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

Task 6 Report: Develop a Montana-Specific Methodology for Selecting Safety Improvement Sites on Local Roads

Prepared by

Ahmed Al-Kaisy, PhD, PE – Professor & Program Manager

Kazi Tahsin Huda – Graduate Research Assistant

of the

Western Transportation Institute

College of Engineering

Montana State University

Bozeman, MT 59717-4250

A report prepared for the

MONTANA DEPARTMENT OF TRANSPORTATION

in cooperation with the

U.S. DEPARTMENT OF TRANSPORTATION

FEDERAL HIGHWAY ADMINISTRATION

September 2020

DISCLAIMER STATEMENT

This document is disseminated under the sponsorship of the Montana Department of Transportation (MDT) and the United States Department of Transportation (USDOT) in the interest of information exchange. The State of Montana and the United States assume no liability for the use or misuse of its contents.

The contents of this document reflect the views of the authors, who are solely responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the views or official policies of MDT or the USDOT.

The State of Montana and the United States do not endorse products of manufacturers.

This document does not constitute a standard, specification, policy or regulation.

ALTERNATIVE FORMAT STATEMENT

MDT attempts to provide accommodations for any known disability that may interfere with a person participating in any service, program, or activity of the Department. Alternative accessible formats of this information will be provided upon request. For further information, call 406/444.7693, TTY 800/335.7592, or Montana Relay at 711.

TABLE OF CONTENTS

LIST OF TABLES

1. INTRODUCTION

The objective of this task is to develop and recommend a Montana-specific method that would help the MDT or local agencies in screening the network of low-volume roads within their jurisdictions for sites that are worthy of consideration for safety improvements. The work in this task utilizes 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 Empirical Bayes (EB) method and the combined crash frequency, rate, and severity method. While these methods were found to have merits compared to other methods included in the assessment, they are not appropriate for use on low-volume roads for the following two reasons:

I. The Empirical Bayes method is resource intensive, i.e. 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 at local jurisdictions and are often not accessible by local agencies.

II. 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 low-volume roads due to the random and sporadic occurrence of crashes on the network as a result of low traffic levels.

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 agencies, and can reasonably be applied by staff with limited technical background.

2. METHODOLODGY DEVELOPMENT: GUIDING PRINCIPLES

A successful network screening methodology on low-volume roads should satisfy the following requirements:

I. 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.

II. Most of low-volume roads are local roads and secondary routes that don't enjoy the same geometric features as higher-class roads and many of these roads are unpaved. Therefore, roadway and roadside characteristics on these roads (risk factors) are often associated with crash occurrence and, as such, must be considered by the proposed methodology.

III. Local 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.

IV. Local agencies usually do not have staff with the kind of technical background and expertise required for conducting safety analyses such as the use of statistics and associated data analysis software. Hence, a successful methodology should be easy to use and require staff with limited skills and qualifications.

3. 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 (e.g. 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 that indicates the proportion of crashes that would be expected due to presence of a roadway feature, or upon implementing a safety countermeasure. 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 both fatal and serious injury crashes as well as the remaining injury 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 (e.g. possible injury) may go unreported on low-volume roads. Further, it is reasonable to think that local 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 in a way to ensure 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.

3.1. Proposed Methodology: Roadway Characteristics - Risk Factors

On low-volume roads, 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 the purpose of this project, only roadway features (among risk factors) are considered in the development of the proposed methodology as other potential risks (e.g. environmental, traffic, etc.) are often outside the realm of engineering countermeasures. The proposed methodology includes certain roadway features that: 1) are most relevant to low-volume roads, 2) have tangible impact on safety per HSM guidance and existing literature, and 3) relevant information can reasonably be acquired by the prospective users, i.e. staff at local agencies.

3.1.1. Roadway Segments

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

I. Total roadway width (lane width + shoulder width)
II. Horizontal curvature
III. Grade

IV. Driveway density
V. Roadside (side slope and fixed objects)
VI. Roadway surface type (paved vs unpaved)
VII. Pavement condition

Roadway surface type and pavement condition were included in the methodology for their potential effects on safety despite the fact that these factors are not included in the HSM. This is primarily because some of the low-volume roads owned and operated by local governments are unpaved and some are paved with pavement 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 low-volume roads 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 low-volume roads. Per the HSM and the current practice, lanes narrower than the 12-ft 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 help errant vehicles to restore their path and return to the travel lane thus minimizing the likelihood of roadway departure crashes. In this methodology, low-volume roads with total width equal or narrower than 24 ft. 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. It should be noted that farm and field approaches are not considered driveways for the purpose of this method.

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 low-volume roads 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 low-volume roads. The proposed methodology assigns scores for roadways with poor pavement conditions.

3.1.2. Intersections

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

I. Intersection skew angle
II. No traffic control (uncontrolled intersections)
III. Left-turn lanes on approaches without stop control
IV. 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 [AASHTO 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, i.e. right of way is not assigned through the use of signs or signals. 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 low-volume roads. 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 also important for safe operations at intersections, as good visibility 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.

3.2. 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 times, crash risks at these locations could be lessened or alleviated through the use of safety countermeasures. The proposed methodology considers historical crash data in screening the network for sites that deserve 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.

3.3. 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 (e.g. 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. Similar to 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).

4. 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 Global Risk Score is an indicator of the level of risk or crash likelihood at any given roadway segment or intersection.

4.1. Roadway Segments

A tentative ranking scheme for roadway segments is shown in Table 1. For the purpose of 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.

I. 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 Highway Safety Manual (HSM), 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.

II. 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).

III. 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-recoverable 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 1: 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)	

4.2. Intersections

For local road intersections, a separate ranking scheme was developed using intersection characteristics, historical crash data, and traffic exposure as shown in Table 2. 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 (ADT_{int}) 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 (e.g. 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 ped/bike modes into consideration when analyzing safety at intersections in the process of network screening.

Table 2: 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?	-5
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)	

5. 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 low-volume roads 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 low-volume roads. The proposed methodology could help local agencies setting priority list of sites for the implementation of systemic improvements given the limited resources available at any given time.

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. CONCLUDING REMARKS

This report discussed the development of a proposed network screening methodology for use on low-volume roads 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 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 CMS 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 (a.k.a. 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 (e.g. unpaved roads).

It should be remembered that while the Highway Safety Manual is the main reference document for performing safety analyses in the US, it represents the general US context which could still 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 become 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 mainly because the RRCS and the GRS scores cannot be used to predict crash numbers or crash rates at a specific site.

7. REFERENCES

American Association of State Highway and Transportation Officials (AASHTO). *Highway Safety Manual, First Edition*. Washington, DC (2010).

El-Basyouny, K., and T. Sayed. "A Full Bayes Approach to Before-After Safety Evaluation with Matched Comparison." *Presented at the 89th Annual Meeting of the Transportation Research Board*, *Washington, D.C.*, (2010).

Federal Highway Administration (FHWA). *Crash Modification Factors Clearinghouse*. Accessible at: http://www.cmfclearinghouse.org/.

Ksaibati, K., Zhong, C., Evans, B. (2009). "*WRRSP: Wyoming Rural Road Safety Program*" Report No. FHWA-WY-09/06F, Cheyenne, Wy., Wyoming Department of Transportation, 2009.

Souleyrette, R., Caputcu, M., McDonald, T., Sperry, R., Hans, Z., and D. Cook. “Safety Analysis of Low-Volume Rural Roads in Iowa,” *Institute for Transportation, InTrans Project 07-309, Iowa State University*, Ames, Iowa, (2010).