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COST EFFECTIVE SAFETY IMPROVEMENTS ON TWO-LANE RURAL STATE ROADS IN WASHINGTON STATE

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16. ABSTRACT

Two-lane rural highways in Washington State represent approximately 4,900 miles. From 1999 to 2005 , 42.8% of the fatal collisions reported on state highways occurred on two-lane rural highways. WSDOT determined that the traditional high collision frequency location approach do not necessarily reflect the safety needs of two-lane rural highways. The research team first conducted a systematic review of the network and then developed a proposed decision-matrix for the selection of countermeasures on two-lane rural highways. A rate-based approach was used to show various trends across different user groups, geometric features, and contexts. It is generally accepted that the context of the two-lane rural highway would influence countermeasure choice. The project tested two contextual surrogates for the identification of particular two-lane rural highways that may exhibit safety characteristics that are different from the rest of the network. First proximity to K12 schools (in half mile increments up to 2 miles) was tested to determine whether it could assist in identifying more developed areas, such as rural town centers. It showed promise and identified areas with lower collision severity but higher collision frequency along with a higher incidence of pedestrian related collisions. Second proximity to urban boundaries (increments up to 2 miles) as means to identify transition areas showed less promise. The decision-matrix summarizes countermeasure effectiveness by collision group and also make reference to the findings from the systematic assessment. The project also included a limited before-after study of centerline rumble strip installations (CLRS). Although results indicate some benefits and possible collision increases, caution is noted in terms of application of these findings because of small sample sizes in the analysis and the fact that roadside characteristics could not be incorporated in the evaluation process. The report recommends the development of safety performance functions that would incorporate these features. These multivariate approaches could further assist the department in the development of system-wide and corridor level approaches for two-lane rural highways.

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EXECUTIVE SUMMARY

This report documents the methodology and results of a research project that developed a proposed decision-matrix for two-lane rural highway countermeasure selection in Washington State. The researchers performed a systematic assessment to identify particular features exhibiting higher collision and severity rates on the two-lane state rural highway system. Local and county roads were not included in the analysis.

The project also introduced two particular contextual surrogates, in other words, ways to identify or distinguish between different road environments in the rural context and subsequently different collision behavior. The first contextual surrogate provides an indication of segments along more developed areas, such as rural town centers where data to account for this condition does not exist. The second contextual surrogate identifies transition areas, i.e. transitions from high-speed rural environments to lower speed urbanized roadways where collision exposure is greater.

Findings from the study suggest that there are specific characteristics and contexts (e.g., proximity to rural town centers) of two-lane rural highways in Washington that exhibit higher collision and/or severity rates (across different collision types and different severity groupings). Segments with these characteristics may offer opportunities for systematic approaches or individual countermeasures to collision reduction consistent with Washington State's strategic safety plan.

A contextual surrogate for level of development on rural facilities, "the extent of proximity to K12 schools", showed promise. When comparing segments from more developed areas with those in relatively undeveloped areas, the study showed that, the surrogate successfully distinguished between these two contexts. For example, in more developed areas one would expect larger portions of collisions involving pedestrians because of increased exposure, while relatively undeveloped areas would have higher portions of run-off-the-road collisions due to factors such as higher operating speeds.

The surrogate for the identification of transition areas, "proximity to urban boundaries," also showed promise, but to a lesser extent. The results suggest that further exploration of this measure would be beneficial to assess the differences found in results for varying terrain types and development levels.

Of particular interest in this study was the summary of features of segments on the two-lane rural highway network. The research developed this summary to assist WSDOT in the development of focused strategies for use in areas showing greater potential in reducing fatal and disabling injuries in Washington State. The summary also has merit in addressing system wide strategies as well.

The study developed a proposed decision-matrix for countermeasure selection on two-lane rural highways. The decision-matrix consists of three parts. The first part identifies segments with particular characteristics with higher associated rates of collisions and severities with summarized results from the systematic assessment. The second part of the matrix provides a list of all the major collision types identified during the study and provides reference to particular countermeasure groups. The third part consists of a summary of countermeasures, with focus on lower cost measures. It is organized by countermeasure group, and contains results from an extensive literature of potential effectiveness of countermeasures on two-lane rural highways.

CHAPTER 1 INTRODUCTION AND BACKGROUND

PROBLEM STATEMENT

The Washington State Department of Transportation (WSDOT) highway safety program ranks as one of the best performing safety programs in the nation. To achieve this success, the Department has focused on both preventative and historic components in its approach to reducing societal cost related to collisions.

WSDOT outlines its highway safety vision in its 20-year Transportation Plan and its strategic highway safety plan "Target Zero." In 2007, the Washington State Traffic Safety Commission, made up of key safety stakeholders in Enforcements, Education and Engineering, approved Target Zero for signature by the Governor of the State of Washington. This plan sets a target of zero highway related fatalities and disabling injuries by the year 2030 (WSDOT 2007a).

The WSDOT approach to safety has met with legislative understanding and approval, and with this, the safety program has seen trends toward higher levels of safety funding. WSDOT bases its safety approach on the performance of safety investment. To maximize performance, the Department uses a holistic approach to local, corridor and system wide safety initiatives. It is felt, that this approach allows for flexibility and focus in decision-making. WSDOT sees safety as a matrixed approach among the various safety disciplines and an integral part of its ongoing daily activities. The Department uses multi-disciplinary teams in safety decision-making and the Highway Safety Issues Group provides a leadership function.

Figure 1 demonstrates the progress made in terms of reducing fatal and disabling collisions on state highways since 1980 to 2005. This chart shows a 37 percent reduction in fatal injury collisions over this period. Fatal and disabling injury collisions have decreased despite an increased demand on the highway system (the vehicle miles traveled) (WSDOT 2006). Fatal and disabling injuries decreased and less severe collisions increased. Increases in lower severity collision are common for increases in vehicle miles traveled (Figure 2).

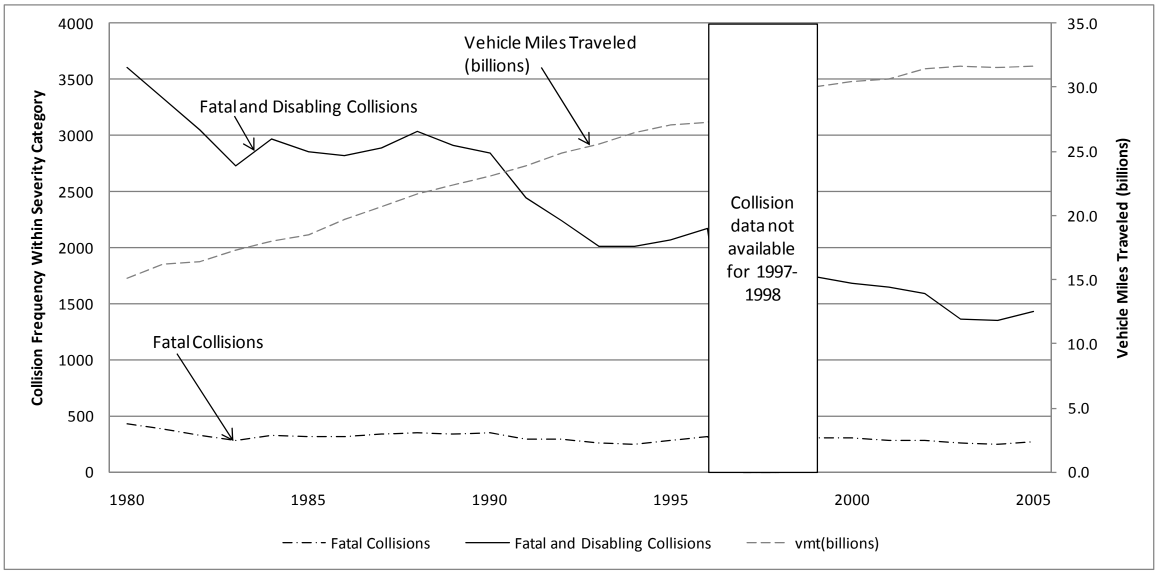


Figure 1: Fatal and Disabling Collisions and annual vehicle miles traveled on state highways for the years 1980 to 2005

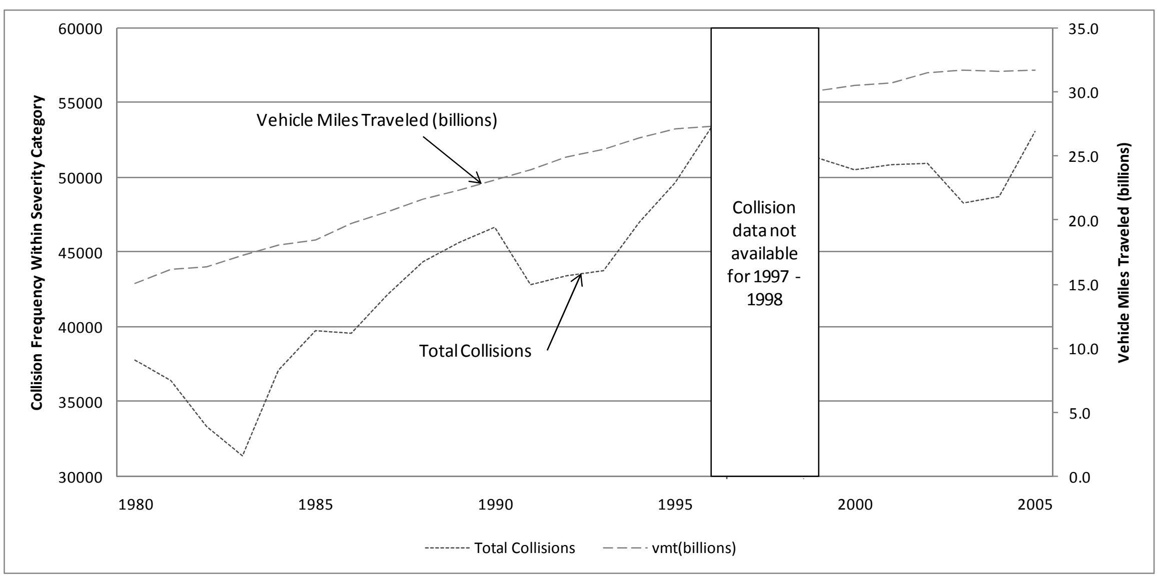


Figure 2: Collisions and annual vehicle miles traveled on state highways for the years 1980 to 2005

Washington State's success serves as a national example for its innovative approach toward safety. The underlying philosophy is that highway safety must encompasses all aspects of safety including education, enforcement and engineering and that success within each of these elements must be measurable through the assessment of data rather than drawn from anecdotal conclusions.

Further, safety must contain both reactive and proactive (preventative) approaches to both respond to current needs and to prevent future occurrence. To meet these objectives requires the ability to assess performance with sound data and methodology, and when appropriate to perform research in the development of new approaches.

The WSDOT approach includes, but is not limited to the following elements and activities:

- approaches which address local, corridor and systematic components,
- quick implementation of proven safety improvements such as cable median barriers,
- support for the improvement of state of the practice by investing in the development of roadway and roadside safety features,
- large-scale application of lower cost safety features such as centerline and edgeline rumble strips,
- improvement of roadside safety through roadside safety data collection and analysis, and
- timely updates of manuals in support of safety and risk reduction.

Within this approach, two-lane rural highways continue to be an emphasis area for WSDOT. Building upon national level research projects including the IHSDM (FHWA 2005) and Vogt and Bared (1988), WSDOT has recognized that Washington State is unique in terms of terrain and weather conditions and that the methods outlined in these national research projects may require adjustment to fit Washington's particular needs. To continue to improve upon the safety performance of the network, WSDOT identified a possible benefit from the development of a tool to select cost-effective countermeasures towards the reduction of fatal and injury collisions on two-lane rural state highways. WSDOT believes that this tool allows for the assimilation of research results to better address Washington State's specific needs.

PROJECT OBJECTIVES

The objective of this study is to develop cost effective and focused approaches to highway safety on two-lane rural highways, by:

- Assessing and identifying the safety characteristics and trends for two-lane rural state highways through a data analysis that, where appropriate, distinguishes between roadway and behavioral factors,
- identifying solutions to the safety concerns with an emphasis on lower-cost and effective solutions, and
- developing a decision-matrix that will allow for the selection of countermeasures based on different collision types and with a primary focus on providing the greatest benefit for safety investments on the two-lane rural road network.

SCOPE OF THE STUDY

The study included a detailed analysis of the safety characteristics and trends on WSDOT two-lane rural highways, and the development of a framework that identifies the major focus areas for cost-effective safety investments. This process was supported by a comprehensive literature review. The research also presents a proposed decision-matrix for the selection of cost-effective countermeasures for two-lane rural highways in Washington. As a general assessment of countermeasure selection, the study includes a naïve (simple) before-after analysis of a limited set of centerline rumble strip installations on segments of two-lane rural highways in Washington State during 2002.

The study is limited to two-lane rural highways on the state route network. Current dataset formats and descriptions do not allow for the complete identification of two-lane rural county owned roads and corresponding collisions. Projects such as the Washington Transportation Framework Project (WA-Trans) may facilitate such efforts in the future.

ORGANIZATION OF THE REPORT

The project report is divided into seven chapters, a bibliography, and three appendices:

- Chapter 1 presents an introduction and background for the study.
- Chapter 2 provides background on previous research related to countermeasures on two-lane rural highways.
- Chapter 3 presents the empirical setting for the systematic analysis of two-lane rural highways that formed part of the project.
- Chapter 4 provides results from the systematic assessment. Also included in the report is the introduction and evaluation of a new approach to identify different types of two-lane rural highways, termed context.
- Chapter 5 contains a discussion of the process followed during development of the decision-matrix for two-lane rural highway countermeasures.
- Chapter 6 covers the results from a limited before-after evaluation of a selected group of centerline rumble strip installations on two-lane rural highways on the Washington state route network.
- Chapter 7 provides conclusions and recommendations for the project.
- Appendix A contains the proposed decision matrix. It include (i) Part A: a summary of major collision types on two-lane rural highways and contexts that were identified in the systematic analysis, (ii) Part B: a master list of collision types, collision groups, and

countermeasure groups, and (iii) Part C, tables with countermeasures, the corresponding target collision types (or conditions) and expected results.

- Appendix B contains a bibliography of the literature review that was completed in the course of this project.
- Appendix C presents the safety performance functions for the centerline rumble strip analysis.

CHAPTER 2 PREVIOUS RESEARCH

The purpose of this chapter is to provide a discussion of previous work and relevant documents in the area of the estimation and application of crash reduction factors (CRFs) and the selection of countermeasures. The discussion contained in this chapter does not include specific countermeasures. Results from the literature review of the different countermeasures are included in Part C of the proposed decision-matrix (included in Appendix A).

INTRODUCTION

The focus of the literature review was on literature that could support the development of a decision-matrix for countermeasures for two-lane rural highways.

Literature on countermeasures for two-lane rural highways and the effectiveness thereof is extensive and is of varying quality. The research team reviewed over 200 research reports and papers related to the selection process of countermeasures, the effectiveness of countermeasures, and guidelines for the application of countermeasures. Appendix B contains a list of the sources that were included in the review process.

CRASH REDUCTION FACTORS AND ACCIDENT MODIFICATION FACTORS

The purpose of this subsection is to give an overview of crash reduction factors (CRFs), and aspects relevant to the development and use of CRFs.

Defining Crash Reduction Factors (CRFs) and Accident Modification Factors (AMFs)

A crash reduction factor refers to the percentage change attributed to the implementation of a particular countermeasure or a combination of countermeasures. Accident modification factors (AMFs) on the other hand, refers to the factor applied to collision counts to calculate the expected collision count after implementation of countermeasure(s). For example, a particular measure may be expected on average to reduce fatal and disabling injury severity collisions by 20%. The CRF would be 20% and the AMF would be 0.80 (1-20%). In other words, an AMF can be expressed as AMF = 1 – CRF.

A Discussion of Issues Relevant to Crash Reduction Factors

This subsection provides a discussion of relevant issues when applying CRFs.

The Impact of Assumptions in the Calculation of CRFs. Assumptions made during the countermeasure evaluation process can influence results. For example, selection criteria for before and after periods may be different and therefore affect the number of observations included in the analysis. Some studies may or may not account for differences in weather or land use changes and the inclusion or exclusion could have had significant impact to the study results.

Isolating the Impact of a Particular Countermeasure. In some studies, the installation of countermeasures takes place in combination with other changes to the road environment. This makes it difficult to isolate the safety effect of one particular measure compared to the contribution of the other changes that took place. For example, an improvement project may install rumble strips and widen shoulders during a safety project. The combination of these improvements does not allow for the isolation of the safety benefit of the shoulder widening from the safety benefit achieved by the rumble strip installation. Measures other than engineering-related-changes, such as enforcement or awareness campaigns may change driver behavior (even if the impact is just temporarily) and influence the measured difference.

