		1		5		3		5		5		5			
Resource Requirements		8		9		5		7		5		5		5	**26**	**4.1**
	2		1		5		3		5		5		5			
Total Weight	**48**		**55**		**26**		**38**		**26**		**26**		**26**			
Normalized Weight	**7.6**		**8.7**		**4.1**		**6.0**		**4.1**		**4.1**		**4.1**			

Note: Green cells show weights assigned to column criteria while Blue cells show weights assigned to row criteria.

5.1.3. Assessment Matrix

The scoring scheme and relative weights developed in the previous steps are used in establishing the assessment matrix and ranking of the network screening methods. The assessment is accomplished using the following steps:

1. All methods are scored using the scoring scheme developed earlier in the process and normalized using a common scale of 0 to 10.
2. The normalized scores are then multiplied by the weights of their respective criteria discussed previously (shown in **Table 7**) resulting in a weighted score for each assessment criterion.
3. Finally, the weighted scores for the various criteria are summed to yield the overall score for each method included in the assessment.

Table 9 shows the assessment matrix using the steps discussed above.

Table 9: Assessment Matrix for the Different Methods

	Assessment Criteria																												
	(1) Level of Risk				(2) Economic Effectiveness				(3) Precision				(4) Previous Performance Record				(5) Ease of Understanding				(6) Ease of Implementation				(7) Resource Requirements				Overall Score
	Actual Score	Normalized Score	Weights	Weighted Score	Actual Score	Normalized Score	Weights	Weighted Score	Actual Score	Normalized Score	Weights	Weighted Score	Actual Score	Normalized Score	Weights	Weighted Score	Actual Score	Normalized Score	Weights	Weighted Score	Actual Score	Normalized Score	Weights	Weighted Score	Actual Score	Normalized Score	Weights	Weighted Score	
	4	**10**	**7.6**		**3**	**10**	**8.7**		**3**	**10**	**4.1**		**4**	**10**	**6**		**2**	**10**	**4.1**		**3**	**10**	**4.1**		**2**	**10**	**4.1**		
Methods Using Only Historical Data																													
Crash Frequency Methods	1	2.5	7.6	19	2	6.7	8.7	58	3	10	4.1	41	2	5	6.0	30	2	10	4.1	41	3	10	4.1	41	2	10	4.1	41	272.49
Crash Frequency and Severity Methods	1	2.5	7.6	19	3	10	8.7	87	3	10	4.1	41	3	7.5	6.0	45	2	10	4.1	41	3	10	4.1	41	2	10	4.1	41	316.67
Crash Rate Methods	2	5	7.6	38	2	6.7	8.7	58	3	10	4.1	41	2	5	6.0	30	2	10	4.1	41	3	10	4.1	41	2	10	4.1	41	291.53
Crash Frequency and Rate Methods	2	5	7.6	38	2	6.7	8.7	58	3	10	4.1	41	3	7.5	6.0	45	2	10	4.1	41	3	10	4.1	41	2	10	4.1	41	306.61
Crash Frequency, Rate and Severity Methods	2	5	7.6	38	3	10	8.7	87	3	10	4.1	41	3	7.5	6.0	45	2	10	4.1	41	2	6.67	4.1	28	2	10	4.1	41	**321.96**
Methods Using Prediction Only																													
Using only Traffic Characteristics	2	5	7.6	38	2	6.7	8.7	58	3	10	4.1	41	1	2.5	6.0	15	2	10	4.1	41	2	6.67	4.1	28	2	10	4.1	41	262.70
Using only Geometric Characteristics	3	7.5	7.6	57	2	6.7	8.7	58	3	10	4.1	41	1	2.5	6.0	15	2	10	4.1	41	2	6.67	4.1	28	2	10	4.1	41	281.75
Using Traffic and Geometric Characteristics	4	10	7.6	76	2	6.7	8.7	58	3	10	4.1	41	2	5	6.0	30	2	10	4.1	41	2	6.67	4.1	28	2	10	4.1	41	315.87
Using Surrogate Safety Measures	2	5	7.6	38	1	3.3	8.7	29	2	6.7	4.1	28	2	5	6.0	30	1	5	4.1	21	1	3.33	4.1	14	1	5	4.1	21	179.89
Comb. of Historical and Prediction Methods																													
Emperical Bayes	4	10	7.6	76	3	10	8.7	87	3	10	4.1	41	4	10	6.0	60	1	5	4.1	21	1	3.33	4.1	14	1	5	4.1	21	**320.11**
Index Methods	4	10	7.6	76	3	10	8.7	87	3	10	4.1	41	3	7.5	6.0	45	1	5	4.1	21	1	3.33	4.1	14	1	5	4.1	21	305.03
Other Methods																													
FHWA Systemic Approach to Safety	3	7.5	7.6	57	1	3.3	8.7	29	2	6.7	4.1	28	4	10	6.0	60	2	10	4.1	41	3	10	4.1	41	2	10	4.1	41	297.88

5.2. Results

As can be seen in this matrix, the overall scores for different methods roughly ranged between 180 and 320. Only two methods scored greater than 320: methods using crash frequency, rate, and severity (321.96) and the empirical Bayes method (320.11). These two scores are very close, and for all practical purposes, they can be considered comparable. A careful examination of the assessment matrix clearly reveals that the empirical Bayes scored very high on all criteria except the last three criteria in the matrix which are assigned lower weights (that is, less significant criteria). On the other hand, the conventional frequency, rate, and severity methods scored lower on criteria 1 and 4 (level of risk and previous performance record) and higher on the last three criteria. Methods using surrogate safety measures scored lower than all other methods included in the matrix, which is somewhat expected. Another important observation is that the FHWA systemic approach to safety scored right in the middle compared to other methods. Nonetheless, this method could have scored higher than all other methods if the cost effectiveness criterion was assessed more objectively. Specifically, this method scored lowest on cost effectiveness due to the way the scoring scheme was developed (no crash frequency nor severity is used). However, it is well known that systemic improvements consist of low-cost countermeasures that are often associated with relatively high benefit-cost ratios. Taking this into account, it is advised that this method be given serious consideration in later project tasks as its merits were underestimated relative to other methods in this assessment.

5.3. Summary and Findings

This chapter presented Task 5 analyses regarding the assessment of the various network screening methods using the set of criteria developed in Task 3 of the project. To a large extent, the analyses aimed to minimize the subjectivity in the assessment process by following a consistent quantitative scoring and ranking techniques. First, a scoring scheme was developed for each of the seven criteria used in this assessment. Next, the seven criteria were assigned relative weights based on their significance in the network screening process. The third and last step involved establishing the assessment matrix using input from the previous two steps and the degree to which each respective method met the assessment criteria. The major findings of the assessment can be summarized in the following:

1. The methods that scored highest in the assessment are the combined frequency, rate, and severity method and the empirical Bayes method.

2. Using surrogate safety measures in network screening scored lowest in the assessment.
3. The FHWA systemic approach to safety scored right in the middle according to the assessment matrix. However, this method was somewhat penalized by the scoring scheme of the cost effectiveness criterion, which relies on the method being sensitive to crash frequency and severity. This method could have scored much higher if the cost effectiveness criterion had considered the high benefit-cost ratio often associated with low-cost systemic improvements.

It is important to note that the assessment performed in this task is high-level assessment, which did not involve any validation using empirical data. Further, it is also important to mention that the weights assigned to assessment criteria and the level to which those criteria were satisfied by different methods represent the opinions and judgement of the researchers performing the analysis, and not necessarily those of the Montana Department of Transportation.