Other Changes to the Road Environment. Data collected during installation of countermeasures may not reflect other changes to the road environment shortly before, during or after installation. This would include undocumented modifications to the countermeasure, such as added delineation or signage done as a normal part of maintenance for a section.

Transferability of Results between Regions and States. State-by-state differences such as reporting thresholds can affect the magnitude of CRFs (lower reporting thresholds would result in higher reported collision frequencies and higher likelihood of larger observed reductions) (Bonneson and Lord 2005, 2). This also applies to the use of results from other regions such as European countries where driver behavior or response to measures may or may not be different.

Change Resulting From a Measure across Collision Types. The effect of countermeasures across different collision types may not be uniform (installation of a traffic signal are likely to reduce right-angled collisions but tend to increase the incidence of rear-end collisions) (Bonneson and Lord 2005, 5).

Studies of the Same Countermeasure May Generate Different Results. Results from countermeasure evaluation may appear to be contradictory, due to outside influences, limiting the usability of results.

The Importance of Context. The context in which countermeasures are applied may affect results and influence the choice of appropriate countermeasures. For example, the use of speed humps are appropriate for low-speed urbanized environments but not for high-speed rural environments.

Crash Reduction Factors May be Applicable to Severity Rather than Frequency. During the selection of appropriate countermeasures, collision severity may be the focus rather than collision reduction, resulting in measures that increase frequency and reduce severity for particular locations, for example, cable median barriers.

The Effect of a Countermeasure May Vary (Even Within Jurisdictions). Variability of the effect of a countermeasure may be significant, even within a jurisdiction. For example, during the evaluation of red-light running camera installations Washington and Shin (2005 122) found that variability of safety benefits of these installations within jurisdictions in the same state were significant.

Sample Sizes and Statistical Significance. Small sample sizes (i.e. low observed collision frequencies) can limit the ability to determine statistically significant results. The empirical Bayes (EB) methodology is generally regarded as a more appropriate statistical methodology compared to traditional simple before-after analysis when one considers correction for the regression-to-the-mean effect. The EB methodology requires a minimum level of observed collisions to measure statistical significant differences, and therefore may limit the ability of the scientist to measure the effect on particular collision types or more severe collision categories. For this reason, alternative before-after methodologies are still used. Note that the absence of a statistically significant CRF does not imply that a particular measure would not improve safety.

The Data Needs for Safety Prediction Model Development. The calculation of CRFs requires the use of safety prediction models that require significant data resources to obtain desired predictive capability.

A Crash Reduction Factor Does Not Represent An Absolute Change. CRFs represent the likely average expected safety benefit of a measure and may vary from site to site and between different contexts.

Concerns Regarding Meta-Analysis Results. In a meta-analysis, results from a number of different research efforts for a particular countermeasure are combined. If the site conditions, measurement criteria, and assumptions during the different evaluation processes are not consistent across the different studies, the CRF may not reflect the average expected effect of a particular measure at a group of similar sites. There are several other concerns regarding meta-analysis that are well documented (Rosenthal and DiMatteo 2001).

There are also other less obvious items for consideration when using CRFs. In NCHRP Research Results Digest 299, the authors point out that collision migration may occur because of a particular measure, however this is rarely considered in the development and provision of AMFs. The authors note that the quality of material that is available for the development of AMFs varies. They also comment that publication bias (publishing only when results indicated that a particular measure is beneficial) and selective reporting of results (reporting only the positive effects of a particular measure without referencing adverse effects) can affect the development of AMFs that would adequately reflect the average expected effect of a particular countermeasure (Harkey, et al. 2005).

The evaluation of countermeasures and the development of CRFs are therefore complex and consideration of the abovementioned should form part of responsible use of compendiums of countermeasures.

Compendiums of Countermeasures for Two-Lane Rural Roads

There are various compendiums of countermeasures available. These compendiums take various different forms. The following list represents the different kinds of countermeasure compendiums that were found and reviewed:

- A list of countermeasures with corresponding CRFs without distinguishing between facility types or particular applications or results from different sources (Ohio Department of Transportation 1997).
- A list of countermeasures with corresponding CRFs along with a few references to particular application conditions but without reference to specific sources of the results (Illinois Department of Transportation 2006)
- A list of countermeasures with references of the source of the results but without discussion of individual countermeasures (North Carolina Department of Transportation 2007)
- A compendium of countermeasures that includes reference to particular sources, discussion of countermeasures, and references in some cases to specific roadway types such as two-lane rural highways (Monsere, et al. 2006)
- A compendium of countermeasures for a particular roadway type (such as two-lane rural highways) that includes references to specific source materials and discussions of countermeasures (Dixon 1997).

Countermeasure compendiums can also be part of a larger document. For example:

- A document with safety tools, such as the *Toolbox of Highway Safety Strategies* (Iowa Highway Safety Management System 2001). This toolbox also includes materials pertaining to behavioral measures and provides discussion of other tools for safety (such as road safety audits).
- A set of guidebooks for safety, for example, the NCHRP 500 series that provides different volumes for different safety challenges, such as run-off-the-road collisions (Neuman, et al. 2003).

When using or referencing these compendiums there are also other aspects to consider. The values provided in the documents do not necessarily represent values from individual research projects. The recently released Desktop Reference for Crash Reduction Factors (Bahar, et al. 2007) and documents from NCHRP projects 17-27 and 17-29 are examples of documents that present results that represent values from individual studies, values from meta-analysis (combination of various research results into one single result), and values estimated by expert panels. For these documents, the researchers also developed and used their own criteria to determine which studies to include in the document.

COUNTERMEASURE SELECTION APPROACHES AND METHODOLOGIES

The implementation process for countermeasures usually consists of the following components:

- Identifying particular sites with safety needs.
- Investigation of each location.
- Assessment of expected benefit-cost ratio
- Implementation of projects or individual countermeasures.

- Identifying particular sites with safety needs.

Identification of sites is the first step in countermeasure selection. These lists are policy based and can focus on frequency, severity or collision type. Priority lists may take the form of system wide, corridor or spot location analyses. Having identified sites each location is investigated to determine possible countermeasures. This step can be quite detailed or merely consist of a brief site visit or review of site photographs and collision history. Evaluating countermeasures for the benefits to cost ratio (b/c) is the next step. The priority lists use a ranking from highest to lowest b/c. The use of CRFs is common at this part of the process since future potential benefits must be determined over the countermeasure life. Implementation of the project or countermeasures is the final step.

Ideally, countermeasure implementation is followed by a continued evaluation of the safety performance at these particular locations (along with monitoring for other impacts such as operational efficiency etc.).

CHAPTER 3 EMPIRICAL SETTING FOR THE SYSTEMATIC ANALYSIS OF TWO-LANE RURAL HIGHWAYS IN WASHINGTON

EMPIRICAL SETTING FOR THE SYSTEMATIC ANALYSIS OF TWO-LANE RURAL HIGHWAYS

The purpose of this chapter is to provide information regarding the empirical setting for the systematic analysis of the two-lane rural highway network. This includes a discussion of the dataset and the methodology used for the assessment.

The Dataset

The systematic analysis used information from a comprehensive homogeneous segment dataset developed during previous research (van Schalkwyk). Segments located within a rural area (i.e. outside urban boundaries as defined by FHWA) with one through lane per direction were included in the systematic assessment.

The original homogeneous data were assembled using geoprocessing in ArcGIS 9.0 and dataset manipulation in the SAS 9.1 environment. The researchers used the ArmCalc module to combine data from different years. The ArmCalc module is necessary since highway milepost may change from year to year, thus requiring changes in the linear referencing system (LRS). The WSDOT Traffic Data Office (TDO) supplied the ArmCalc module. The data development process also accounted for modifications of the highway system over the analysis years. 1997 and 1998 were excluded because complete collision data are not available for these years. Data from 2006 was not included in the report because traffic volumes were not available at the time of completion of the project report. Annual averages were generally calculated for the 1999 to 2005 period. Table

1 provides the distribution of segment lengths in the homogeneous dataset for two-lane rural highways.

Table 1: Data Elements in Analysis Dataset

DATASET ELEMENTS	YEARS	SOURCE
Traffic volumes	1999 - 2005	WSDOT TDO TRIPS Dataset
Geometric features: horizontal curves, vertical curves, grades	1999 – 2005	WSDOT TDO TRIPS Dataset
Intersection locations and characteristics	1999 – 2005	WSDOT TDO TRIPS Dataset
Lane configuration (lane width, shoulder width, special use lanes, auxiliary lanes)	1999 - 2005	WSDOT TDO TRIPS Dataset
Motor vehicle collision data	1993-1996, 1999 - 2005	WSDOT TDO TRIPS Dataset
Washington State Route Network for 2005-12-31	2005	WSDOT GIS layers as developed and maintained by the Office of Information Technology at WSDOT (http://www.wsdot.wa.gov/mapsdata/geodatacatalog/default.htm).
Urban boundaries	1999 - 2005	
Pavement characteristics	1999 – 2005	The WSDOT Pavement Management System (WSPMS) that contains pavement specific data
Annual weather characteristics	1993-1996, 1999 - 2005	Daily weather data from NOAA, providing information regarding rainfall, snow, and observed weather.
Socio-demographic characteristics	2000 and, 2006	US Census data for 2000 by block group, using data from both the Summary File 1 and 3 datasets (US Census 2000)
K12 school locations	2005	Office of Superintendent of Public Instruction in Washington.(2005)
Locations with liquor licenses	2006	Washington State Liquor Control Board
Frequency of licensed drivers by age and zip code	2006	Washington State Department of Licensing (March 2006)

During the systematic assessment process, homogenous segments were not combined. The values used in the analysis represents measured values for each segment rather than average values calculated when combining segments.

Table 2: Distribution of Segment Lengths in Homogeneous Segment Dataset

Segment Length Category	Number of Segments in Category	Total Miles	Proportion of Mileage of Two-Lane Rural State Highways
0.01 mi	5367	53.67	1.1%
0.02 mi	4613	92.26	1.9%
0.03 mi	4218	126.54	2.6%
0.04 mi	3450	138	2.8%
0.05 - 0.1 mi	12734	903.47	18.4%
>0.1 - 1.00 mi	13524	3423.61	69.9%
>1.0 - 1.5 mi	156	156.77	3.2%
>1.5 - 2 mi	2	3.6	0.1%
>2.5 - 3 mi	1	2.64	0.1%

The WSDOT Transportation Data Office classification was used to distinguish between intersection and intersection-related, and segment (non-intersection) collisions. This action provides consistency and ease of use for WSDOT. In a memo to FHWA, Hughes, Nedzesky, and Council (1998) presented a criteria for the identification of intersection crashes:"(1) crashes must occur within 250 feet (76 meters) of the intersection center and (2) they must be (a) vehicle-pedestrian crashes; (b) crashes in which one vehicle involved in the collision is making a left turn, right turn, or U-turn prior to the collision; or (c) multiple-vehicle crashes in which the accident type is either sideswipe, rear end, or broadside/angle." This 250-ft radius methodology was tested during the initial evaluation process during the research for this report. The use of the 250-ft methodology increased the proportion of intersection and intersection-related collisions significantly and this increase could not be substantiated scientifically.

Assumptions Made During Dataset Development Process

Researchers and safety professionals understand that various assumptions are made during the development of datasets. The following represents the most significant and relevant assumptions during the dataset development process:

- Any change in alignment (such as horizontal curves, lane and shoulder width), volume, or special feature (such as census block group boundaries) constitute a segment break.
- Intersections with public roadways constitute segment breaks.
- Traffic volumes are not available for all locations and measured volumes are transferred to the closest segment in a downstream direction (this is consistent with the approach followed by the WSDOT Transportation Data Office).
- Collisions occurring at the end of one segment and the start of the adjacent segment are assigned to the beginning milepost of segments (this is consistent with methodologies used by other research teams (e.g. the Highway Safety Information System).
- Where area-specific information, such as socio-demographics from the US Census are assigned to segments, homogeneity of the block group characteristics is assumed.
- The beginning and ends of vertical curves do not constitute segment breaks.

Systematic Analysis Methodology

Rate based analysis were completed for various different aspects of two-lane rural highways. This included evaluating and applying contextual surrogates for the identification of different contexts of two-lane rural highways; evaluation of different terrain types and roadway features (such as horizontal curves, and different shoulder widths).

Where the discussion of results refers to segment collisions, it is referring to collisions that were not classified as intersection or intersection-related. In the investigation of crossover collisions, we used the WSDOT Transportation Data Office crossover algorithm.

The technical monitor also indicated that the use of a homogeneous segment dataset for analysis is preferred (rather than a fixed length segment dataset that reflects average values of a segment rather than measured values for a segment) and that the development of safety prediction models should not be the focus of the project.

CHAPTER 4 A SYSTEMATIC ASSESSMENT OF TWO-LANE RURAL HIGHWAYS IN WASHINGTON

INTRODUCTION

The study included a systematic safety assessment of two-lane rural state highways. This chapter describes the purpose of the assessment, introduces the concept of context for two-lane rural highways and then report select results.

PURPOSE OF THE SYSTEMATIC ASSESSMENT

The intent of the systematic analysis was to review trends, safety performance and the major collision types associated with this facility type. This approach allowed the research team to identify key areas with a high probability of success if system wide approaches were to be applied across the subject network. The overall objective was the reduction of fatal and disabling injury collisions rather than a reduction in overall collision frequency.

REDUCING SEVERE INJURY COLLISIONS VERSUS REDUCING OVERALL COLLISION FREQUENCY

The strategic highway safety plan for Washington State is contained in a document titled “Target Zero.” This plan identifies action strategies with the overall intent of reducing fatal and disabling injuries. In addressing fatal and disabling injuries, the frequency of fatal and disabling injury collisions is used as performance measure since the number of passengers in any one collision can vary randomly from location to location. The approach reduces variability in the frequency calculation and provides a better indicator of location and system performance. Washington State groups fatal and disabling injuries since it is believed that the difference between these higher level injuries types are often minor, or health related, and that the frequency of fatal collisions is too low at locations to provide significant data to draw conclusions from the information.

Another motivation for using fatal and disabling injury collision frequency as a measure rather than just collision frequency is the fact that collision frequency is often a poor estimator of fatal injury outcome. This is true because some collision types are less likely to result in fatalities than others. For example, a rear-end collision is more likely to result in property damage as opposed to head-on collisions where disabling or fatal injuries are of higher likelihood.

Given these facts, one can deduce that there is a relationship between certain collision types and injuries, and that part of a productive strategy could be to focus on reducing particular collision types with the highest severity propensity on two-lane rural highways.

THE CONTEXT OF TWO-LANE RURAL HIGHWAYS

The purpose of this section is to introduce the concept of contextual surrogates and context. The term "context" is used as a means to describe different types of rural two-lane highways. Contextual surrogates on the other hand, refers to ways (in this case through GIS) to distinguish between contexts. Besides the usefulness of distinguishing between contexts in terms of analysis, it also assists in the development of a countermeasure selection process aimed at reducing fatalities and injuries. For this reason, the evaluation and discussion of results for surrogates to differentiate between different contexts are also included as part of this section.

Background to Different Contexts of Two-Lane Rural Highways

When reviewing different types of highways, there are specific characteristics that may be associated with each highway type. For example, a freeway commonly represents a multilane highway with higher speed limits and full access control (access is limited to interchanges). However, when one reviews two-lane rural highways, speed limits are assigned based on 85^{th}

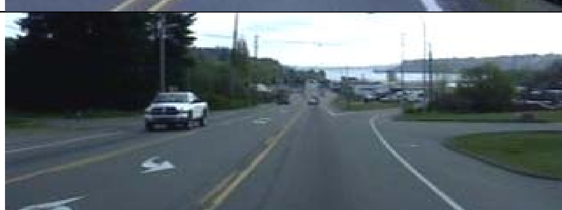
percentile speeds and the context of the corridor. Access control also varies based on context, access management requirements, roadside characteristics, design features (curvature etc.), and land use. In the countermeasure selection process, the inclusion of consideration of context may provide direction in terms of particular needs and the extent to which the treatment would be improving safety at the location, while existing knowledge from previous research activities, engineering judgment, and lessons learned through practical experience are used to supplement this information.

Table 3 shows six examples of two-lane rural road highways on state routes, using SRView images from the WSDOT Transportation Data Office. The six examples provide a simplistic representation of some of the typical differences found on two-lane rural highways.