6. DEVELOPING A METHODOLOGY FOR SELECTING SAFETY IMPROVEMENT SITE ON LOW-VOLUME ROADS

The objective of this task was to develop and recommend a Montana-specific method that would help the Montana Department of Transportation (MDT) or local government transportation agencies in screening the network of low-volume roads (LVRs) within their jurisdictions for sites that are in greatest need for safety improvements. The work in this task utilized the findings from the previous project tasks including Task 5, The Assessment of Existing Methodologies, in developing the proposed method.

The two methods that scored high in Task 5 are the combined crash frequency, rate, and severity method and the empirical Bayes (EB) method. While these methods were found to have merits compared to other methods included in the assessment, they are not appropriate for use on LVRs for the following two reasons:

1. The combined crash frequency, rate, and severity method relies solely on crash history in screening the network. The use of this method is deemed impractical on LVRs due to the random and sporadic occurrence of crashes on the network because of low traffic levels.
2. The empirical Bayes method is resource intensive, that is it requires detailed geometric, crash, and traffic data for input as well as personnel with relatively high technical expertise in safety and statistical analyses. These resources usually do not exist and are often not accessible at local jurisdictions.

As such, the prospective methodology developed in this task has taken two considerations into account: 1) the method should not rely solely on crash history in identifying sites for safety improvements, and 2) the method should require minimal amount of information that can easily be acquired by local transportation agencies and can reasonably be applied by staff with limited technical background and resources.

6.1. Methodology Development: Guiding Principles

A successful network screening methodology on LVRs should satisfy the following requirements:

1. For the proposed method to be effective in assessing potential risks at specific sites throughout the network, the method should be based on theoretical principles in safety

science or empirical evidence that are well accepted in practice by the traffic safety community.

2. Most LVRs are local roads and secondary routes that do not include the same geometric features as higher-class roads and many of these roads are unpaved. Therefore, roadway and roadside characteristics and their risk factors are often associated with crash occurrence and, as such, must be considered by the proposed methodology.
3. Local jurisdictional agencies often lack access to detailed roadway and/or traffic data. Therefore, inputs to the proposed methodology should consider this limitation in data availability and/or accessibility.
4. Local jurisdictional agencies usually do not have the technical resources, background and expertise required to conduct safety analyses using statistics and associated data analysis software. Hence, a successful methodology should be easy to use by local transportation agency staff with limited resources.

6.2. Overview of the proposed methodology

The proposed methodology consists of assigning a score to each individual site that is part of the roadway network. These scores are assigned based on roadway characteristics, observed crashes, and traffic exposure over the analysis period (crash data for a minimum of five-year period, preferably a longer period up to 10 years whenever feasible).

In using this method, roadway characteristics are assigned scores based on the presence of certain roadway features (for example horizontal curve, grade, etc.). These scores were developed based on the rural two-lane highways crash modification factors (CMFs) provided in the Highway Safety Manual (HSM) (AASHTO, 2010), the CMF clearinghouse (FHWA, 2020), or published in the current literature. A crash modification factor is a multiplicative factor used to compute the expected number of crashes after implementing a given countermeasure at a specific site. Roadway characteristics are expressed in simple classified variables that do not require exact values or access to detailed databases.

The observed crashes involve the use of include fatal, serious injury, minor injury, and possible injury crashes and property-damage-only (PDO) crashes in assigning scores to specific sites. Unlike fatal and serious injury crashes, it is expected that many of the PDO and less serious crashes (minor and possible injury for instance) may go unreported on LVRs. Further, it is reasonable to think that local jurisdictional agencies have knowledge of the recent fatal and serious injury crashes occurring within their jurisdictions, as such crashes represent unusual occurrences. Fatal and serious injury crashes are assigned scores such that their sites will receive further consideration regardless of existing roadway features (risk factors).

Traffic exposure is another component of the proposed methodology. The methodology assigns a multiplier (multiplicative factor) in adjusting the relative risk score based on traffic level.

Upon systemically applying the scoring method for all sites that are part of the roadway network, a list of high-priority sites ranked on their scores (from highest to lowest) can be established and used for further investigation and potential safety treatments.

6.2.1. Proposed Methodology: Roadway Characteristics – Risk Factors

On LVRs, crash occurrence, particularly fatal and serious injury crashes, is less frequent. This makes it difficult to identify trends and treat hazardous sites based on historical crash data alone. Roadway and roadside features may lead to elevated crash risks at specific roadway segments or spot locations. The identification of such features and sites is a proactive approach to addressing safety at locations where potential hazards may exist but no/few crashes may have occurred to date. For this project, only roadway features (among risk factors) are considered in the development of the proposed methodology as other potential risks (for example environmental, traffic, etc.) are often outside the realm of engineering countermeasures. The proposed methodology includes certain roadway features that: 1) are most relevant to LVRs, 2) have tangible impact on safety per HSM guidance and existing literature, and 3) relevant information can reasonably be acquired by the prospective users, that is, local government staff.

6.2.1.1. Roadway Segments

For segments, the following roadway features were included in the methodology:

1. Total roadway width (lane width + shoulder width)
2. Horizontal curvature
3. Grade
4. Driveway density
5. Roadside (side slope and fixed objects)
6. Roadway surface type (paved vs unpaved)
7. Pavement condition

Roadway surface type and pavement condition were included in the methodology for their potential effects on safety even though these factors are not included in the HSM. This is primarily because some of the LVRs owned and operated by local governments are unpaved and some are paved, but considered to be in poor condition, and they constitute an integral part of local road networks.

The risk factors on roadway segments and how they are used in the proposed methodology are described in the following paragraphs:

Total roadway width: total roadway width usually consists of lane and shoulder widths. As many LVRs are unpaved or lack lane striping, the use of total roadway width instead of separate lane and shoulder widths was deemed more appropriate. Lane width is an important cross section element that is associated with roadway safety. The standard width recommended in the current highway design practice is 12 feet. However, narrower lanes are often encountered on LVRs. Per the HSM and the current practice, lanes narrower than the 12-foot standard width are associated with greater likelihood of crash occurrence. Shoulder width, on the other hand, is another roadway cross section element that is directly related to safety on rural highways. Specifically, wider shoulders provide drivers of errant vehicles area to regain control and return to the travel lane thus minimizing the likelihood of roadway departure crashes. In this methodology, LVRs with a total width equal to or narrower than 24 feet will receive a score for increasing crash risks.

Horizontal curvature: this is the most important alignment design element that has a profound impact on crash occurrence, particularly run-off-the-road crashes on rural highways. The proposed methodology classifies sites into three categories: tangent segments, flatter curves, and sharper curves. Tangent segments denote the absence of horizontal curves and are assigned no scores. Flatter curves are horizontal curvatures with radii that are approximately equal to or greater than 300 feet. Sharper curves, on the other hand, are horizontal curves with radii that are less than 300 feet. The flatter and sharper curve categories are assigned scores for increasing crash risks.

Grade: one of the roadway features that is believed to have an impact on crash risk is whether the site is in level terrain or on a significant grade. The proposed methodology assigns a score for the presence of a significant grade for its impact on safety. Significant grades are defined as upgrades or downgrades with percentage grade greater than 4%.

Driveway density: driveways on local roads from adjacent land uses increase the number of conflict points and thus the risk of being involved in traffic crashes. Roadway segments with number of driveways above certain cut-off value are assigned a score for increasing crash risks. Per the HSM (AASHTO, 2010), *"Driveways serving all types of land use are considered in determining the driveway density. All driveways that are used by traffic on at least a daily basis for entering or leaving the highway are considered. Driveways that receive only occasional use (less than daily), such as field entrances are not considered."*

Roadside features: roadsides play an important role in controlling the number and severity of crashes along roadways in rural areas. In this regard, two roadside features are of particular interest: side slopes and presence of non-breakaway fixed objects in close proximity of the roadway. The proposed methodology assigns scores for these roadside features due to their contribution to increased crash risks.