These pictures underline the fact that there are common differences between these "contexts" that would not necessarily be distinguishable with the mere use of existing roadway related information within the TDO datasets. Such differences that may impact collision outcomes include:

- Cross sectional elements of the roadway: lane widths, median (passing, no-passing), presence of turning lanes
- Roadside characteristics: shoulder width, roadside cross-section, clear zone characteristics, roadside safety devices, presence of vegetation and/or trees
- Geometric characteristics: straight, horizontal curvature, vertical curvature, sight distance
- Posted speed and operating speed
- Adjacent land use and associated trip generation
- Parking provisions
- Access related

Table 3: Different Contexts for Two-Lane Rural Highways

ILLUSTRATION	DESCRIPTION
	SCENARIO 1: This two-lane rural highway is located in an area with agricultural land-use. The facility has no clear zone restrictions and relatively few accesses are provided.
	SCENARIO 2: This Scenario is much like Scenario 1 in terms of adjacent land use and clear zone. In this case, the geometry includes horizontal curves and access density is higher.
	SCENARIO 3: The two-lane rural highway shown here is also located in a rural area. It has a limited clear zone (narrow shoulder with a substantial sideslope). The segment also has sharp horizontal curves.
	SCENARIO 4: This two-lane rural highway is located in an area with some industrial development, a two way left turn lane is provided; and access points and intersections are located relatively closely together.
	SCENARIO 5: The land use adjacent to this two-lane rural highway is more characteristic of a rural town center. Notice the lack of shoulders, extent of access control, and parking.
	SCENARIO 6: This two-lane rural highway is also located in a more developed setting. However, in contrast with Scenario 5, the roadway has a shoulder and angled on-street parking.

  - Access management levels
  - Access design (varies from controlled access points or full access for strip development)
  - Density of driveways and intersections
- Provision for vulnerable road users (varying from none, to paved shoulders, to sidewalks and bicycle facilities)
- Terrain (level, mountainous, and rolling)
- Compatibility between driver expectation and road environment design, i.e. a driver on a high-speed facility (wide shoulders, agricultural land use) may not expect the presence of pedestrians crossing the facility
- Weather conditions
- Visibility conditions.

In terms of collision occurrence and injury outcome, several other factors may be of relevance. These include the quality and timeliness of emergency medical care (Evanco 1996); speed differentials on the facility (e.g. a segment on a two-lane rural road facility that travels through a small rural town where through traffic are traveling at higher speeds than the posted speed limit and local traffic are entering and exiting adjacent land use); vehicle incompatibility in collisions that can result in more severe injuries (Lund, et al. 2000); and driver characteristics (e.g. age, experience, fatigue, use of drugs and/or alcohol).

Apart from the differences in characteristics listed above, there are also transition areas, sections where rural two-lane roadways transition into more urbanized environments. These segments are often associated with higher collision rates and operating speeds in excess of the posted speed limit (TRB 2006).

The Need to Identify Different Contexts

The nature of two-lane rural highways across the state route network can differ substantially from location to location. There are differences in terms of environment (rural with no development, rural with some development, segments in a small rural town center (includes commercial development)) and roadway features (such as roadway widths, shoulder characteristics, and the roadside).

Because of these differences, the safety characteristics can vary across these differences. For example, some collision types can be more prevalent or collision severity can be different. This implies that sites would have different safety needs.

During the countermeasure selection process, a number of possible countermeasures are identified based on a) the safety characteristics of the site or set of sites with a particular safety need, and b) appropriateness in terms of environment (as part of context). For example, the particular need may be parking related collisions for segments located in small rural town centers. Therefore, the measures that one might consider in areas with parking would include measures associated with developed environments rather than the rural environments with no commercial development since these measures trend towards lower speed environments.

This site-specific selection process highlights the importance of context. Context defined here not only refers to the difference in environments, but also refers to the particular roadway features associated with the segment: such as transition areas (discussed in a later section), segments in different terrain, segments in rural town centers, etc.

This section offers the hypothesis that the analysis of two-lane rural roads with particular attention to different context, could offer further insight in the nature of relationships of features and the environment of a particular highway. Attention to this concept of context could assist with the identification of focus areas for safety investment on two-lane rural highways.

The following sections cover discussions regarding transition areas, segments in rural town centers, and closing comments regarding the ongoing roadside data collection process by WSDOT on state highways.

Context of Transition Areas

Challenges often arise on two-lane rural highways when these facilities transition from rural environments into more developed areas. These more urbanized areas can range from the town center of a small rural town to urbanized areas with populations greater than 5,000. The transition is the portion over which the context of a segment changes from a higher speed rural environment into a lower speed and more developed environment.

When traffic transition from higher speed rural environments into more developed areas, speed limits and visual features in the road environment assist the driver in making appropriate speed reductions across the transition area. These transition segments are often characterized by changes in land-use, increase in access densities and the introduction of more developed features such on-street parking and pedestrian facilities. Instead of primarily providing for mobility, the role of the facility changes to a larger focus on accessibility. The frequency of turning movements to and from facilities along these segments is also higher as demonstrated in Scenarios 4 to 6 in Table 3.

These 'transition areas' often experience operating speeds well above the posted speed limits (TRB 2006) and changes in the design standards across a relatively short distance. In some locations, this may result in an increased potential for collisions. Apart from being the topic of a recent TRB Research Needs Statement (TRB 2006), The Oregon Department of Transportation is also evaluating methods to reduce speeds in these transition areas: "Transitions from Rural to Urban Areas on State Highways" (TRB 2004).

Given the challenge that these segments pose, it is beneficial to quantify transition segment boundaries. This allows the practitioner to identify these areas systematically. The result of which allow for the application of systematic or site-specific countermeasures.

This project used different levels of proximity to urban boundaries as a surrogate for transition areas. Although, one should take note, that data limitations only allow for the identification of transitions into urban areas with a population of 5,000 or more and not small rural town centers. Results for the evaluation of this surrogate measure are included in the results from the systematic assessment.

Consideration of Land Use in Defining Context

Although recent efforts by Ivan et al (2007) showed limited results in collision prediction based on land use and trip generation information, there remains a consensus that land use information may assist in identifying relationships between location features and safety outcomes. In other words, land use information could provide a tool to identify different contexts.

Up to date and detailed level information for land use for the entire WA state is not currently available in GIS. Land use information in GIS can also be challenging in that the representation may represent approved land-use and may not be indicative of the actual use.

Without land use information it would be particularly challenging to distinguish a segment that is serving a rural town center from those connecting two small rural towns. By using surrogates (i.e. indirect measures) for identifying regions with development, these differences can be incorporated into the analysis.

In the search for surrogates of development, it was hypothesized that there are state-maintained datasets that could be of assistance in identifying more developed areas (such as those associated with small rural towns). For example, the locations of schools and establishments with liquor licenses are available to WSDOT. It is plausible that the presence of these locations could provide a surrogate measure for identifying more developed regions with higher associated trip generation and exposure. GIS technology would allow for the identification of segments in close proximity to these locations.

Note that collision characteristics in close proximity of particular land use do not necessarily reflect the safety-related characteristics for the particular development or location type (i.e. the land use is not the cause of the collision occurrences). Yet, these characteristics may be indicative of increased exposure and risk resulting from increased trip generation by retail development or elements of more developed contexts. In other words, the presence of schools and establishments with liquor licenses would only be indicative of the presence of other retail developments or town centers in close proximity.

The Use of Roadside Features to Define Context

Roadside features and characteristics also provide information regarding the context of a facility. For example, in reviewing Table 3, Scenario 1 differs substantially from Scenarios 2 and 3 in terms of roadside characteristics. Clear zone widths for Scenarios 2 and 3 are narrower than those shown in Scenario 1.

In mountainous terrain and in more developed environments clear zone widths are often restricted. When a vehicle runs off the road in each of these scenarios, it is possible that the occupants will sustain different levels of injury. The outcome depends on the speed of the vehicle along with proximity and nature of fixed objects, and recovery areas that are available alongside the roadway.

WSDOT started a roadside features data collection project during 2005. Estimates indicate that during the 05-07 biennium this project collected 897 miles of roadside feature information on two-lane rural roads and this will increase to a total of 1,309 miles by the end of 2007 (WSDOT

2007b). Because this data is not yet readily available, the presence and nature of roadside features were not incorporated into this project. Future analysis is likely to benefit greatly by incorporation of this information.

The nature of particular roadside features alongside a particular roadway is likely to affect the outcome and severity of run-off-the-road collisions. This is of particular importance to two-lane rural highways when one considers the high frequency of run-off-the road collisions.

RESULTS OF THE SYSTEMATIC ASSESSMENT

The remainder of the chapter presents results of the systematic assessment of the two-lane rural highway system. It includes assessment of involvement of different road users, regional distribution of fatalities and injuries, behavioral factors, differences by time of day and day of week, collision types, and different contexts. The chapter concludes with a set of findings from the systematic assessment.

THE EXTENT OF THE TWO-LANE RURAL HIGHWAY NETWORK

There are approximately 4,900 miles of two-lane rural highways on the Washington state route network (2006 road network). Two-lane rural highways represent 70% of the state network mileage and 53.5% of the total lane miles on the state network. During 2005, approximately 5.53 billion vehicle miles were recorded on these highways, accounting for 48.4% of rural vehicle miles traveled (VMT) and 17.3% of total state route VMT for the year. Between 1999 and 2005 an average of 42.8% of the fatal severity collisions reported on state highways occurred on two-lane rural highways.

THE SAFETY OF TWO-LANE RURAL ROAD NETWORK COMPARED TO THE REST OF THE STATE ROUTE NETWORK

During the period from 1999 to 2005, 14.4% of the collisions reported on state highways occurred on two-lane rural highways. The most significant difference between collisions on the rural two-lane highways and the rest of the network is that collisions on two-lane rural highways tend to be more serious. The collision type distributions are also different. This subsection describes some of the observed differences in safety characteristics.

Collision Severity

Figure 3 to Figure 6 show the frequencies and proportional distribution collision severities for two-lane rural highways when comparing it to the rest of the state route network. Three different cases are presented: a) all collision types, b) collisions on segments, and c) intersection and intersection-related collisions.

For 1999 to 2005, 1.7% of collisions occurring on two-lane rural highways resulted in fatal injury severity collisions compared to 0.4% on the rest of the network. In addition, 4.4% of collisions occurring on two-lane rural highways resulted in disabling injury severity collisions compared to 1.6% on the rest of the network; and 18.8% of collisions occurring on two-lane rural highways resulted in evident injury severity compared to 9.9% on the rest of the state highway network.

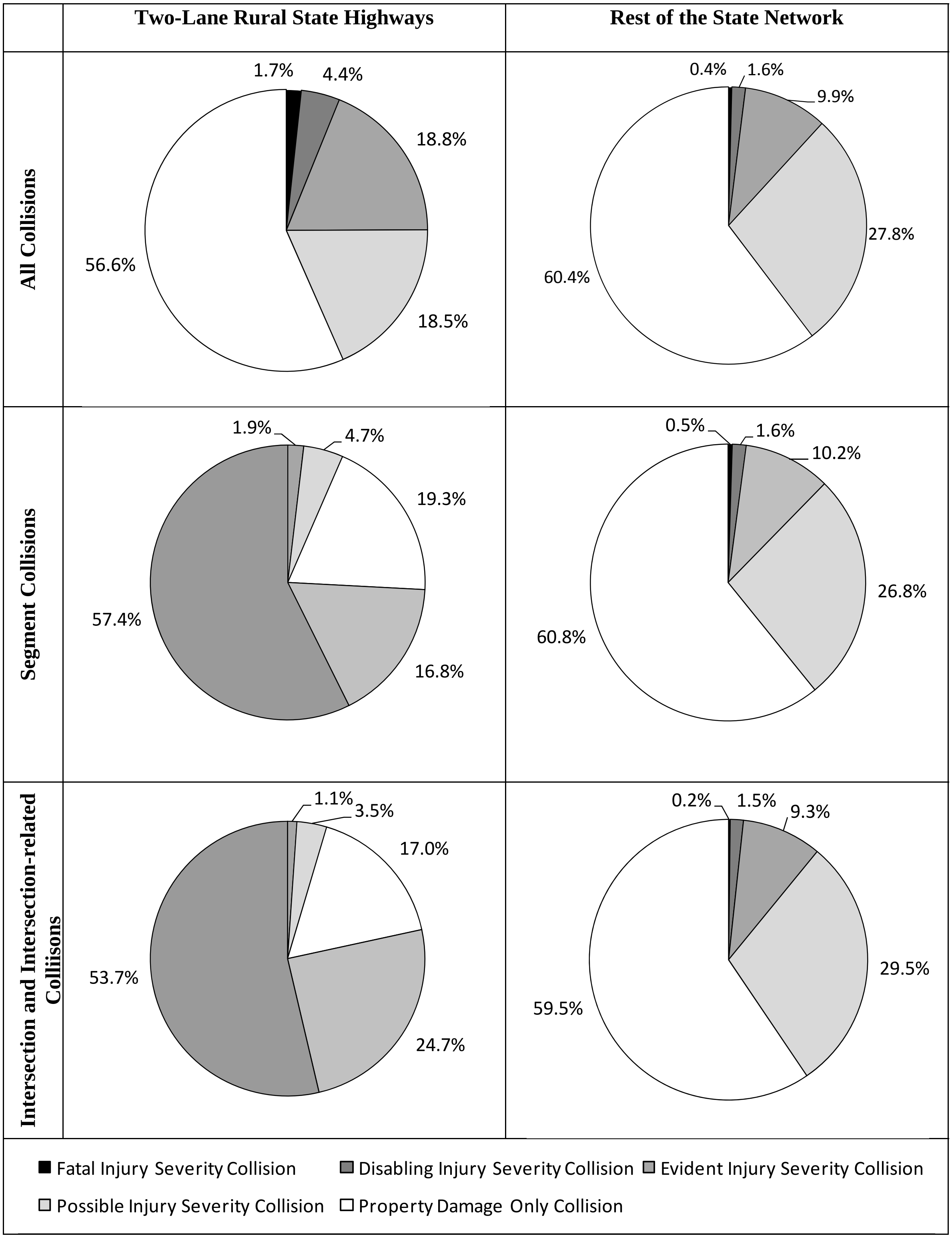


Figure 3: Collision Severity Distribution for Two-Lane State Maintained Rural Highways and the Rest of the State Route Network for a) All Collisions, b) Segment Collisions and c) Intersection and Intersection-Related Collisions (annual averages for 1999 – 2005)

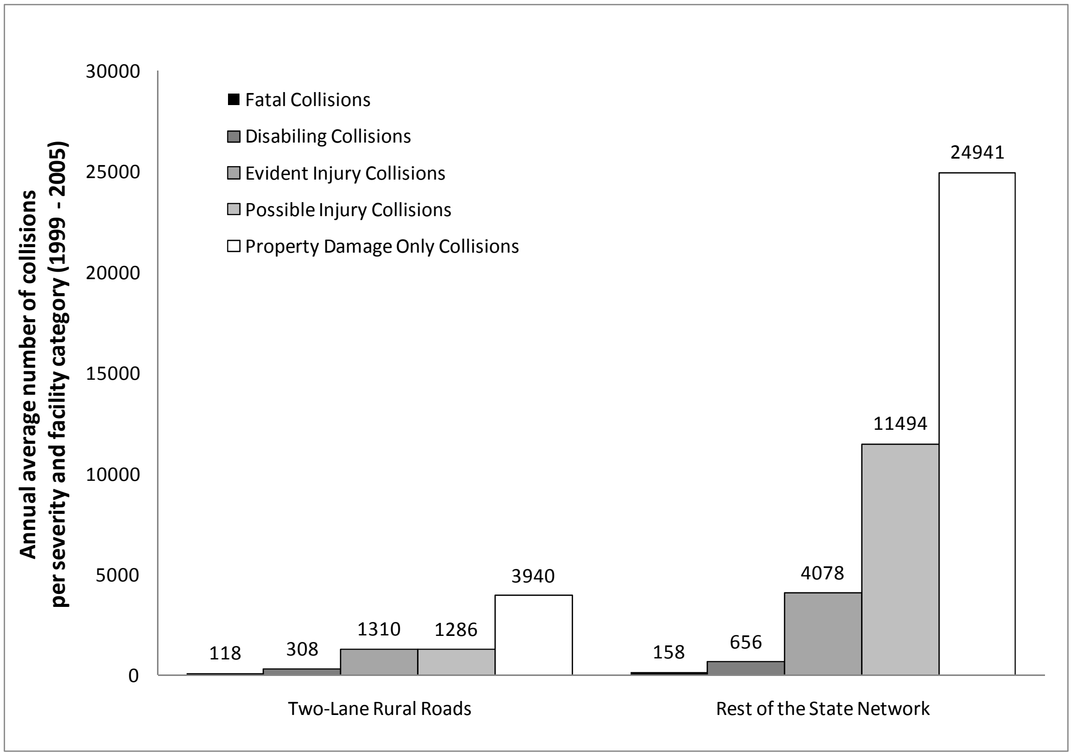


Figure 4: Collision Severity Distribution Comparison between Two-lane Rural Highways and the Rest of the State Route Network (1999 – 2005 annual averages)

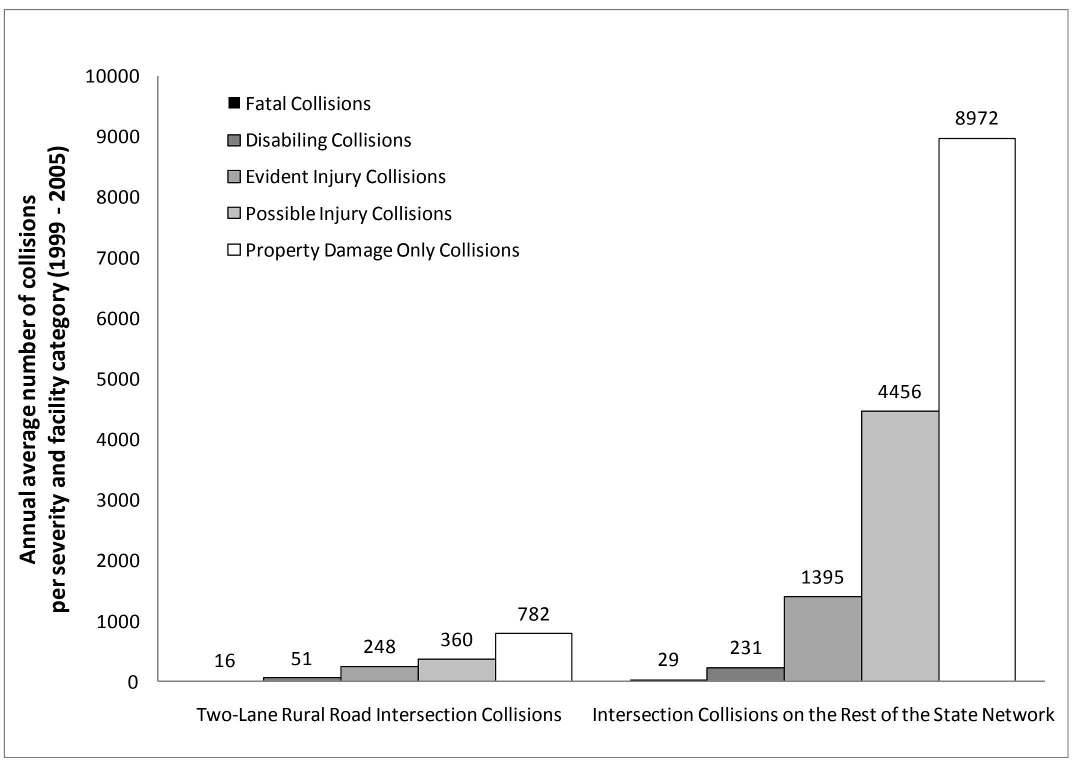


Figure 5: Collision Severity Distribution Comparison for Segments on Two-lane Rural Highways and Segments on the Rest of the State Route Network (1999 – 2005 annual averages)

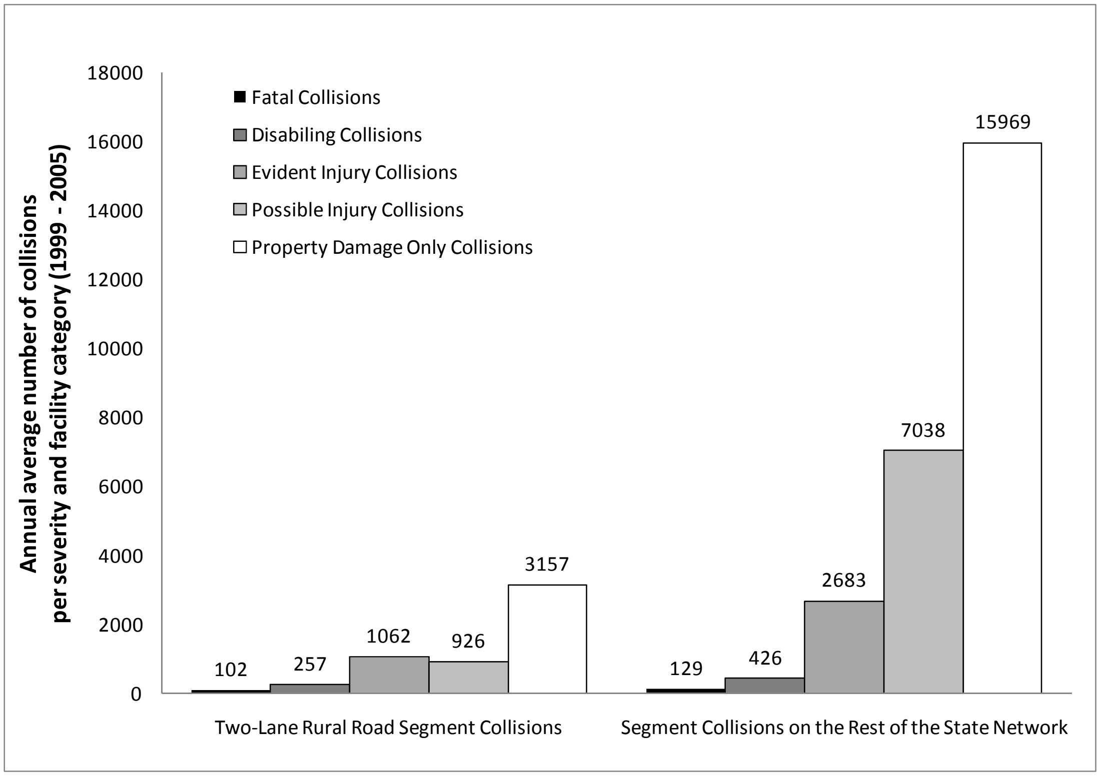


Figure 6: Collision Severity Distribution Comparison for Intersections on Two-lane Rural Highways and Intersections on the Rest of the State Route Network (1999 – 2005 annual averages)

<u>Collision Type Comparisons</u>

This subsection highlights the difference in the observed distribution of collision types on two-lane rural highways and shows how it differs from the rest of the network.

Roadside-related Collisions

Two-lane rural highways experience higher proportions of roadside-related collisions and these collisions are generally associated with higher severity outcomes. For example (1999 – 2005 annual averages):

- In 33.3% of collisions on rural two-lane rural highways one or more vehicles struck a fixed object compared to a proportion of 15.8% on the rest of the network.

- Larger proportions of collisions involved an impact on the right shoulder: 8.62% for two-lane highways, compared to 4.1 % on the rest of the network.
- The proportion of collisions that involved an impact off road and beyond the right shoulder is also higher: 35.2% on the rural two-lane road highways compared to 4.8% on the rest of the network.

Collisions Involving Centerline Crossovers

Because injuries are often severe in collisions involving centerline crossovers, this collision type is of particular concern when reviewing the safety of two-lane rural highways. Two-lane rural highways usually have centerlines rather than medians and passing maneuvers generally require vehicles to enter opposing lanes. Excess speeds, driving under the influence, or fatigue may therefore also influence the likelihood of collisions.

Two-lane rural highways experience a larger proportion of crossover collisions: 6.2% compared to 0.7% on the rest of the network (annual averages for 1999 to 2005). Two-lane rural highways also experience much higher proportions of head-on collisions than the rest of the state network: 1.2% versus 0.4%. The proportion of collisions involving U-turns are also higher: 1.7% on two-lane rural highways compared to 0.6% on the rest of the network. Even though these values are low, these collisions closely relate to access management along a segment and can result in quite severe collisions.

Involvement of Different Road Users

Although it is surmised that the vehicular types using the different highway facilities are similar (although distributions may differ), observations indicate differences in terms of involvement of vulnerable road users and behavioral aspects that can contribute to collisions. These include (annual averages for 1999 to 2005):

- The proportion of collisions involving drugs and/or alcohol is almost double on rural two-lane highways (10%) compared those on the rest of the network (5.8%).
- Fatigue appeared to play a larger role in collisions on rural two-lane highways: it was a contributing factor in 6.% of rural two-lane road collisions compared to 1.8% on the rest of the network. Note that fatigue is self-reported or reported based on observations by officers (i.e. drivers are not tested) and therefore statistics may not represent the true overall impact of fatigue on collisions.

Although the levels of involvement of motorcyclists on state highways remain relatively low compared to other vehicle types, the proportion crashes involving motorcyclists steadily increased since 2002.

On two-lane rural highways, their involvement in collisions increased from almost zero in 2001 to 2.58% in 2002 and 3.4% in 2005. This increasing trend was also observed for the rest of the state highways: from almost zero in 2001 to 1.14% in 2002 and 1.69% in 2005. The increased proportion of involvement of motorcycles in collisions may be the result of a) higher levels of exposure (i.e., motorcyclists may travel more on two-lane rural highways than on the rest of the network); or b) motorcyclist overdrive the design of the facility; or c) the tendency of motorcyclists to take additional risks given the lower levels of traffic and enforcement. Over the last few years, there have been substantial changes in motorcycle registrations and amount of travel. From 2002 to 2005 motorcycle vehicle miles in the USA increased from an estimated 9.6

billion to 10.8 billion (an increase of 11.3%) while vehicle registrations increased nationally by 27.7% (Bureau of Transportation Statistics 2007). There was also an increase in national fatal collision involvement from 35.23 per 100 million VMT in 2002 to 43.22 in 2005 (NHTSA: FARS 2007). When reviewing incidence of motorcycle collisions on two-lane rural highways it is necessary to consider the nationwide systematic increase in exposure and collision involvement.

Differences in Access Related Collisions

Access management levels differ substantially between two-lane rural highways and the rest of the network. For example, a two-lane rural highway traveling through a rural town center may have no access control while freeways have full access control. 8.8% of collisions occurring on two-lane rural highways take place at driveways or is driveway-related compared to 6.3% on the rest of the network (annual averages for 1999 to 2005).

Parking Related Collisions

Because of the presence of two-lane rural roads in rural town centers, the proportion of parking related collisions is also higher on two-lane rural roads: 0.5% compared to 0.02% on the rest of the network.

The higher proportion of parking; driveway and driveway-related collisions; and U-turn collisions may be indicative of the lower levels of access management on some sections of rural two-lane highways and the provision of parking in more developed environments (populations less than 5,000).

COLLISION CHARACTERISTICS OF THE TWO-LANE RURAL ROAD NETWORK

The purpose of this subsection is to provide basic safety characteristics and trends of collisions on two-lane rural highways.

Collision Rates

Table 4 summarizes the collision frequencies and rates for two-lane rural state highways in Washington.

Table 4: Collision Rates for Two-Lane Rural Highways in the Washington State Route System

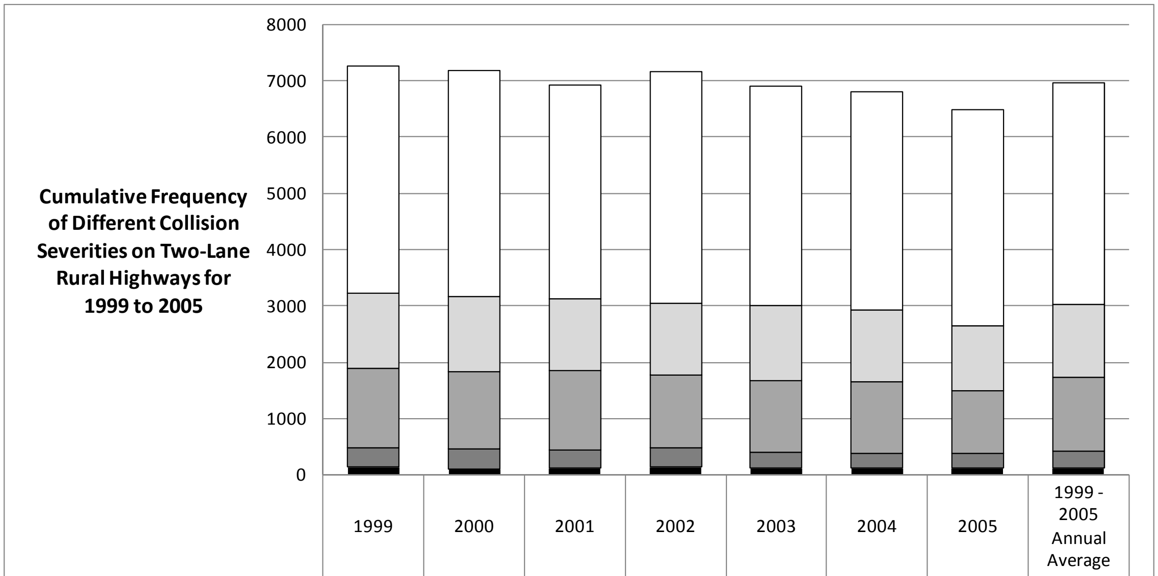
Total Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Injury Collisions per 100 million VMT (1999-2005)	Fatal and Disabling Injury Collisions per 100 million VMT (1999-2005)	Collision Frequency per 100 million VMT (1999-2005)
2005					
6494	111	372	2.00	6.73	117.50
1999 - 2005					
48738	828	2986	2.18	7.86	128.25

Collision Severity Distribution

Figure 7 shows the collision severity frequencies from 1999 to 2005 on two-lane rural road highways. Although overall collision frequency has dropped over time, the frequencies of fatal and disabling collisions remained relatively constant over the seven-year period.

Collision Types on Two-Lane Rural Highways

Having seen the distribution of collision severity, the next step in the development of a decision matrix is the review of collision types to identify areas with higher associated rates (possible priority areas). The subsection first provides overall collision type distributions and the second part discusses the characteristics of specific collision types.



	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
Property Damage Only Collisions	4032	4011	3794	4118	3909	3874	3841	3940
Possible Injury Collisions	1349	1349	1270	1272	1319	1286	1158	1286
Evident Injury Collisions	1411	1369	1420	1304	1281	1262	1123	1310
Disabling Collisions	342	344	324	324	288	275	261	308
Fatal Collisions	131	109	113	144	110	110	111	118

Figure 7: Frequency of Different Levels of Collision Severity on Rural Two-Lane State Roadways for 1999 – 2005

For the purpose of this analysis, several different groupings were included in the assessment:

- Washington State Patrol (WSP) collision types.
- Intersection or intersection-related and segment collisions.
- Single, and multiple vehicle collisions.
- Vehicle types involved in the collisions (e.g. collisions involving heavy vehicles).
- Different groups of vulnerable users involved in the collisions (e.g. pedestrians, bicyclists, older drivers).
- Different impact locations.
- Different contributing factors.

Table 5 lists the major WSP collision types observed on two-lane rural highways using the number of fatal and disabling injury collisions as prioritization criteria. The tables also provide the overall collision frequency for each collision type. It is evident from the table that priorities in terms of reducing fatal and disabling injury severity collisions may, in some cases, be different from priorities set towards reducing overall collision frequency. The table includes the collision types with the top 99% proportion of fatal and disabling injury collision frequency and overall collision frequency. Because of the relatively low annual frequencies of some collision types, the team presents the 7-year totals.