Road surface type: this factor considers the fact that many of the rural LVRs are unpaved, which could increase crash risks along these roadways. While the HSM does not consider road surface type, the proposed method assigns a score for sites on unpaved roads using findings published in relevant studies (Souleyrette et al., 2010).

Pavement condition: poor pavement conditions such as increased roughness, rutting, potholes, and surface skid resistance are all believed to affect crash occurrence on rural LVRs. The proposed methodology assigns scores for roadways with poor pavement conditions.

6.2.1.2. Intersections

For local road intersections, only three-leg and four-leg unsignalized intersections are considered as they are the major intersection types on LVRs (higher traffic levels are required to warrant signal control). The following intersection features are used in the methodology:

1. Intersection skew angle
2. No traffic control (uncontrolled intersections)
3. Left-turn lanes on approaches without stop control
4. Lighting

The risk factors at rural low-volume road intersections and how they are used in the proposed methodology are described in the following paragraphs.

Intersection skew angle: skew angle at intersections has impact on sight distance required for drivers to avoid potential conflicts taking place inside the intersection conflict area. The skew angle for an intersection is defined as the absolute value of the deviation from an intersection angle of 90 degrees (ASHTO, 2010). The ideal situation is for the roads to cross or meet at or close to 90-degree angle. If the skew angle is more than 20 degrees, the proposed method assigns a score indicating an increase in crash risks.

No traffic control: many intersections that are part of the low-volume road network are uncontrolled, that is right of way is not assigned through the use of traffic control devices. The lack of traffic control for right-of-way assignment is believed to contribute to higher crash occurrence. The proposed methodology assigns a score for uncontrolled intersections using information published in the current literature (El-Basyouny et al., 2010).

Left-turn lanes on approaches without stop control: for major-minor local roads, the two-way stop sign, and less often the yield sign, are typical forms of intersection traffic control. At these intersections, approaches with stop or yield signs usually do not have auxiliary lanes. Other approaches not controlled by signs may have turn lanes, though unlikely on LVRs. When left-turn lanes are provided on those approaches, crash risks tend to decrease. Therefore, the proposed methodology deducts scores when left-turn lanes are present on these approaches.

Lighting: nighttime visibility is important for safe operations at intersections. Lighting improves visibility and is believed to reduce nighttime collisions between conflicting movements at intersections. The proposed method deducts a score when lighting is available for its effect in reducing crash risks.

6.2.2. Proposed Methodology: Crash History

Crashes taking place on a roadway network may well be related to roadway features or traffic characteristics that are known to increase crash risks. Often crash risks at these locations could be reduced or alleviated by using of safety countermeasures. The proposed methodology considers historical crash data in screening the network for sites that warrant further consideration of safety treatments. The proposed methodology assigns scores by crash severity to sites where crashes occurred during the analysis period. The scoring scheme is developed so that a site with one or more of the fatal and/or serious injury crashes is identified for further consideration of potential safety improvements regardless of roadway risk factors present. It is important to note that intersection-related crashes occurring on approaches to intersections should be considered in ranking intersection locations, even if they occur on segments leading to intersections.

6.2.3. Proposed Methodology: Traffic Factors

Traffic variables are known to affect crash occurrence on roadway segments as well as at intersections. The proposed methodology considered two important traffic variables: traffic exposure and speed. Traffic exposure is believed to be directly related to the number of crashes occurring on roadway segments and at intersections. The proposed methodology adjusts the relative risk score using a multiplier that is a function of traffic level. The average daily traffic (ADT) measured or estimated for a roadway segment is used as an indicator of traffic exposure. At intersections, intersection ADT is used that is defined as the sum of the ADT of the two crossing roadways (major and minor roads) or the sum of the ADTs on all intersection approaches divided by two (when ADTs are different on opposing approaches). Traffic speed is another traffic variable that is considered in the proposed methodology for roadway segments. Like traffic volume, a multiplier is used to adjust the relative risk score for roadway segments with speed limits of 50 mph or higher using information from published literature (Ksaibati et al., 2009).

6.3. The Proposed Methodology

The proposed methodology consists of a ranking scheme where major risk factors, historical crash data and traffic conditions are assessed and used in assigning a score to individual segments and intersections throughout the network. The sum of all scores assigned to risk factors and observed crashes is called the relative risk compound score (RRCS) while the final score upon adjusting the RRCS using multipliers for traffic conditions is called the global risk score (GRS). The GRS is an indicator of the level of risk or crash likelihood at any given roadway segment or intersection. The following sections discuss the ranking schemes for the roadway segments and intersections respectively, while **APPENDIX D** provide an explanation for the development of the scoring scheme using the intersection methodology as an example.

6.3.1. Roadway Segments

A tentative ranking scheme for roadway segments is shown in **Table 10**. For this project, roadway segments refer to roadway sections with similar (or uniform) cross section and roadside features.

The use of scoring scheme and classified variables eliminated the need to access detailed information and extensive databases. The scoring scheme can be structured in a simple questionnaire format where the user must determine the presence of certain roadway characteristic, observed crashes and traffic conditions in a user-friendly format. In the following, a few clarifications are provided for the development of the scoring scheme.

1. In developing scores for roadway physical characteristics, crash modification factors (CMFs) were used as a guide in assigning the relative scores to different roadway characteristics or risk factors. The HSM and the FHWA CMF clearinghouse as well as a couple of studies in the published literature were the sources for the CMFs used in developing the methodology. Specific values of roadway characteristics for typical scenarios were used as a guide in deriving the relative scores for risk factors used in this table. The objective was to use scores that generally maintain the relative safety impacts of various risk factors in the proposed method.
2. As the AADT is part of the HSM safety performance functions (not the CMFs), multiplicative factors (referred to as multipliers here) were used to account for the different ranges of traffic level. The multipliers for various traffic levels were estimated using the HSM safety performance functions for rural tow-lane highways and rural intersections. It was decided to use a multiplier for traffic speed as well so that all traffic variables are treated similarly in the proposed methodology. The multiplier for traffic speed was derived using the crash modification factor from a study referenced in the CMF clearinghouse (Ksaibati et al., 2009).
3. The scores assigned to observed crashes were mainly selected to ensure that sites with one or more fatal or serious injury crashes receive further consideration/review for potential safety improvements regardless of the risk factors present. The score assigned to property-damage-only crashes and other non-serious injury crashes was primarily based on judgment.

It is important to note that this scoring form is intended to be used by staff with limited technical background, and therefore the different questions in the form can be revised or edited to be more clear to the users to ensure proper application of the proposed method. For example, the question “Side slope steeper than 1V:3H?” could be replaced with “Non-traversable side slope?” if deemed easier to understand by prospective users. Further this form could easily be implemented in a spreadsheet application, so that the user would answer the relevant questions without the need to assign scores.

Table 10: Relative Risk Ranking Scheme for Roadway Segments

LVR Segments Ranking Scheme	
Safety-Related Questions	**If yes, add:**
Risk Factors	
Total width (TD)	
TD ≤ 20 ft.?	7
20 ft. < TD ≤ 24 ft.?	4
Horizontal curve?	
Flatter curve (R ≥300 ft.)	30
Sharper curve (R<300 ft.)	60
Grade steeper than ± 4%?	3
Six or more driveways per mile?	5
Side slope steeper than 1V:3H?	4
Fixed objects within 15 ft of travel lane?	4
Unpaved Road?	14
Poor pavement condition? (ruting, potholes, etc.)	7
Crash History?	
Fatal or serious injury crashes (N_1)	N_1 X 80
Other crashes (N_2)	N_2 X 5
Relative Risk Compound Score (RRCS)	
Speed ≥ 50 mph?	RRCS X 1.25
Got ADT?	
ADT *≤ 300*	RRCS X 1.0
300 < ADT ≤ 600	RRCS X 3.0
600 < ADT ≤ 1000	RRCS X 5.0
ADT > 1000	RRCS X 7.0
Global Risk Score (GRS)	

6.3.2. Intersections

For local road intersections, a separate ranking scheme was developed using intersection characteristics, historical crash data, and traffic exposure as shown in **Table 11**. In this scheme, a baseline score is used to ensure that the relative risk compound score (RRCS) does not assume a negative value regardless of intersection characteristics and crash history. The presence of left-turn lanes and lighting, while not often encountered at low-volume road intersections, are believed to improve safety at the intersection, thus the negative scores. Again, the scores for fatal and serious injury crashes were selected to ensure that intersections with one or more fatal or serious injury crashes receive further consideration/review for potential safety improvements. The method considers crashes occurring in the intersection conflict area as well as intersection-related crashes occurring on intersection approaches. Intersection ADT (ADTint) is used as an indicator of traffic exposure at the intersection. It is defined as the sum of the ADT for the two crossing roadways (major and minor roads) or the sum of the ADTs for intersection approaches divided by two (when ADTs of opposing approaches are different). While pedestrian and bicyclist traffic add to the crash risks at intersections, they are not included in the ranking scheme as their contribution to crash occurrence is not reported in the literature. However, users of the proposed methodology should take the pedestrians and bicyclist into consideration when analyzing safety at intersections in the process of network screening.

Table 11: Relative Risk Ranking Scheme for Intersections

LVR Intersections Ranking Scheme	
Safety-Related Questions	**If yes, add:**
Baseline Score	50
Roadway Factors	
Skew angle > 20 deg ?	10
Non-controlled intersection?	60
Lighting?	-7
Left-turn lanes on non-controlled approach?	-30
Crash History?	
Fatal or serious injury crashes (N_1)	N_1 X 80
Other crashes (N_2)	N_2 X 5
Relative Risk Compound Score (RRCS)	
Got ADT?	
$ADT_{int} \leq 600$	RRCS X 1.0
$600 < ADT_{int} \leq 1200$	RRCS X 2.0
$1200 < ADT_{int} \leq 2000$	RRCS X 4.0
$ADT_{int} > 2000$	RRCS X 6.0
Global Risk Score (GRS)	

6.4. Application of the Proposed Methodology

The proposed methodology allows transportation professionals the ability to assess safety at the network level and rank sites that deserve further consideration of safety treatments. Current network screening tools, using data-driven methods are challenged with identifying sites on low volume roads. This is based on only using crash data for site identification. Using crash data often only identifies sites on higher road classifications due to higher traffic exposure. Thus, although LVRs experience fatal and serious injury crashes, they are under-represented with safety projects identified through the Highway Safety Improvement Program.

The proposed methodology could also be used in making decisions needed for the implementation of systemic safety improvements at the network level. Many states use systemic improvements at the network level to address roadway features associated with certain crash types that are separate from their ongoing network screening and hot-spot identification process. The merit of using systemic safety improvement on local roads is that most of these improvements consist of low-cost safety countermeasures that are more viable for safety projects on LVRs. Given the limited resources, the proposed methodology could help local transportation agencies in setting priority list to implement systemic improvements.

Further, the proposed methodology could be used with and without traffic exposure data. If traffic data is impractical to obtain for all or part of the network, the relative risk compound score (RRCS) could be used in ranking the sites using risk factors and crash history alone. However, it is more appropriate to use the global risk score (GRS) when traffic data is available for the entire network.

6.5. Remarks

This report discussed the development of a proposed network screening methodology for use on LVRs in the state of Montana. The methodology consists of two scoring schemes, one for roadway segments and the other for intersections, that allow state and local transportation agency staff the ability to assess safety at the network level. These scoring schemes were developed primarily using guidance provided in the Highway Safety Manual for rural two-lane roads and intersections, as well as the CMF Clearinghouse and a few studies in the current literature. Specifically, the crash modification factors were used to account for the safety impacts of roadway and roadside characteristics (that is, risk factors) while the safety performance functions were used to account for the effect of traffic exposure on crash occurrence. Further, published studies were used to account for aspects not included in the Highway Safety Manual (like unpaved roads).

It should be remembered that while the Highway Safety Manual is the main reference document for performing safety analyses in the U.S., it represents the general U.S. context which could be different than that in a specific state or region. Therefore, this methodology should be treated as a first version that can be amended and enhanced once Montana-specific data or information becomes available. Further, the RRCS and the GRS scores proposed in the methodology are only meaningful for use in a comparative analysis such as for network screening application or for comparing multiple improvement alternatives at a specific site. This is because the RRCS and the GRS scores cannot be used to predict crash numbers or crash rates at a specific site.

7. ASSESSING BENEFITS OF PROPOSED METHODOLOGY

This chapter summarizes the results of Task 7 which aims at assessing the potential benefits of the network screening methodology developed and proposed in Task 6 of this project. To that end, an economic assessment was performed in the form of benefit-cost analysis where the estimated benefits and costs of implementing the new methodology were quantified and analyzed. This report discusses the analysis methodology used, analysis inputs and data used, the different benefit and cost elements and major analysis results.

7.1. Methodology

To assess the potential benefits of the network screening methodology proposed in Task 6, an economic analysis was conducted. The economic analysis, in the form of the conventional benefit-cost ratio, using the present worth of costs and benefits was used in this assessment. Upon consultation with the panel, an analysis period of 10 years was selected. All the cost elements were discounted to their present worth and were then used to calculate the benefit-cost ratios. The discount rate is defined as "the forgone rate of return if an investor chose to accept an amount in the future versus the same amount today" (Murphy, 2020). The ten-year average of daily yield curve rate for treasury bonds with 20-year maturity (US Department of Treasury, n.d.) was used as the discount rate. **Equation 1** shows the formula for calculating the present worth.

$$Present\ Worth = Future\ Worth \times (1 + \frac{Discount\ Rate}{100})^{-n} \ldots\ldots\ldots (1)$$

Where n = number of years,

The following sections discuss the different inputs and assumptions that were used in this analysis, that is in the estimation of the potential benefits and the associated costs for developing and implementing the proposed screening method.

7.1.1. Approximations and Assumptions

For a quantitative benefit-cost analysis, a few approximations and/or assumptions were made to assess the potential benefits and costs of the proposed method. This section discusses these approximations and/or assumptions and how it was used in the analysis.

I. A crash reduction factor (CRF) is the percentage crash reduction that might be expected after implementing a given countermeasure at a specific site (AASHTO, n.d.). A CRF is calculated by subtracting the CMF of a countermeasure from 1 then multiplying by a 100. This project used CRFs to estimate the number of crashes that would be reduced by implementing the common safety countermeasures on Montana low-volume roads (LVRs). CRFs relevant safety improvements were used in assessing the potential benefits of the new method. As it is not possible to predict which countermeasures would be applied to the low volume road (LVR) network during the analysis period, specific CRFs could not be used directly in the analysis. Therefore, instead of using specific CRFs, crash reduction for general countermeasure categories were found using the average CRFs for category-related countermeasures. For example, crash reduction for the "Signing and Delineation" category is found using the average of the CRFs for countermeasures like installing edgeline, centerline, and delineator.

II. Due to budget constraints, it is both expected and logical that safety countermeasures could not be applied across the whole LVR network during the analysis period. However, it was necessary to estimate the proportion of the LVR network that would undergo any form of safety improvement during the analysis period. Based on input from the project technical panel, it was assumed that 33 percent of the Montana LVR network would receive some sort of safety improvement during the 10-year analysis period.