Run-Off-the-Road Collisions

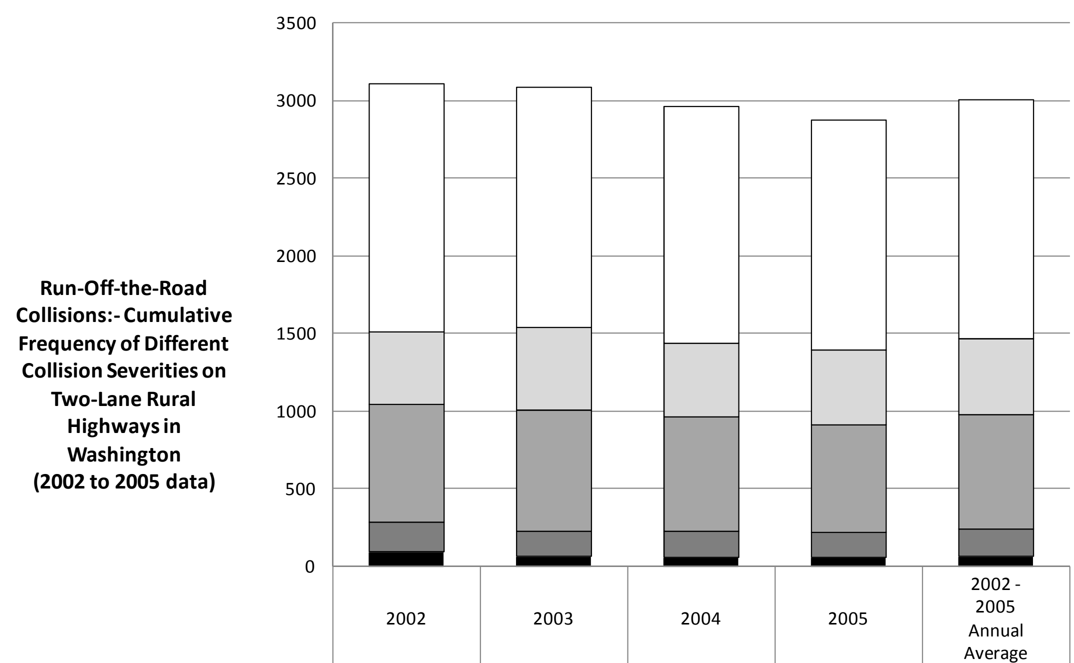
The term run-off-the-road collision refers to any collision in which the vehicle(s) left the roadway. Typically, this collision type represents a segment collision involving single vehicles. These collisions are often more severe and outcomes depend largely on available recovery distance along the roadway, fixed objects within the clear zone, and roadside safety features. It is recognized that human factors and passenger kinematics from failure to use restraint systems can also dramatically influence collision outcomes.

Run-off-the-road collisions represents 43.9% of the two-lane rural highway collisions, 58.5% of fatal and disabling injury collisions, and 56.6% of fatal injury collisions on two-lane rural highways (annual averages for 2002 to 2005). Annual averages are only shown for 2002 to 2005 because WSDOT TDO only started identifying collisions as being run-off-the-road in 2002.

Figure 8 shows the collision severity distribution for run-off-the-road collisions for the years 2002 to 2005. Although the more minor injury categories remained relatively stable, slight reductions in fatal, disabling and evident injury frequency have occurred since 2002.

Table 5: Major Collision Type Ranking Based on Frequency of Fatal and Disabling Injury Collision Frequency for 1999 – 2005 (also showing overall collision frequency for each type)

WSP Collision Type 1	Frequency of Fatal and Disabling Injury Collisions	Collision Frequency	Segment Collision Frequency	Intersection and Intersection-Related Frequency	Portion of Fatal and Disabling Injury Collisions	Portion of Total Collision Frequency
Hits Fixed Object	1019	17086	16000	1086	30.3%	30.9%
Vehicle Overturns	592	7240	6972	268	17.6%	13.1%
From Opposite Direction, Both Moving, Head-On	342	673	635	38	10.2%	1.2%
From Opposite Direction, All Others	244	1269	1182	87	7.3%	2.3%
Entering at Angle	225	3536	55	3481	6.7%	6.4%
From Opposite Direction, Both Going Straight, Sideswipe	181	1292	1258	34	5.4%	2.3%
One Vehicle Entering/Leaving Driveway Access	139	3087	2809	278	4.5%	5.5%
From Same Direction, Both Going Straight, One Stopped, Rear end	123	5957	2884	3073	3.7%	10.8%
From Same Direction, Both Going Straight, Both Moving, Rear end	80	2836	2058	778	2.4%	5.1%
Vehicle Going Straight Hits Pedestrian	80	173	140	33	2.4%	0.3%
From Opposite Direction, One Turning Left, One Straight	70	876	28	848	2.1%	1.6%
Non Domestic Wildlife - Deer, Bear, Bird, etc.	52	5398	5384	14	1.5%	9.8%
From Same Direction, All Others	46	911	653	258	1.4%	1.6%
Bicycle	28	156	95	61	0.8%	0.3%
Hits Other Object	22	718	701	17	0.7%	1.3%
From Same Direction, One Turning Left, One Going Straight	20	623	77	546	0.6%	1.1%
All Other Non-Collision	20	508	470	38	0.6%	0.9%
From Same Direction, Both Going Straight, Both Moving, Sideswipe	15	666	556	110	0.4%	1.2%
One Vehicle Parked, One Moving	12	635	576	59	0.4%	1.1%

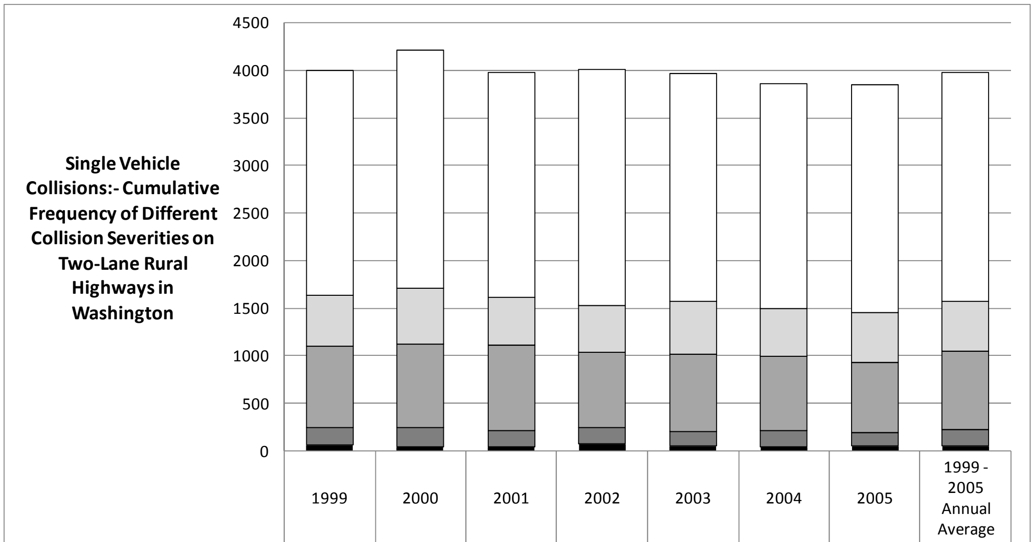


	2002	2003	2004	2005	2002 - 2005 Annual Average
Property Damage Only Collisions	1598	1547	1519	1479	1536
Possible Injury Collisions	466	531	474	485	489
Evident Injury Collisions	760	781	739	691	743
Disabling Collisions	189	160	170	162	170
Fatal Collisions	93	63	56	57	67

Figure 8: Collision Severity Distribution for Run-Off-the-Road Collisions on Two-Lane Rural Highways for 2002 to 2005

Single Vehicle Collisions

Single vehicle collisions represent 57.2% of two-lane rural road collisions, 52.4% of fatal and disabling injury collisions on two-lane rural highways, and 43.7% of fatal injury collisions on two-lane rural highways (annual average for 1999 to 2005). Figure 9 shows the collision severity trend from 1999 to 2005. Between 2002 and 2005, approximately 68.3% of the single vehicle collisions were also run-off-the-road collisions. Collision rates for single vehicle collisions for the years 1999 - 2005 are: 1.2 fatal injury collisions per 100 million VMT, 5.2 fatal and disabling injury severity collisions per 100 million VMT, and 93.2 collisions per 100 million VMT.



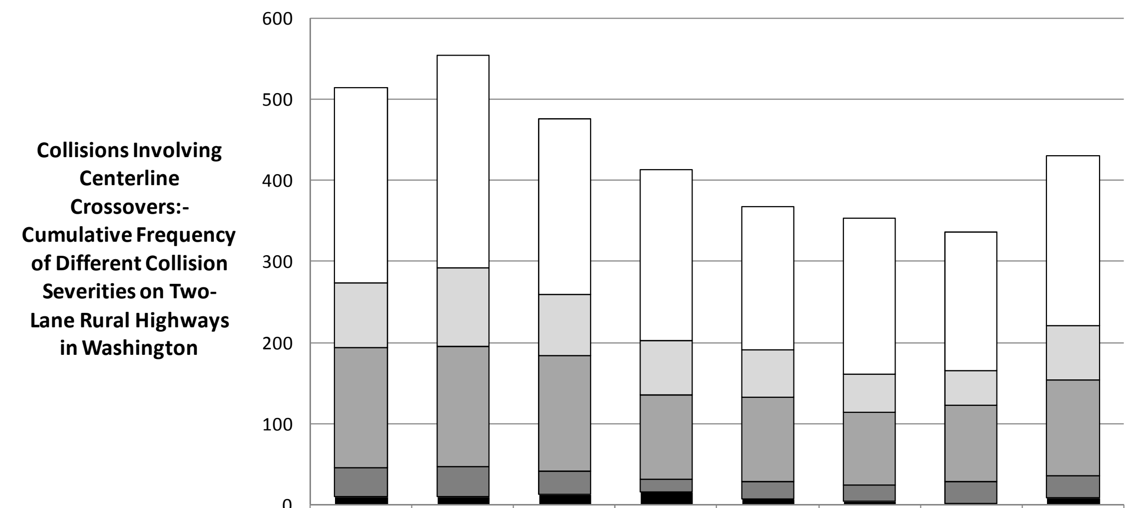
	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
Property Damage Only Collisions	2367	2497	2362	2476	2388	2362	2394	2407
Possible Injury Collisions	532	583	504	500	562	499	527	530
Evident Injury Collisions	853	879	894	792	803	787	735	820
Disabling Collisions	186	204	179	167	157	163	147	172
Fatal Collisions	60	44	38	74	51	46	49	52

Figure 9: Collision Severity Distribution for Single Vehicle Collisions on Two-Lane Rural Highways for 1999 to 2005

Collisions Involving Centerline Crossover

While the number of collisions in which centerline crossovers occurred represents a small proportion of the collisions on two-lane rural highways, this collision type often result in higher severity outcomes than single vehicle collisions. In cases involving more than one vehicle traveling in opposite directions, these collisions can result in multiple fatalities and injuries.

Over the 7-year period, centerline crossover collisions decreased along with fatal injury collisions and while fatal and disabling injury collision frequencies remained relatively steady over the 1999 to 2005 period. Figure 10 presents the collision severity distributions across the 7-year period.



	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
Property Damage Only Collisions	241	263	216	212	177	192	171	210
Possible Injury Collisions	79	97	76	66	58	47	42	66
Evident Injury Collisions	149	148	143	104	105	90	94	119
Disabling Collisions	35	37	28	17	21	20	28	27
Fatal Collisions	10	10	13	15	7	4	1	9

Figure 10: Collision Severity Distribution for Collisions in Which Centerline Crossover Is Reported as a Contributing Factor Two-Lane Rural Highways ((1999 to 2005)

An analysis of collisions involving centerline crossovers by right shoulder width category and terrain (shown in Table 6 and Table 7) indicated that crossover collision frequency and severity rates are significantly higher on level highway segments with shoulder widths less than 5-ft compared to the other categories (even mountainous terrain). This may be indicative of drivers' lower perceived risk of level terrain compared to mountainous terrain and/or more passing opportunities.

Table 6: Collisions Involving Centerline Crossover by Shoulder Width Category and Terrain Type - Extent of the Network and Collision Frequencies (1999 – 2005)

Right Shoulder Width Category	Terrain Type	Total Collisions	Fatal Injury Collisions	Fatal and Disabling Injury Collisions	Miles
5 ft or more	*Level*	355	6	27	487.57
	Mountainous	93	0	0	95.79
	Rolling	1120	21	98	1504.61
less than 5-ft	*Level*	275	7	22	385.6
	Mountainous	122	4	11	347.99
	Rolling	1051	22	88	2079

Table 7: Collisions Involving Centerline Crossover by Shoulder Width Category and Terrain Type – Collision and Severe Injury Collision Rates (1999 – 2005)

Right Shoulder Width Category	Terrain Type	Fatal Injury Collisions per 100 million VMT	Fatal and Disabling Injury Collisions per 100 million VMT	Collision Rate per 100 million VMT
5 ft or more	*Level*	0.64	2.87	37.75
	Mountainous	0	0	35.21
	Rolling	0.5	2.35	26.87
less than 5-ft	*Level*	1.41	4.44	*55.52*
	Mountainous	0.76	2.09	23.18
	Rolling	0.72	2.88	34.44

Behavioral Issues and Special Road Users

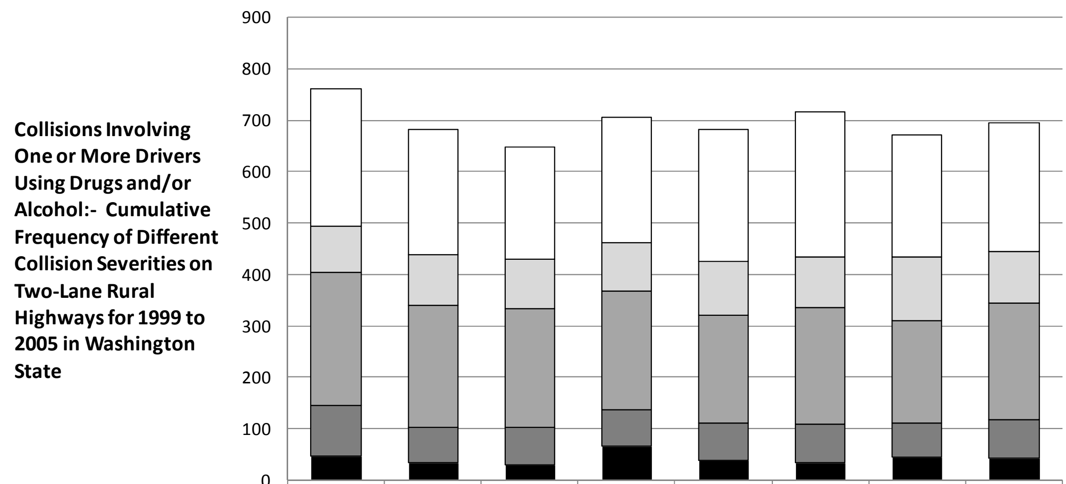
Behavioral issues not only affect collision frequency but also injury outcomes on two-lane rural highways. However, it is recognized that addressing behavioral related safety issues falls outside the direct responsibilities of WSDOT. The decision-matrix does not include these results, but these are provided in subsections for information purposes. Specific focus areas of the assessment included involvement of drugs and/or alcohol and then involvement of special user groups (heavy vehicles, young drivers, and older drivers). For the purpose of this report, drivers ages 15 to 17 were classified as young drivers and drivers ages 65 and over were classified as older drivers.

Involvement of Drugs and/or Alcohol. Collision reports for 1999 to 2005 indicate that 10% of the collisions on two-lane rural highways involved one or more drivers who were using drugs and/or alcohol. Collision reports also show that in 27.4% of the fatal and disabling collisions there is evidence of drugs or alcohol (for fatal collisions this percentage increases to 35.8%).

Drug and/or alcohol involvement not only affects the incidence of collisions but also outcome severity. When comparing collisions where drugs or alcohol was not a factor, to collisions where one or more drivers used drugs or alcohol, the proportion of fatal collisions increased from 1.2% to 6.1%, and the proportion of disabling collisions increased from 3.7% to 10.7%, and evident injury collisions from 17.3% to 32.7% (for the period 1999 to 2005).

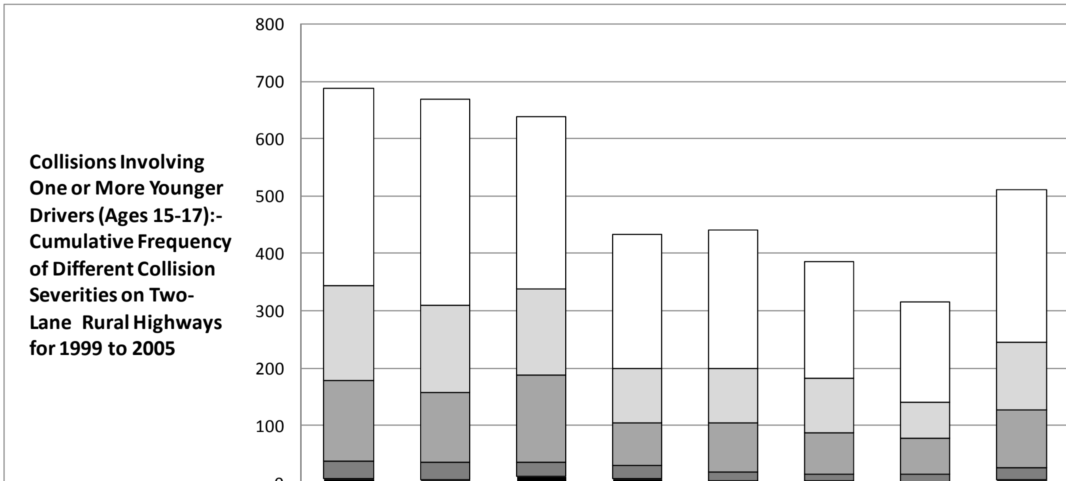
Figure 11 shows the collision severity distribution for collisions where one or more drivers used drugs or alcohol. Involvement of these behavioral factors can also be time and day dependent. On two-lane rural highways, the proportion of collisions involving drugs and/or alcohol vary substantially between Fridays at 5pm to midnight on Sundays. It increases from 31.6% at midnight to 47.2% at 2am and then steadily reduces to 3.7% at 10am. From 10am to 11pm, the rate increase steadily to 27.8%. These patterns offer insight into the hourly distribution of the impact of drugs and/or alcohol on the incidence and severity of collisions on two-lane rural highways on weekends.