III. The goal of any network screening method is to identify and rank at-risk sites that are expected to yield greater safety benefits upon implementing safety improvements. Therefore, the potential benefit from the implementation of the proposed network screening method would be a greater reduction in crashes on LVRs since the selection and prioritization process would be more robust. Therefore, it was assumed that the implementation of the proposed method would increase the average crash reduction of safety countermeasures by 5 percent. For example, if the crash reduction factor for a specific countermeasure is 20%, then the economic analysis assumes an increase of 1% in crash reduction as a result of using a more robust process for network screening.

IV. The most recent five-year crash numbers (2015-2019) for different severity levels on LVRs were used in the estimation of the potential benefits of the proposed method. In estimating the number of crashes over the analysis period (10 years), the average number of crashes per year using crash data for the years 2015-2019 inclusive was used in this estimation.

7.1.2. Benefits

LVRs warrant the reduction of crashes based on the specific countermeasures implemented on the specific low-volume rural roads or locations. The main purpose of the proposed LVRs network screening methodology is to have an independent and justifiable approach for evaluating, nominating, and prioritizing low-volume road safety improvement projects based on the unique merits of LVRs. The primary expected benefit of developing and implementing the proposed methodology would be an increase in crash reduction on LVRs.

To obtain an estimate of crash reduction, common safety countermeasure categories applied to Montana's LVRs were estimated in consultation with the project technical panel. **Table 12** shows the common countermeasure categories and their respective percentages of projects on Montana's LVRs. It is important to note that the analysis used the top three categories of countermeasures shown in **Table 12** which primarily involve low-cost safety treatments that are commonly used on LVRs.

Table 12: Common Countermeasures for Montana Low-Volume Roads

Countermeasure Category	Percentage
Signing and Delineation (Curve)	40
Signing and Delineation (Non-curve)	27
Intersection Improvements	17
Other	16

Appropriate crash reduction factors (CRFs) for different countermeasures under each of these broad categories were identified using the Highway Safety Manual (HSM) (AASHTO, 2010) and the Crash Modification Factor (CMF) clearinghouse website (CMF Clearinghouse, n.d.). Then using those CRFs, an average crash reduction for each of the three countermeasure categories was calculated. Finally, the weighted average crash reduction was calculated using the average CRFs for each category and their respective weights based on the percentages shown in **Table 12**. **Table 13** shows the relative weight and average crash reduction for each countermeasure along with the weighted average crash reduction for all safety countermeasures on Montana's LVR network.

Table 13: Crash Reduction for Countermeasures Categories and the Weighted Average Crash Reduction on Montana Low-Volume Roads

Countermeasure Categories	Relative Weight	Average Crash Reduction
Signing and Delineation (Curve)	0.48	0.27
Signing and Delineation (Non-curve)	0.32	0.27
Intersections	0.20	0.30
Weighted Average Crash Reduction		**0.274**

The weighted average crash reduction was then multiplied by 0.33 to account for the assumption that 33 percent of the total LVR network would receive a form of safety improvement during the 10-year analysis period. Then, to estimate the potential benefit of applying the new method, it was assumed that the expected crash reduction for the network would increase by 5 percent once the proposed method is used for identifying the at-risk sites on Montana's LVR network. **Table 14** shows the expected crash reduction both before and after the implementation of the proposed screening method.

Table 14: Expected Crash Reduction Pre- and Post-Implementation of the Proposed Screening Method

Expected crash reduction pre-implementation of proposed method	0.0919
Expected crash reduction post-implementation of proposed method	0.0965

Using the crash reductions in **Table 14** above and the number of crashes on Montana's LVRs, the potential benefits of implementing the proposed screening method can be estimated. **Table 15** shows the number of crashes by crash severity for the period 2015 to 2019, the average crash number per year for each severity level, and the estimated number of crashes for the 10-year analysis period. The crash numbers by severity for the period 2015-2019 inclusive were used as a basis for estimating the crash numbers for the 10-year analysis period.

Table 15: Number of Crashes by Severity and their Estimates for the Analysis Period

Crash Severity	Crash Numbers 2015-2019 Period	Average Crashes per year	Crash Numbers for the Analysis Period
Fatal (K)	301	60.2	602
Suspected Serious Injury (A)	1,158	231.6	2,316
Suspected Minor Injury (B)	3,540	708	7,080
Possible Injury (C)	3,486	697.2	6,972
No Apparent Injury (O)	29,158	5,831.6	58,316

The estimated crash numbers for the analysis period shown in **Table 15** and expected crash reductions shown in **Table 14** were used in estimating the number of crashes by severity that are reduced due to the implementation of the proposed method. The crashes reduced by severity were then converted to monetary terms using the estimated crash cost for each crash severity. The analysis used the Highway Safety Manual (AASHTO, 2010) crash costs that were adjusted for inflation using the consumer price indexes (CPI) to reflect the costs in January 2021 dollars. The CPI value for 2009 (crash costs in the HSM were in 2009 dollars) was obtained from a 2010 US Bureau of Labor Statistics (BLS) report. The CPI value for January 2021 was obtained from the trading economics website (Trading Economics, n.d.). **Equation 2** shows the inflation adjustment equation used in the calculations and **Table 16** shows the inflation adjusted crash costs for each severity level.

$$Crash\ Cost(January\ 2021) = Crash\ Cost\ (December\ 2009) \times \frac{CPI\ for\ January\ 2021}{CPI\ for\ December\ 2009} \ldots\ldots (2)$$

Table 16: Inflation Adjusted Crash Costs for Different Crash Severities

Crash Severity	HSM Crash Costs (Dec. 2009 Dollars)	Inflation Adjusted Crash Costs (Jan. 2021 Dollars)
Fatal (K)	$ 4,008,900.00	$ 4,868,042.82
Suspected Serious Injury (A)	$ 216,000.00	$ 262,290.72
Suspected Minor Injury (B)	$ 79,000.00	$ 95,930.40
Possible Injury (C)	$ 44,900.00	$ 54,522.47
No Apparent Injury (O)	$ 7,400.00	$ 8,985.89

Finally, the expected benefits from implementing the proposed method were calculated using the number of crashes reduced by severity and the inflation-adjusted crash costs shown in **Table 16**. **Table 17** shows the expected economic benefits from the implementation of the proposed network screening method.

Table 17: Benefits Calculation for a 10-Year Analysis Period

Crash Severity	Crash Numbers	Existing Reduction (Crashes)	New Reduction (Crashes)	Increase in Reduction (Crashes)	Benefits ($)
Fatal (K)	602	55.34	58.10	2.77	$ 13,468,822.68
Suspected Serious Injury (A)	2316	212.89	223.53	10.64	$ 2,791,902.37
Suspected Minor Injury (B)	7080	650.79	683.33	32.54	$ 3,121,535.44
Possible Injury (C)	6972	640.86	672.91	32.04	$ 1,747,075.37
No Apparent Injury (O)	58316	5360.39	5628.41	268.02	$ 2,408,393.07
Total Benefits					**$ 23,537,728.92**

7.1.3. Costs

For calculating the benefit-cost ratios, an estimate of the costs associated with developing and implementing the proposed methodology is required. **Table 18** shows the different cost elements and the total cost for the 10-year analysis period. As seen from the table, the estimated total costs for implementing the proposed method is around one million dollars.

The different cost elements that were considered in estimating the costs for the economic analysis are discussed in the following paragraphs.

Method Development Cost: This cost element encompasses the cost expended by the MDT on this research project. The exact amount of this cost element is $63,501 per the project contract documents.

Training Costs: This element covers all costs that would be involved in providing training to the MDT and local government agency staff on implementing the new proposed method. This element has three components: training materials development, training session, and online content development. The three cost value components were estimated in consultation with the Montana Local Technical Assistance Program (LTAP) Director (M. Ulberg, personal communication, July 9, 2020).

The training material development cost is a one-time cost and it was estimated to be $10,000. The online materials development cost is also a one-time cost that would be required to develop the online training contents (website, documents, videos, etc.). The online training content would provide the MDT and local agency staff with the necessary resources required for understanding and applying the proposed methodology.

The training session costs are annually recurring costs. These sessions, to be conducted by MDT staff or an external contractor, are estimated to have an average cost of $1,000 per session. It is assumed that the first three years would require a larger number of training sessions to promote the use of the method to all incorporated local transportation agencies in Montana. For the first three years, it is assumed that 12 training sessions will be required each year. For the following years, only two sessions per year are considered in the analysis. These sessions would accommodate staff turnovers and/or staff that have missed the training in the first three years.

Additional Staff Costs: While implementing the new methodology should not be different from implementing any other methodology in terms of MDT staff requirements, it was decided to include it in the cost elements to be conservative in our approach. The assumption that is made in this economic analysis is that the proposed methodology would require an additional time of a safety professional that is equivalent to 0.8 FTE (full-time employee).

The median wage for a civil engineer in Montana was used for estimating the additional staff cost. The median hourly wage was collected from the Montana Department of Labor and Industry (2020) report. Further, a 30 percent benefits rate was added to the median wage in estimating the cost of additional staff. This analysis also incorporated a two percent annual raise to the staff salary in calculating the annual cost of additional staff time.

Table 18: Development and Implementation Costs for the 10-Year Analysis Period

Item	Years										Totals
	1	2	3	4	5	6	7	8	9	10	
Method Development Project Cost	63,501										$ 63,501
Training Material Development Costs	10,000										$ 10,000
Training Sessions	12,000	11,329	11,007	1,783	1,732	1,683	1,635	1,589	1,544	1,500	$ 45,800
Online Training Contents Development	30,000										$ 30,000
FTE Time	78,654	80,227	81,832	83,468	85,138	86,840	88,577	90,349	92,156	93,999	$ 861,239
Total Costs											**$ 1,010,540**

7.2. Results and Discussion

This section discusses the results of the economic assessment associated with developing and implementing the proposed network screening method. Specifically, this section provides the estimates of the benefit-cost ratios using the benefits and costs discussed in the previous sections.

Table 19 shows the estimated benefit-cost ratios for the proposed method using three different inputs in estimating the benefits: 1) all crashes 2) fatal and suspected serious injury crashes, and 3) fatal and all injury crashes (suspected serious injury, suspected minor injury, and possible injury). As shown in the table, all the benefit-cost ratios for the three different analysis inputs are notably higher than 1, making a strong case for the cost effectiveness of the proposed screening method.

Table 19: Benefit Cost Ratios for Different Analysis Inputs

Scenarios	Benefit-Cost Ratios
All Crashes (KABCO)	23.29:1
Fatal and Serious Injury Crashes Only (K & A Only)	16.09:1
All Fatal and Injury Crashes (KABC)	20.91:1

The first benefit-cost ratio is for a scenario where the crash reduction for all crash types, including property damages was used in estimating the benefits. As shown in **Table 19**, the benefit of implementing the proposed method outweighs the costs by almost 23 times.

The second scenario is when only fatal and suspected serious injury crashes are considered in estimating the benefits. In this case, the benefits of the proposed method are estimated to outweigh the costs of developing and implementing the proposed method by almost 16 times, still indicating a very high rate of return on the expended safety funds. Finally, the benefit-cost estimate for the third scenario included (all fatality, suspected serious injury, suspected minor injury, and possible injury crashes fell between the ratios of the first two scenarios. In this scenario, the expected benefits outweigh the costs of the proposed method by around 21 times.

7.3. Concluding Remarks

This chapter presented the results of Task VII of the project titled "Developing a Methodology for Implementing Safety Improvements on LVRs in Montana." This task aimed at assessing the benefits of the proposed network screening methodology. An economic assessment in the form of benefit-cost analysis was performed to estimate the economic feasibility of using the new proposed method. This report discussed the methodology used in the analysis, analysis inputs and assumptions, and the economic analysis results.

The results of the analysis clearly showed that the expected safety benefits of the proposed screening method significantly outweigh all the costs associated with developing and implementing the proposed methodology. This finding was applicable to the three different severity scenarios investigated in this assessment. Specifically, the benefit-cost ratio for the three scenarios varied between 15 and 23 which makes a strong case for the cost effectiveness of using the new network screening method in identifying candidate safety improvement sites on Montana's LVRs.

8. SUMMARY OF FINDINGS AND RECOMMENDATIONS

The main objective of this project was to develop a network screening method for low-volume roads (LVRs) in Montana. Overall, six main tasks were completed to achieve this objective. This chapter summarizes the major findings of each of these tasks and culminates in some recommendations stemming from the project work including recommendations for the implementation of the proposed methodology.

8.1. Summary of Findings

8.1.1. State-of-the-Art Review

The review conducted in this task focused on risk factors associated with rural LVRs and on network screening methods and applications. The review included materials published in reports, studies and websites that have been either applied in practice or proposed in the literature.

- The literature review identified risk factors associated with roadway characteristics that are believed to affect safety performance on LVRs in relation to roadside features, cross-section elements, and alignment design.
- The identified screening methods were classified in this task into three major classes: methods using historical crash data, predictive methods, and methods using historical crash data and prediction models in combination.

8.1.2. Develop Criteria for Site Identification and Prioritization

- This task identified and discussed some of the important criteria that should be considered in assessing the suitability of different network screening methods for LVRs.
- Eight criteria were identified and discussed in this task: sensitivity to level of risk, sensitivity to economic effectiveness, precision, previous performance record, ease of understanding, ease of implementation, data requirements, and resource requirements.

8.1.3. State of Practice Survey

A state of practice survey was conducted to learn about state agency practices in managing safety on LVRs. The survey was sent to Department of Transportation (DOTs) safety personnel in all 50 states and 32 of the states responded to the survey. The major survey findings in relation to the technical aspects of the network screening process and safety management on LVRs are summarized below.

- Crash severity is the most frequently used criterion for identification of potential safety improvement sites on LVRs. Also, around 48 percent of the responding DOTs reported using the FHWA systemic approach in combination with one or more of other network screening criteria.
- Cost effectiveness was the most frequently reported criterion in justifying safety improvement projects on state-owned as well as non-state-owned LVRs.
- About 80 percent of those responding had a separate method for selecting sites on state-owned LVRs from the method used for other state-owned roads with higher traffic volumes.
- Around 90 percent of the responding DOTs involved local DOTs (cities, counties, townships, etc.) in identifying safety improvement sites on non-state-owned local roads. Crash experience at sporadic sites was the most frequently reported method for identifying safety improvement sites on non-state-owned local roads.
- More than half of the responding transportation DOTs (55 percent) reported using one process for identifying safety improvement sites on state-owned and non-state-owned LVRs.
- Most of the responding DOTs (70 percent) reported not allocating a set amount of funds for safety projects on non-state-owned local roads. Further, similar percentage reported allocating less than 20 percent of total safety funds to systemic improvements on non-state-owned local roads.

8.1.4. Assessment of Existing Methodologies

In this task, different methodologies identified from the literature review and the practice survey tasks were assessed and scored for their merits (or demerits) in screening the low-volume road networks. The set of criteria developed in a previous project task was used in the assessment. A scoring scheme was employed to assign weights to different criteria which were then used in scoring the alternative methodologies. Major findings from this task are provided below.

- The methods that scored highest in the assessment are the conventional frequency, rate, and severity methods and the Highway Safety Manual (HSM) empirical Bayes method.
- Network screening using surrogate safety measures was found to have the least merit.
- The FHWA systemic approach to safety scored right in the middle. This method could have scored much higher if the cost-effectiveness criterion used in the assessment had accounted for the high benefit-cost ratio usually associated with low-cost systemic improvements.