Younger Drivers. Since 1999, the incidence of collisions involving young drivers has reduced significantly, as shown in Figure 12. The likelihood of a younger driver being involved in a collision where one or more drivers were using drugs or alcohol also decreased. These changes are likely the results of graduated licensing, enforcement or educational efforts (a graduated driver's license law was enacted in July 2001 (NHTSA 2003)).



	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
□Property Damage Only Collisions	268	245	218	244	257	281	237	250
□Possible Injury Collisions	89	99	96	94	105	100	125	101
■Evident Injury Collisions	260	237	232	231	209	226	198	228
■Disabling Collisions	97	67	72	71	73	75	66	74
■Fatal Collisions	48	35	30	66	38	34	45	42

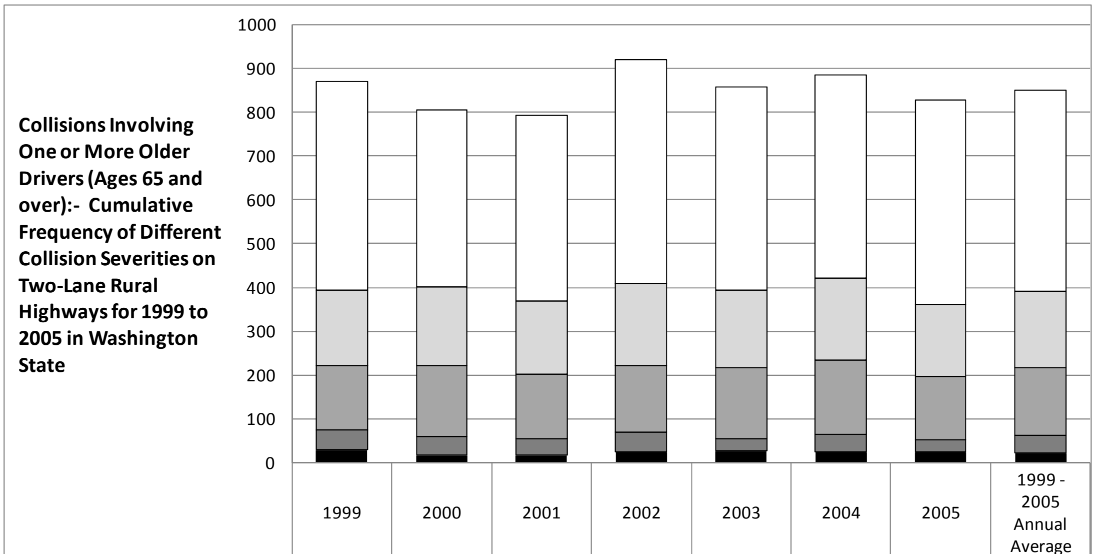
Figure 11: Collision Severity Distribution for Collisions Where One or More Drivers Used Drugs and/or Alcohol for 1999 to 2005



	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
□Property Damage Only Collisions	344	360	301	234	240	203	175	265
□Possible Injury Collisions	166	152	149	95	96	96	64	117
■Evident Injury Collisions	140	120	152	75	85	72	62	101
■Disabling Collisions	31	31	26	23	15	11	13	21
■Fatal Collisions	7	6	11	7	4	4	2	6

Figure 12: Collision Severity Distribution for Collisions Involving One or More Drivers Ages 15 to 17 for 1999 to 2005

Older Drivers. The incidence of collisions involving older drivers has remained relatively stable since 1999. Figure 13 shows the collision severity distribution for collisions involving one or more older drivers. It is important to note that the expected increase in the older driver population at the national level (Staplin, et al. 2001) may result in higher representation of this group in collisions in future years. This expected change in trends may require consideration of older driver needs and characteristics in the management of the two-lane rural highway system in the future.



	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
Property Damage Only Collisions	478	405	424	511	463	464	468	459
Possible Injury Collisions	171	180	165	186	176	187	164	176
Evident Injury Collisions	148	162	148	151	163	169	144	155
Disabling Collisions	44	41	38	47	28	40	29	38
Fatal Collisions	30	18	17	24	27	25	24	24

Figure 13: Collision Severity Distribution for Collisions Involving One or More Older Drivers (65/plus) for 1999 to 2005

Heavy Vehicles. Even though only 6.1% of collisions on two-lane rural highways involve one or more heavy vehicles, these collisions represent 13.1% of fatal injury collisions and 7.8% of fatal and disabling injury collisions on two-lane rural highways (annual averages for 2002 to 2005). Between 2002 and 2005 the proportion of collisions on two-lane highways involving heavy vehicles has increased from 5.8% to 6.7%. This may be the result of increased exposure. A comparison of the collision severity distribution of collisions involving one or more heavy vehicles on two-lane rural highways indicated that 3.7% of these are fatal collisions compared to the 1.6% for collisions not involving heavy vehicles (annual averages for 2002 to 2005). Besides the loss of life and injuries sustained in heavy vehicle related collisions, collisions involving these vehicles may be more likely to lead to incident related delays and secondary collisions.

Terrain

Table 8 summarizes the collision and severe collision rates for two-lane rural highways across different terrain types. When compared, the rates for segments in mountainous terrain, approximately 444 miles, are higher than those observed for level and rolling terrain. This may be indicative of the more demanding driving environments at these locations (especially when combined with extreme weather) and the lesser clear zones common to locations with restrictive topography and environment.

Run-off-the-road collisions are the most common collision type for two-lane rural highways. Table 9 shows the results from an assessment of the incidence and rates of run-off-the-road collisions across different terrain types. The rate of run-off-the-road collisions and severe run-off-the-road collisions are higher for mountainous terrain than for the other two terrain types.

Table 8: Collision Frequencies and Rates for Different Terrain Types (1999 to 2005 data)

Terrain Type	Total Collisions	Fatal Injury Collisions	Fatal and Disabling Injury Collisions	Miles	Fatal Injury Collisions per 100 million VMT	Fatal and Disabling Injury Collisions per 100 million VMT	Collision Rate per 100 million VMT
2005							
Level	1556	20	74	873.17	1.52	5.61	118.03
Mountainous	394	6	26	443.78	2.23	9.67	146.59
Rolling	4544	85	272	3583.61	2.16	6.9	115.34
1999 – 2005							
Level	11543	195	648	873.17	2.17	7.22	128.57
Mountainous	2918	54	169	443.78	2.8	8.76	151.32
Rolling	34277	579	2169	3583.61	2.14	8	126.49

Table 9: Run-off-the-Road Collisions – Collision Frequency and Rate by Terrain Type (2002 to 2005 data)

Terrain Type	Total Collisions	Fatal Injury Collisions	Fatal and Disabling Injury Collisions	Fatal Injury Collisions per 100 million VMT	Fatal and Disabling Injury Collisions per 100 million VMT	Collision Rate per 100 million VMT
2005						
L	635	10	43	0.76	3.26	48.17
M	196	4	14	1.49	5.21	72.92
R	2043	43	162	1.09	4.11	51.86
2002 – 2005						
L	2517	64	187	1.23	3.59	48.32
M	875	24	68	2.21	6.27	80.63
R	8628	181	695	1.15	4.43	55.01

* L=level, M=mountainous, R=rolling

Shoulder Width

Shoulder widths may affect vehicle recovery when a vehicle leaves the roadway. Evaluation of countermeasures that included shoulder widening usually shows reductions in collision rates and/or severity. It is therefore reasonable to include assessment of the safety characteristics of segments with different shoulder widths. Findings suggest that the largest differences in trends and characteristics are between shoulders with a width of 5 feet or more and those with a width less than 5 feet.

Table 10 shows the results of a basic assessment of collision and severe injury rates by shoulder width category. Overall collision rates and severe injury collision rates were higher for segments with a shoulder width less than 5-ft.

Table 10: Collision Frequencies and Rates for Different Shoulder Width Categories (1999 to 2005 data)

Shoulder Width	Total Collisions	Fatal and Disabling Injury Collisions	Miles	100 million VMT	Fatal Injury Collisions per 100 million VMT	Fatal and Disabling Injury Collisions per 100 million VMT	Collision Rate per 100 million VMT
2005							
5 ft or more	3442	178	2087.97	33.01	2	5.39	104.27
less than 5 feet	3052	194	2812.59	22.26	2.02	8.72	137.12
1999 – 2005							
5 ft or more	25841	1512	2087.97	226.63	1.99	6.67	114.02
less than 5 feet	22897	1474	2812.59	153.42	2.46	9.61	149.24

The research team also surmised that the recovery characteristics on horizontal curves could be different from those on straight segments. Narrower shoulders may also affect recovery when a vehicle leaves the roadway. Table 11 shows that collision and severe injury collision rates are higher for segments on horizontal curves than for other segment types. The table also shows that segments on horizontal curves with shoulder widths of less than 5 feet are associated with overall collision rates and severe collision rates when compared to segments on horizontal curves with shoulder widths of 5 ft or more. Although these results are insightful, it is also necessary to evaluate how terrain type may influence the safety relationship between horizontal curvature and shoulder width.

Table 11: Shoulder Widths on Horizontal Curves – Collision Frequencies and Rates

Right Shoulder Width	Total Collisions	Fatal Injury Collisions	Fatal and Disabling Injury Collisions	Fatal Injury Collisions per 100 million VMT	Fatal and Disabling Injury Collisions per 100 million VMT	Collision Rate per 100 million VMT
			2005			
5 ft or more	883	21	57	2.68	7.28	112.78
less than 5 feet	983	21	73	3.57	12.4	166.94
			1999 – 2005			
5 ft or more	6698	143	472	2.66	8.78	124.65
less than 5 feet	7045	146	525	3.58	12.89	172.95

Table 12 summarizes the extent of the network across different terrain and shoulder widths for horizontal curves, and provides the collision and severe injury collision rates across the different categories. Results indicate that, across all terrain types, horizontal curves with right shoulder widths less than 5-ft are associated with higher collision and severe collision rates.

An analysis of a 7-year period, 1999 to 2005, indicates that level and rolling terrain segments exhibit higher severe injury rates on horizontal curves where shoulder widths are narrower than 5-ft. For mountainous areas the difference in the collision rates across the various shoulder widths are negligible. However, severe collision frequencies are higher for horizontal curves in mountainous terrain where shoulder widths are less than 5-ft compared those with shoulder widths of 5-ft or more. Note that the annual frequency of collisions on horizontal curves across the terrain and shoulder width categories is low, even when evaluating a 7-year period.

Table 12: Shoulder Widths on Horizontal Curves by Terrain Type - Extent of the Network, Collision Frequencies, and Collision Rates (1999 to 2005 data)

Terrain Type	Right Shoulder Width	Total Collisions	Fatal Injury Collisions	Fatal and Disabling Injury Collisions	Miles	100 million VMT	Fatal Injury Collisions per 100 million VMT	Fatal and Disabling Injury Collisions per 100 million VMT	Collision Rate per 100 million VMT
2005									
Level	*5 ft or more*	182	4	11	81.07	1.37	2.93	8.05	133.21
	less than 5 feet	147	2	12	58.55	0.75	2.67	16.05	*196.57*
Mountainous	*5 ft or more*	62	0	1	38.65	0.37	0	2.68	*166.45*
	less than 5 feet	111	3	12	138.14	0.72	4.17	16.68	*154.26*
Rolling	*5 ft or more*	639	17	45	384.24	6.09	2.79	7.39	104.92
	less than 5 feet	725	16	49	563.41	4.42	3.62	11.08	163.99
1999 – 2005									
Level	*5 ft or more*	1298	32	87	81.07	9.4	3.4	9.25	138.04
	less than 5 feet	901	19	72	58.55	4.95	3.84	14.54	*181.91*
Mountainous	*5 ft or more*	465	7	24	38.65	2.64	2.65	9.09	*176.04*
	less than 5 feet	898	23	74	138.14	5.26	4.37	14.06	*170.61*
Rolling	*5 ft or more*	4935	104	361	384.24	41.69	2.49	8.66	118.37
	less than 5 feet	5246	104	379	563.41	30.52	3.41	12.42	*171.89*

The higher collision and severe collision rates for level segments on horizontal curves with shoulders less than 5 feet is noteworthy. This rate is similar to the rate observed for horizontal curves in mountainous terrain. This finding seems inconsistent with the expectation that a segment on a horizontal curve in mountainous terrain would be more challenging than a similar segment on level terrain. This may be indicative of the relative difference in risk perception of the drivers. On level terrain, drivers may perceive less risk, resulting in an increase in driving speed and a reduction in levels of awareness. On the other hand, the driver may be much more careful on mountainous terrain and in fact, overestimate risk (drive slower and increase concentration levels). This can then result in similar rates for level segments even though the real risk on the level segments may in fact be less.

Shoulder widths are also included as a consideration in the remainder of the discussion of the assessment results, specifically as it relates to different collision types.

Horizontal Curves: Degree of Curvature

Overview

Countermeasures for two-lane rural road usually include references to making changes to horizontal curves. Figure 14 shows the collision and severe collision rates for different degrees of curvature for the 1999-2005 period. Analysis of multiple years of data was required because of the relatively small annual samples of observations within the subcategories. Degree of curvature is calculated as follows: $Degree\ of\ curvature = \frac{5729.59}{Curve\ Radius\ in\ ft}$.

There are approximately 1,264 miles of two-lane rural state highways with horizontal curves. Approximately 140 of these miles are on level terrain, 177 miles on mountainous terrain, and 948 miles are on rolling terrain. When reviewing collision and severe injury collision rates across different degree of curvature, as shown in Figure 14, an increase of degree of curvature above 2 is usually associated with higher rates.

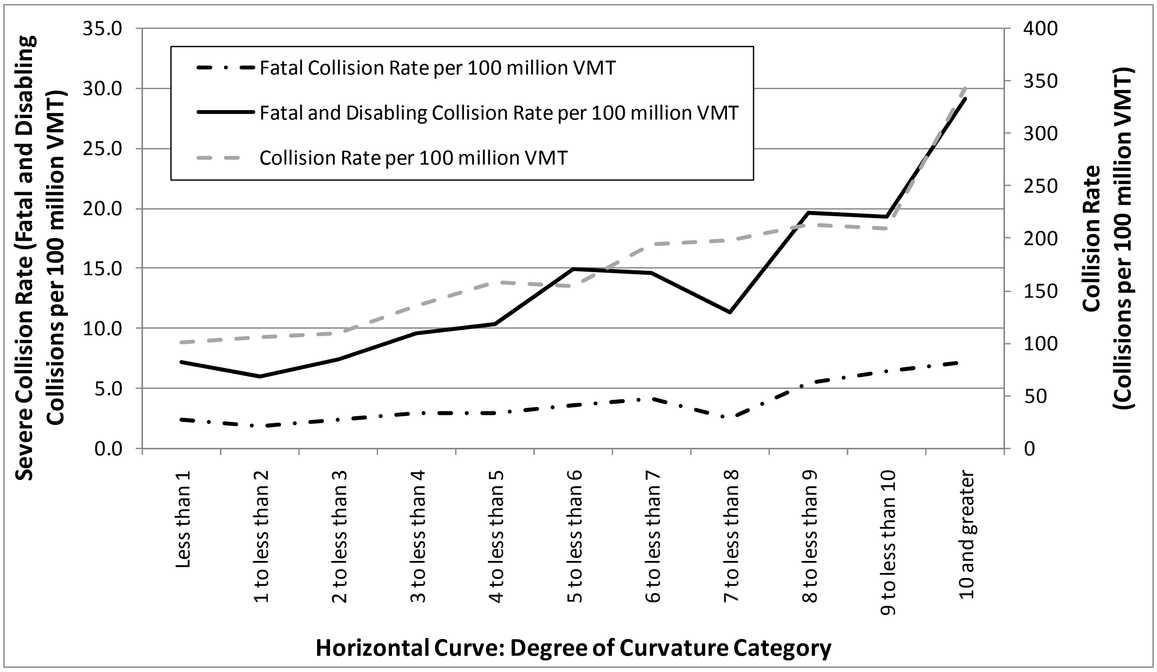


Figure 14: Evaluation of collision; fatal injury; and fatal and disabling injury collision rates for the seven-year period 1999 – 2005 for varying categories of horizontal degree of curvature

Results indicate that, although the amount of travel on segments with horizontal curves is limited, collision rates and severe collisions rates are higher on these segments. One can distinguish between segment collisions and collisions that are intersection or intersection-related. When reviewing the rates for overall collisions and then for segment collisions on horizontal curves, it allows us to determine the impact of intersection or intersection-related collisions on safety performance and to get an idea of the magnitude of differences. The collision rates for collisions on horizontal curves for the years 1999 - 2005 are (with segment only collision rates in parenthesis):

- 3.06 (3.06) fatal injury collisions per 100 million VMT,
- 10.55 (9.48) fatal and disabling injury severity collisions per 100 million VMT, and
- 145.48 (136.03) collisions per 100 million VMT.