8.1.5. Developing a Methodology for Network Screening on Low-Volume Roads

A methodology for screening low-volume road networks for candidate safety improvement sites was developed in this task. The method was developed to satisfy the following criteria: 1) The method should be based on theoretical principles in safety science and/or empirical evidence that are well accepted in practice by the traffic safety community, 2) It should incorporate roadway and roadside characteristics (risk factors) that are associated with crash occurrence, 3) It should not require extensive and exact roadway and traffic data inputs, and 4) Method should be easy to use by local transportation agency staff with limited resources. Below is a brief description of the proposed method.

- The proposed method assigns scores to a site using roadway and roadside characteristics, traffic characteristics, and crash history. These scores can then be used in ranking sites that are part of the low-volume road network.
- Separate scoring schemes were developed for roadway segments and intersections.
- The roadway segment scoring scheme uses the following site information: lane width, horizontal curvature, grade, driveway density, side slope, roadside fixed objects, pavement presence and condition, speed, volume, and crash history.

- The intersection scoring scheme uses the following site information: intersection skew angle, traffic control, presence of turn lanes, presence of lighting, speed, traffic level, and crash history.

8.1.6. Assessing Benefits of the Proposed Method

In this task, the potential economic benefits of the proposed methodology were assessed and analyzed. An overview of the economic analysis is provided below.

- The economic analysis, in the form of the conventional benefit-cost ratio, using the present worth of costs and benefits was used in this assessment.
- Costs associated with the use of the proposed methodology involved methodology development, training resources development, training sessions, and additional agency staff.
- In using a more robust process for identifying sites for safety improvement projects, it was assumed that the crash reduction would increase by a small percentage (5 percent) upon the implementation of the proposed network screening method. Crash reduction was estimated using the crash modification factors for the most common safety countermeasures on Montana LVRs. This was the main expected benefit from the use of the proposed methodology.
- Using a 10-year analysis period, benefit-cost ratios for three different scenarios were calculated. Crash reduction using all crashes, fatal and serious injury crashes only, and all crashes except property-damage-only crashes were considered in the analysis. The benefit-cost ratios for the three scenarios varied between 16 and 23.

8.2. Recommendations

Considering the overall project and the findings from project tasks, the researchers would like to make the following recommendations regarding safety management on Montana LVRs and the implementation of the proposed network screening methodology.

I. The first recommendation for MDT is to review on a periodic basis that the percentage of HSIP Funding being spent on LVRs balances with the higher severity crash percentages experienced on these roads. This recommendation is based on the following factors:
    a. The information gathered in this project confirmed that most DOTs use conventional network screening methods based on historical crash data. These

methods mostly focus on sites with higher crash frequencies, often associated with high traffic exposure.

b. A large proportion of LVRs is owned and operated by local transportation government agencies that have limited staff and financial and technical resources to undertaking safety evaluations/programs.

II. Consistent with the first recommendation above, it is important for the MDT to appoint exclusive personnel for safety management on LVRs. This is primarily due to the unique safety challenges encountered on these roads and the multi-agency ownership of the low-volume road network. The appointed staff member(s) are expected to work closely with local transportation agency staff that oversee implementing the network screening at the local level.

III. The researchers recommend that the MDT implement the network screening methodology developed in this project for identifying and ranking candidate sites for safety improvement projects. This research project confirmed the lack of any robust and science-based methodology for network screening on LVRs at the national level. Therefore, applying the proposed methodology provides potential in improving the process for managing safety on these roads.

IV. As a large proportion of LVRs is owned and operated by local transportation agencies, appropriate training for the use of the proposed methodology should be provided to local transportation staff for those agencies to successfully adopt the new network screening process. The MDT is expected to take the lead in coordinating these training efforts for meeting local agency technical support needs to promote increased involvement of local transportation agencies in safety management on roads within their jurisdictions.

V. The full implementation of the proposed methodology by local government agencies is expected to take time. Therefore, it is recommended that the proposed method be used in the interim for ranking sites as part of identifying systemic safety improvement projects, or as part of selecting safety improvement project sites on local roads, that is, using the methodology score as one of the considerations in selecting safety improvement project sites on Montana LVRs.

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APPENDIX A

Identification of Sites for Safety Improvement on Low-Volume Roads in Montana

The purpose of this survey is to understand the state of practice in selecting highway safety improvement sites on rural low-volume roads (LVRs). Low-volume roads may be owned and operated by state DOTs or by local agencies such as counties, cities, and townships. For local agencies non-state owned local roads will be used to refer to low-volume roads under local jurisdictions.

The survey is divided in two parts. Part A is concerned with the agency practice in identifying sites for safety improvement projects on state-owned and operated low-volume roads. Part B includes questions about safety improvement projects on non-state owned local roads, i.e. roads that fall under local jurisdictions (primarily counties, townships and cities).

This survey should be completed by those in your agency who are involved in the safety improvement programs. Participation is voluntary, you can choose not to answer any question that you do not want to answer, and you can stop at any time. The survey has 17 questions in total and is expected to take approximately 15-20 minutes to complete. Thank you in advance for your participation.

Please enter your contact information: (We may wish to contact you if we need clarification or desire more information regarding a response)

NAME:

TITLE:

AGENCY:

PHONE:

EMAIL:

PART A - Identifying Sites for Safety Improvements – State-Owned LVRs

QA1. Defining low-volume roads (LVRs) as roads with AADT less than 1000 vehicles per day, how much do LVRs constitute of your highway network by length?

- ☐ 0% - 10%
- ☐ 10% - 25%
- ☐ 25% - 40%
- ☐ > 40%
- ☐ Don't know

QA2. Is your agency's method / process for selecting sites for safety improvements on state-owned LVRs different from that used on other state-owned roadways?

☐ Yes ☐ No

QA3. What is the method / process used for identifying safety improvement sites on state-owned LVRs? (check all that apply)

- ☐ FHWA systemic approach to safety
- ☐ Network screening using:
  - ☐ Crash frequencies
  - ☐ Crash rates
  - ☐ Combination of crash frequencies and crash rates
  - ☐ Crash severity (check if severity is accounted for by the method)
  - ☐ Other, please specify

QA4. In identifying sites for safety improvement on state-owned LVRs, cost-effectiveness (e.g. benefit-to-cost ratio) is used by the agency to (check all that apply):

- ☐ Rank safety improvement sites at the network level
- ☐ Comparing alternative safety countermeasures at specific sites
- ☐ Cost effectiveness is not used

QA5. On a scale of 1 to 10, how satisfied is your agency using this method / process on state-owned LVRs? (1 = not satisfied, 10 = extremely satisfied)

☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ 9 ☐ 10

Q A6. Do safety personnel in your agency have ready access to the following low-volume road data <u>at the network level?</u> (check all that apply)

- ☐ Detailed crash data
- ☐ Traffic data (i.e. counts, vehicle class)
- ☐ Roadway geometry
- ☐ Roadside features

QA7. Please add any other information related to how your agency select sites for safety improvements on state-owned low-volume roads.

PART B - Identifying Sites for Safety Improvements – Non State-Owned Local Roads

QB1. Is the HSIP program leader for non-state owned roadways (counties, townships, etc.) different from the staff member leading the program for state-owned roadways?

- ☐ Yes ☐ No

QB2. Are local agencies (counties, townships, etc.) involved in the <u>identification of safety improvement project sites</u> on local roads under their jurisdiction?

- ☐ Yes ☐ No

QB3. What is the process for determining <u>how much funding is allocated</u> to local (non-state owned and operated) safety projects?