Eastern and Western Washington

Locations with significant horizontal curves are often located in mountainous and forested terrain. Based on the premise that these locations will show regional differences in terms of collision and severity outcomes, the research included a comparative analysis on rates for eastern and western Washington. Figure 15 graphically summarizes the results.

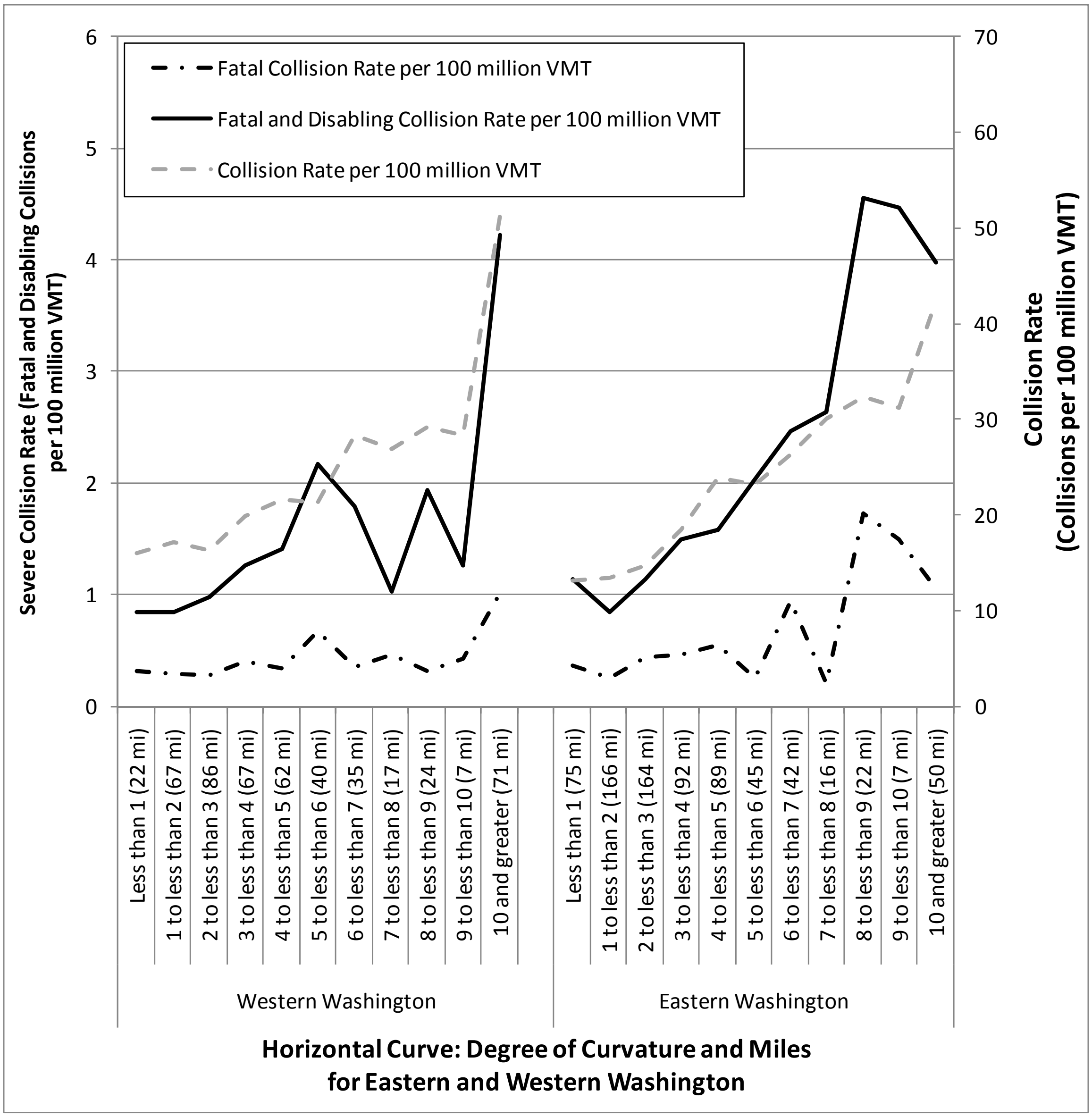


Figure 15: Evaluation of collision; fatal injury; and fatal and disabling injury collision rates for the seven-year period 1999 – 2005 for varying categories of horizontal degree of curvature and comparing eastern and western Washington

Analysis of the 1999 to 2005 collision data indicates that:

- In general, an increase in degree of curvature tends to correlate to collision occurrence and severity.
- In western Washington, severe injury rates were higher in two cases: where the degree of curvature was 5 or more but less than 6 and where it was 10 or more.
- In eastern Washington horizontal curves with a degree of curvature of 6 or more but less than 7 and those with values of 8 or more, exhibited both higher collision and severe collision rates.

The increase in rates as degrees of curvature increase, may indicate that driver behavior on two-lane rural highways differs from behavior on other facilities as described by Milton and Mannering (1996), who found that drivers do not necessarily drive more cautiously along curves on two-lane rural highways. Possible reasons may include familiarity and the lower associated volumes on these facilities that may reduce driver risk perception. For degree of curvature categories where rates do not increase with an increase in degree of curvature, cross sectional differences or particular treatments may explain the difference in behavior. If these locations indeed appear similar to curves with degrees of curvature in adjacent categories, it may indicate that the drivers are driving more cautiously on these particular curves. Weather and traffic volumes may also affect the collision outcomes (Milton, Shankar, and Mannering (2007), Milton and Mannering (1998)).

Terrain Type

An evaluation of terrain type indicates that similar trends for degree of curvature exists across the three terrain categories but that level and mountainous terrain tend to experience higher collision and severe injury rates than curves on rolling terrain. Figure 16 shows these results. Horizontal curves on level and mountainous terrain with degrees of curvature of 8 and more have higher collision and severe collision rates than the other categories. This difference is more pronounced for horizontal curves in mountainous terrain.

Horizontal Degree of Curvature and Run-Off-the-Road Collisions

Run-off-the-road collision is one of the major collision types occurring on two-lane highways. These collisions are also associated with more serious injury outcomes. The evaluation included rates of run-off-the-road collisions for different categories of horizontal degree of curvature. Figure 17 shows the result of this assessment.

Over the 7-year period, an annual average of 575 run-off-the-road collisions occurred on horizontal curves (1999 to 2005). On average, approximately 14 of these collisions would be fatal injury severity collisions and 36 would result in disabling injury severity collisions. The results from this analysis appear to be consistent with those described in the earlier sections: that an increase in degree of curvature generally corresponds with an increase in collision and severity rate.

There are approximately 121 miles of horizontal curves with degree of curvature of 10 or more. These curves are associated with much higher run-off-the-road collision and severe run-off-the-road collision rates. These segments are also the segments with the highest overall collision frequency, fatal injury collision frequency, and fatal and disabling injury collision frequency. Between 1999 and 2005 an annual average of 110 collisions occurred on these curves, of which 10 represent severe injury collisions.

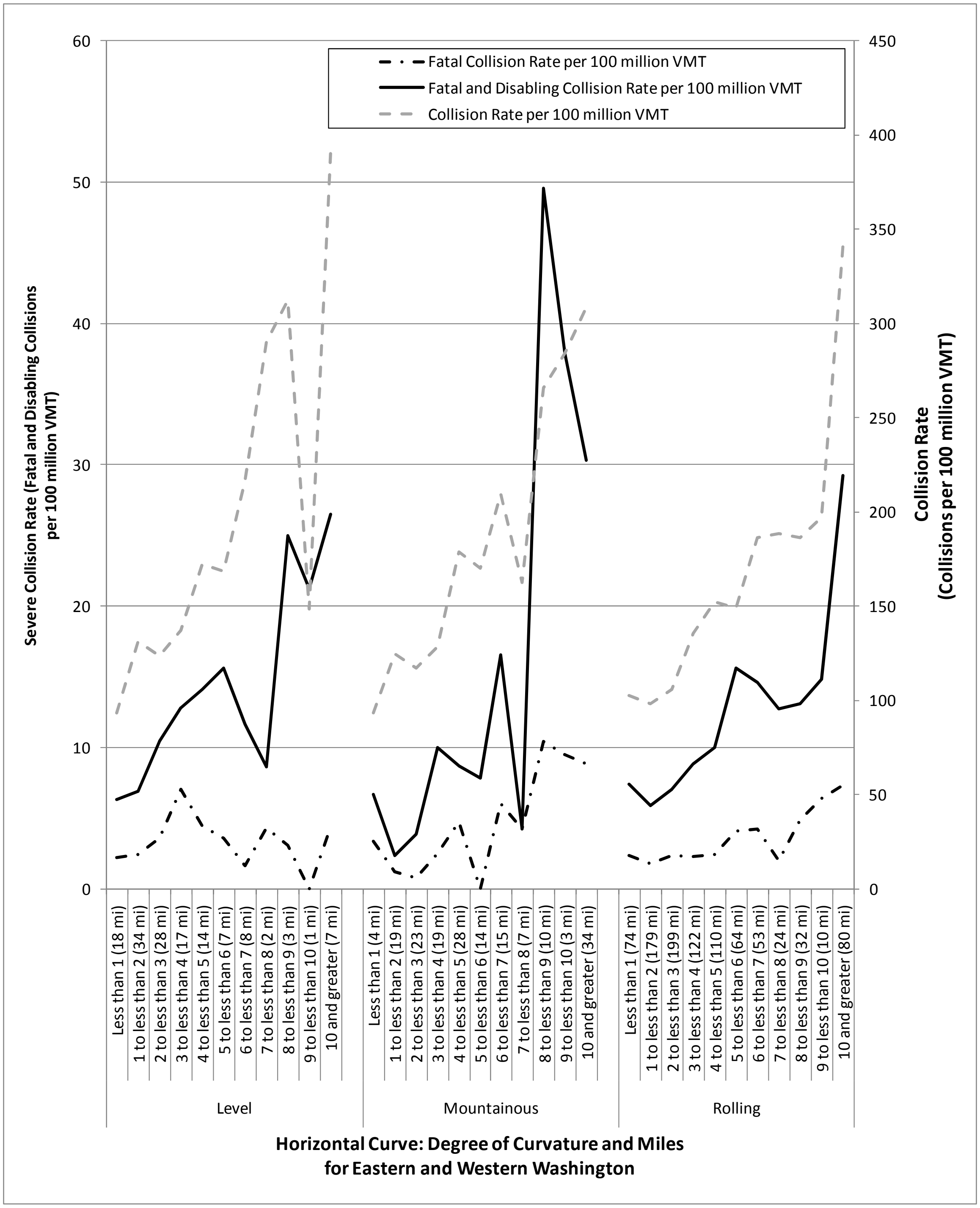


Figure 16: Evaluation of collision; fatal injury; and fatal and disabling injury collision rates on horizontal curves for the seven-year period 1999 – 2005 for different terrain types

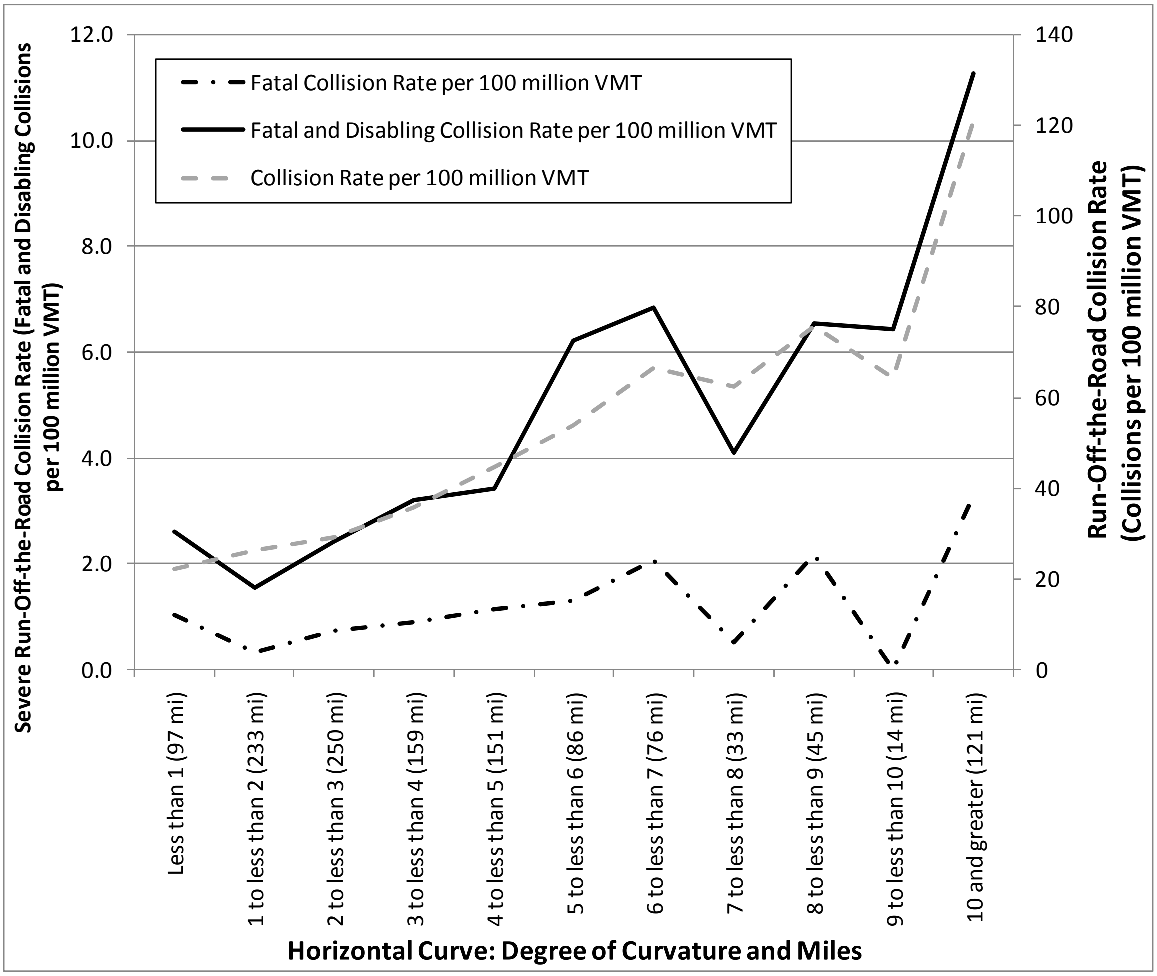
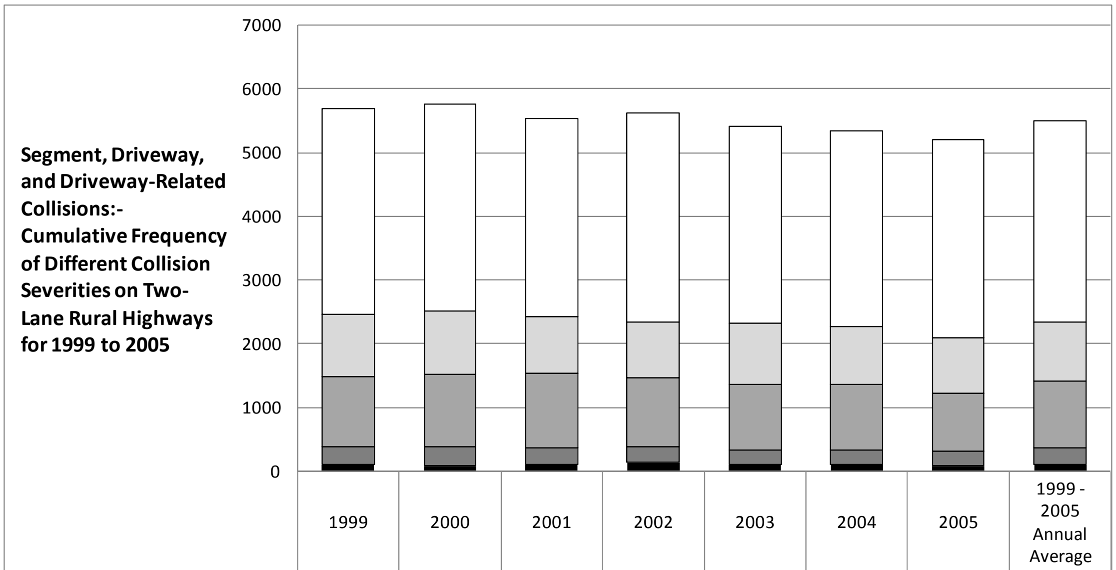


Figure 17: Evaluation of Run-off-the-Road Collisions on Horizontal Curves - collision; fatal injury; and fatal and disabling injury collision rates for the seven-year period 1999 – 2005 for different degrees of curvature

Segment Collision Trends and Characteristics

Collisions are often categorized as either segment or intersection (or intersection-related) types. This distinction not only assists in identifying differences in collision behavior but also provide distinction necessary to identify appropriate countermeasures.