- ☐ Past crash experience (e.g. proportion of crashes on non-state owned roads)
- ☐ Size of network by length (e.g. proportion of network consisting of non-state owned roads)
- ☐ Estimated vehicle miles of travel (e.g. proportion of travel on non-state owned roads)
- ☐ Other, please specify

QB4. From past experience, safety improvement sites on local roads (counties, townships, and cities) are identified based on (check all that apply):

- ☐ Statewide hotspot network screening
- ☐ Network screening within local jurisdiction
- ☐ Crash experience at sporadic (individual) sites
- ☐ Risk perception by local agency staff or law enforcement
- ☐ Risk perception by the public

- ☐ Other, please specify

QB5. For sites on non-state owned local roads proposed by local agencies, traffic and roadway data collection is usually undertaken by:

- ☐ State DOT
- ☐ Respective local agency (county, township, etc.)
- ☐ Both (i.e. for some sites, local agencies provide data, and for others state DOT does)
- ☐ Other, please explain:

QB6. How is the selection of safety improvement sites (and their ranking) justified on non-state owned local roads?

- ☐ Cost effectiveness (e.g. benefit-to-cost ratio)
- ☐ Crash frequency
- ☐ Crash rate
- ☐ Combination of crash frequency and rate
- ☐ Crash severity (if severity is accounted for in the process)
- ☐ Other, please explain:

QB7. Is the selection of safety improvement sites on non-state owned local roads performed separately from state-owned roadways, (i.e. the list of sites, rankings, etc. is done exclusively for non-state owned roadways)?

- ☐ Yes ☐ No

QA8. For non-state owned local roads, what is the percentage of safety improvement funds allocated to systemic safety improvements? (i.e. using the FHWA systemic approach to safety)

- ☐ 0% - 20%
- ☐ 21% - 40%
- ☐ 41% - 60%
- ☐ > 60%
- ☐ Don't know

QA9. Do safety improvement project sites involve unpaved non-state owned local roads?

- ☐ Yes ☐ No

QB10. Please provide any additional information on selecting sites for safety improvements on non-state owned local roadways that are not covered in the previous questions.

APPENDIX B

Responses of the Different Methods
SPIS (Safety Priority Index)
Roadway characteristics (usRAP). Any proposed project is evaluated for BCR in three manners. 1) 3 year crash history, 2) Predictive methods of the HSM, 3) usRAP evaluation for crash risk.
VA-SPFs
Safety Analyst expected/predicted crashes
HSM network screening by Excess method with EB adjustment
observed site conditions
Level of Service of Safety
Risk analysis on fatal and serious injury crashes
Excess Crash Costs with EB Adjustment
Levels of Service of Safety
Use HSM methodology to develop SPF for local routes

APPENDIX C

Different Site Identification Methods Reported by the Respondent
Statewide network screening (roadway departure, intersection and bike/ped
Local Road Safety Plans. We have developed plans for approximately 60 percent of counties in our state.
We don't have a lot of local roadway information. So the best we can do is develop local road clusters by street name only.
NYSDOT is implementing a new safety management system that will provide the ability to perform network screening on local roads.
Some consultants have started working with local agencies to assist them with city-wide network screening.
Systemic risk analysis based on fatal and serious injury crashes
A few horizontal curve signing projects used a systemic network screening method to identify locations for engineering study and/or signing.

APPENDIX D

This appendix is intended to explain the approach followed in developing the network screening methodologies that were presented in Chapter 6 of this report. The intersection methodology presented in **Table 11** will be used in this explanation.

The proposed network screening methods for roadway segments and intersections each consists of a scoring scheme that utilizes roadway, crash, and traffic data in assigning a score for each individual site that is part of the network. The approach and considerations used in developing the three different components of the proposed methods are discussed below.

Roadway Characteristics

The proposed method attempts to quantify the safety impact of different roadway characteristics (a.k.a. risk factors) using the guidance provided in the Highway Safety Manual (HSM). The HSM accounts for the effect of those characteristics using the Crash Modification Factors (CMFs). Therefore, in developing the proposed methodology, the CMFs were calculated for typical values of those roadway characteristics, and scores were assigned consequently while roughly maintaining the relative magnitudes of those impacts (that is, CMFs). Approximation and rounding were part of the process given the practical nature of the proposed screening method.

The scores for roadway characteristics and their underlying information (assumptions and CMFs) are shown in Table D-1 below.

Table D-1: Scores for Roadway Characteristics and Underlying Information (Intersection Methodology)

Roadway Characteristic	Case I	CMF	Case II	CMF	Score
Skew Angle					
3-leg	0 deg	1	30-deg	1.13	10
4 leg	0 deg	1	30-deg	1.18	
Uncontrolled Intersections	No Control	1	2-Way Stop Control	0.49	60*
Lighting	No lighting	1	Lighting	0.9	-7
Left-turn lane on uncontrolled legs					
3-leg (one approach)	No LTL	1	LTL	0.56	-30
4 leg (one approach)	No LTL	1	LTL	0.72	
3-leg (two approaches)	No LTL	1	LTL	0.31	
4 leg (two approaches)	No LTL	1	LTL	0.52	

* This score is based on a 104% increase in crashes for having no control compared to 2-way stop sign.

To explain how these scores were selected, the following arguments were made:

I. The average increase in crashes due to the skew angle is in the order of 15%-16%. The corresponding score was set to positive 10 taking into consideration that the sum of scores for risk factors should not exceed 80, which is the score that correspond to one fatal or serious injury crash (discussed in the following section).

II. The lack of control at low-volume road intersections is considered a risk factor, thus the positive score. However, the base scenario in the CMF clearinghouse is "no control" and thus the CMF of 0.49 for installing two-way stop control. Nonetheless, the score was derived based on the fact that crashes at an intersection with no control is around 2.04 times the number of crashes upon the installation of two-way stop control, or in other words, the lack of control is expected to result in around 100% increase in the number of crashes, thus the score of positive 60.

III. Installation of lighting results in around 10% decrease in the number of crashes, thus the negative 7 score.

IV. Adding left-turn lanes on uncontrolled approaches of 3-leg and 4-leg low-volume road intersections would result in a decrease in the number of crashes in the order of 30% to 50% depending on the intersection configuration. Therefore, a single score of negative 30 was assigned to this feature (for practical reasons).

Crash History

The scores assigned to observed crashes were mainly selected to ensure that sites with one or more fatal or serious injury crashes receive further consideration/review for potential safety improvements regardless of the risk factors present. The score assigned to property-damage-only crashes and other non-serious injury crashes was primarily based on judgment and is not necessarily intended to reflect the average cost of the two types of crashes.

Traffic Characteristics

As the ADT is part of the HSM safety performance functions (not the CMFs), multiplicative factors (referred to as multipliers in Chapter 6) were used to account for the different ranges of traffic level. The multipliers for various traffic levels were estimated using the HSM safety performance functions (SPFs) for rural two-lane highways and rural intersections. For example, in the method for LVR intersections, the ADT for the major and minor roadways were assumed, then the HSM safety performance function for two-lane rural roadway intersections was applied, and the predicted number of crashes was used in deriving the multiplication factors. The ADTs for major and minor roads, the predicted number of crashes along with the proposed scores are provided in Table D-2.

Table D-2: Multiplication Factors for Various Traffic Levels and Underlying Information (Intersection Methodology)

Traffic Level	ADT_{maj}	ADT_{min}	ADT_{int}	N_{spf}	Multiplier
$ADT_{int} \leq 600$	300	200	500	0.1487	1
$600 < ADT_{int} \leq 1200$	600	400	1000	0.2887	2
$1200 < ADT_{int} \leq 2000$	900	600	1500	0.5619	4
$ADT_{int} > 2000$	1200	1000	2200	0.9119	6

As shown in Table D-2, the lowest traffic level was considered as the baseline thus no adjustment is needed (multiplier of 1.0). Other higher traffic levels have multipliers that are multiples of 1.0 based on the expected number of crashes (N_{spf}) shown in this table.