Segment collisions represent collisions at driveways, collisions that are driveway-related, and those that are not intersection or intersection-related. This is consistent with current approaches in highway safety research. In this review, driveway and driveway-related collisions are also evaluated separately from other segment collisions because of the difference in the nature of contributing circumstances for these collision types. Driveway and driveway-related collisions usually relates to access management issues while other segment collisions are associated with a broader range of contributing circumstances. Figure 18 shows the collision severity distribution for segment collisions from 1999 to 2005. Segment collisions represent approximately 5,500 of the average annual state highway collisions of which 102 are fatal collisions (annual averages for 1999 to 2005).



	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
□Property Damage Only Collisions	3230	3239	3101	3272	3082	3065	3113	3157
□Possible Injury Collisions	971	997	903	887	962	899	863	926
■Evident Injury Collisions	1095	1135	1159	1070	1029	1033	914	1062
■Disabling Collisions	277	292	275	258	237	238	223	257
■Fatal Collisions	112	90	98	132	97	99	89	102

Figure 18: Collision Severity Distribution for Segment Collisions for 1999 to 2005

Table 13 provides a summary of the collision rates for segment crashes on two-lane rural highways.

Table 13: Segment Collision Trends (including Driveway and Driveway Related Collisions)

Total Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Injury Collisions per 100 million VMT (1999-2005)	Fatal and Disabling Injury Collisions per 100 million VMT (1999-2005)	Collision Frequency per 100 million VMT (1999-2005)
2005					
5202	89	312	1.61	5.65	94.12
1999 - 2005					
38536	717	2517	1.89	6.62	101.40

Driveway and driveway-related collisions represent 8.8% of collisions reported on two-lane rural state highways (annual average for 1999 – 2005). This proportion is higher than the 6.3% that this collision category represents on the rest of the network. In terms of collision severity, these collisions also present a much higher proportion of fatal and disabling collisions: 4.4% compared to 1.6% for the rest of the network. This underlines the importance of access management in the two-lane rural highway context.

Table 14 presents a summary of the segment collision rates when driveway and driveway-related collisions are excluded). The table provides a summary for 2005 and then the 7-year period from 1999 – 2005.

Table 14: Segment Collision Trends (Excluding Driveway and Driveway Related Collisions)

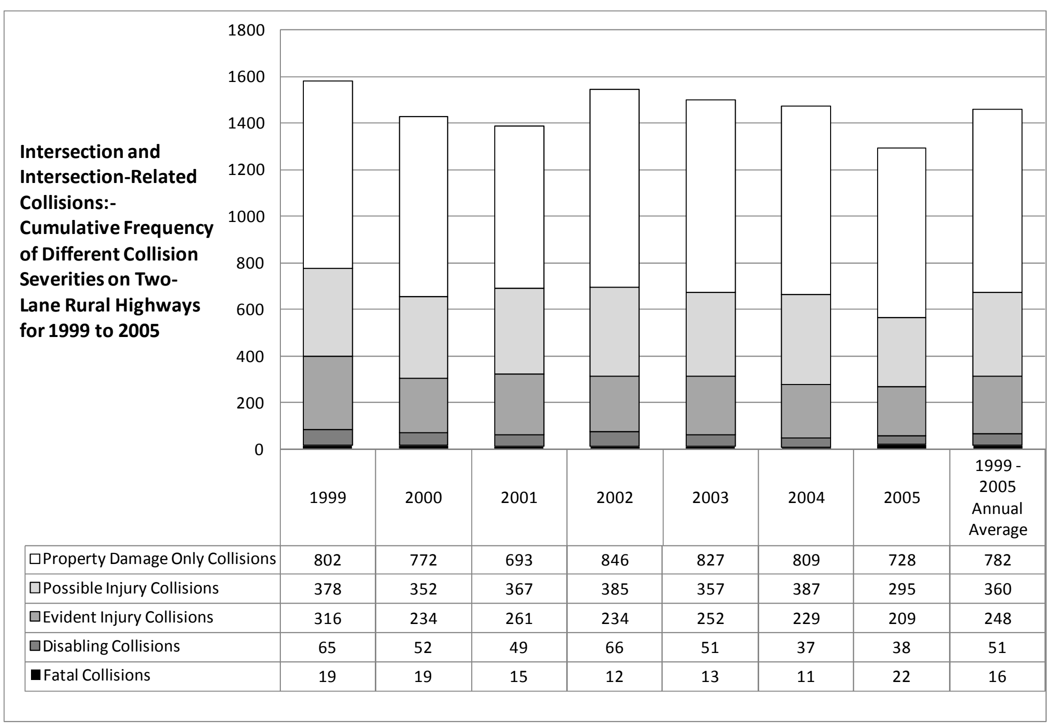
Total Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Injury Collisions per 100 million VMT (1999-2005)	Fatal and Disabling Injury Collisions per 100 million VMT (1999-2005)	Collision Frequency per 100 million VMT (1999-2005)
2005					
4727	86	287	1.56	5.19	85.53
1999 - 2005					
34497	693	2337	1.82	6.15	90.77

Intersection Collision Trends and Characteristics

Annually an average of 1,292 intersection and intersection-related collisions are reported (1999 to 2005 data). Table 15 provides intersection collision rates and Figure 19 shows the collision severity distribution for collisions in this category. The proportion of fatal and disabling injury collisions reported as intersection or intersection-related is relatively low compared to those reported for segment collisions. The majority of these collisions occur on arterials.

Table 15: Intersection and Intersection-Related Collision Trends

Total Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Injury Collisions per 100 million VMT (1999-2005)	Fatal and Disabling Injury Collisions per 100 million VMT (1999-2005)	Collision Frequency per 100 million VMT (1999-2005)
2005					
1292	22	60	0.40	1.09	23.38
1999 - 2005					
10202	111	469	0.29	1.3	26.85



	1999	2000	2001	2002	2003	2004	2005	1999 - 2005 Annual Average
Property Damage Only Collisions	802	772	693	846	827	809	728	782
Possible Injury Collisions	378	352	367	385	357	387	295	360
Evident Injury Collisions	316	234	261	234	252	229	209	248
Disabling Collisions	65	52	49	66	51	37	38	51
Fatal Collisions	19	19	15	12	13	11	22	16

Figure 19: Collision Severity Distribution for Intersection and Intersection-Related Collisions for 1999 – 2005

Further investigation of annual averages for intersection and intersection-related collisions indicates that (annual averages for 1999 to 2005):

- In 165 collisions, one or more vehicles were controlled by a traffic signal (no fatal or disabling injury collisions were reported).
- In 533 collisions, one or more vehicles were controlled by a STOP controlled intersections (10 fatal and 24 disabling injury collisions)
- In 71 of the collisions, one or more of the drivers disregarded the STOP sign (44 fatal and 6 disabling injury collisions were reported).
- In 6 collisions, one or more vehicles were controlled by a YIELD sign (no fatal or disabling injury collisions were reported).
- 754 collisions occurred at uncontrolled intersections (5 fatal and 25 disabling injury collisions).

Distribution across Counties

Table 16 summarizes the collision distribution across counties along with collision and severe collision rates. The reader should note that in some cases frequencies are low, suggesting caution in terms of interpretation.

WSDOT Regions

Table 17 shows the regional distribution of collision frequencies and rates of fatal, and fatal and disabling injury across regions. The reader should note that in some cases frequencies are low, suggesting caution in terms of interpretation. The distribution of miles across the three terrain types differs substantially between regions. Table 18 was prepared to show the different rates by terrain for each region. As stated previously, the reader should take care in interpretation of results where frequencies are low.

Table 16: Distribution of Collisions across Counties and Rates for Collisions, Fatal Injury Collisions, and Fatal and Disabling Collisions for 1999 to 2005

County	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
Adams	161.01	5.848	778	111	25	57	4.27	9.75	133.03
Asotin	44.01	1.019	83	12	2	13	1.96	12.76	81.46
Benton	111.18	6.771	673	96	20	54	2.95	7.97	99.39
Chelan	103.51	11.068	1326	189	23	85	2.08	7.68	119.81
Clallam	155.27	13.843	1558	223	31	85	2.24	6.14	112.55
Clark	35.7	4.286	853	122	7	36	1.63	8.40	199.02
Columbia	43.27	2.156	255	36	3	20	1.39	9.28	118.26
Cowlitz	94.15	6.499	912	130	13	50	2.00	7.69	140.34
Douglas	185.31	7.644	764	109	16	68	2.09	8.90	99.95
Ferry	152.81	3.184	450	64	11	49	3.45	15.39	141.33
Franklin	77.3	2.368	256	37	9	22	3.80	9.29	108.11
Garfield	43.06	2.147	288	41	1	21	0.47	9.78	134.16
Grant	284.2	18.169	1805	258	56	143	3.08	7.87	99.35
Grays Harbor	156.31	13.390	1680	240	33	156	2.46	11.65	125.46
Island	47.82	12.113	1558	223	17	80	1.40	6.60	128.62
Jefferson	124.87	14.176	1475	211	35	96	2.47	6.77	104.05
King	91.3	20.250	2666	381	37	168	1.83	8.30	131.65
Kitsap	33.05	10.649	1543	220	21	92	1.97	8.64	144.89
Kittitas	87.81	5.937	833	119	11	29	1.85	4.88	140.31
Klickitat	189.51	10.960	1591	227	28	115	2.55	10.49	145.16
Lewis	206.47	16.753	2139	306	44	129	2.63	7.70	127.68
Lincoln	270.69	7.986	761	109	10	47	1.25	5.89	95.30
Mason	109.25	14.290	2396	342	36	119	2.52	8.33	167.67
Okanogan	268.49	16.604	1772	253	37	88	2.23	5.30	106.72
Pacific	161.06	12.085	1608	230	17	82	1.41	6.79	133.06
Pend Oreille	108.42	4.689	631	90	6	43	1.28	9.17	134.56

County	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
Pierce	128.69	11.159	1844	263	40	128	3.58	11.47	165.25
San Juan	0	0	0	0	0	0	0.00	0.00	0.00
Skagit	121.7	10.656	1613	230	28	87	2.63	8.16	151.36
Skamania	46.39	4.179	704	101	9	48	2.15	11.49	168.46
Snohomish	83.54	18.050	2247	321	22	92	1.22	5.10	124.49
Spokane	119.47	15.652	1633	233	29	107	1.85	6.84	104.33
Stevens	230.06	14.277	1371	196	28	102	1.96	7.14	96.03
Thurston	45.18	7.643	1468	210	15	54	1.96	7.07	192.07
Wahkiakum	40.59	2.299	349	50	5	23	2.17	10.00	151.79
Walla Walla	116.53	10.128	1027	147	24	56	2.37	5.53	101.40
Whatcom	159.84	15.077	2496	357	24	106	1.59	7.03	165.55
Whitman	265.44	14.691	1817	260	22	113	1.50	7.69	123.68
Yakima	197.3	11.338	1509	216	33	121	2.91	10.67	133.09

* 6 collisions were not assigned to any particular county in the WSDOT TDO Collision Database

Table 17: Distribution of Collisions and Severe Injury Collisions across WSDOT Regions (1999 to 2005)

WSDOT Regions	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate per 100 million VMT	Fatal and Disabling Collision Rate per 100 million VMT	Collision Rate per 100 million VMT
Northwest Region	530.58	77.253	10759	1537	134	555	1.73	7.18	139.27
North Central Region	919.22	59.468	6487	927	156	438	2.62	7.37	109.08
Olympic Region	717.4	83.849	11756	1679	205	710	2.44	8.47	140.20
Southwest Region	788.55	57.753	8336	1191	123	494	2.13	8.55	144.34
South Central Region	657.29	39.410	4428	633	94	307	2.39	7.79	112.36
Eastern Region	1287.52	62.301	6972	996	116	482	1.86	7.74	111.91

Table 18: Distribution of Collisions and Severe Injury Collisions across Regions and Different Terrain Types for 1999 to 2005

Region	Terrain	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate per 100 million VMT	Fatal and Disabling Collision Rate per 100 million VMT	Collision Rate per 100 million VMT
Northwest Region	Level	109.11	14.74	2125	304	22	84	1.49	5.70	144.14
	Mountainous	74.04	4.47	436	62	6	26	1.34	5.81	97.50
	Rolling	347.43	58.04	8198	1171	106	445	1.83	7.67	141.25
North Central Region	Level	155.54	13.59	1320	189	43	109	3.16	8.02	97.11
	Mountainous	153.35	8.32	1332	190	30	76	3.61	9.14	160.17
	Rolling	610.33	37.56	3835	548	83	253	2.21	6.74	102.11
Olympic Region	Level	152.79	24.75	3407	487	49	172	1.98	6.95	137.68
	Mountainous	25.04	0.56	160	23	3	9	5.32	15.95	283.54
	Rolling	539.57	58.54	8189	1170	153	529	2.61	9.04	139.89
Southwest Region	Level	248.76	21.64	3072	439	40	169	1.85	7.81	141.97
	Mountainous	52.1	2.62	500	71	5	27	1.91	10.32	191.10
	Rolling	487.69	33.50	4764	681	78	298	2.33	8.90	142.22
South Central Region	Level	166.42	13.43	1463	209	41	107	3.05	7.97	108.93
	Mountainous	59.26	1.67	248	35	4	13	2.40	7.79	148.52
	Rolling	431.61	24.31	2717	388	49	187	2.02	7.69	111.77
Eastern Region	Level	40.55	1.61	156	22	0	7	0.00	4.34	96.65
	Mountainous	79.99	1.64	242	35	6	18	3.65	10.94	147.12
	Rolling	1166.98	59.04	6574	939	110	457	1.86	7.74	111.34

Functional Class

Analysis of safety characteristics by functional class is common. It recognizes differences in design standards (such as design speed and cross-section characteristics), access management, and overall traffic characteristics. The annual collision frequencies on horizontal curves across the different terrain and right shoulder width categories are low, even when evaluated using a longer 7-year period. Table 19 shows the collision frequencies and rates across different functional classes.

The findings show no substantial differences in terms of collision or severity rates between the three different functional classes for two-lane rural road highways, except for rural collectors, which exhibit slightly higher collision and severe injury collision rates. This may be the result of reduced levels of access control and differences in design standards.

Functional Class and Posted Speed Limits. When reviewing highways with a speed limit less than 40-mph, 40-mph or more but less than 55-mph, and 55-mph and over, other differences emerge. Table 20 summarizes results from the comparisons across functional class and posted speed limit.

Results consistently indicate that in each functional class category, highways with posted speeds less than 40-mph experience higher annual average collision rates than those with posted speeds of 40-mph or higher. In terms of assessment of the fatal and disabling collision rates, the reader should note that in some cases frequencies are low, suggesting caution in terms of interpretation.

Table 19: Collision Frequency and Rates for Different Functional Classes

State Functional Class	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
2005									
Rural Principal Arterial	1710.39	28.963	3247	463.86	62	166	2.14	5.73	112.11
Rural Minor Arterial	1566.74	16.241	1978	282.57	29	122	1.79	7.51	121.79
Rural Collector	1623.43	10.063	1269	181.29	20	84	1.99	8.35	126.11
1999 - 2005									
Rural Principal Arterial	1710.39	200.267	24064	3438	406	1430	2.03	7.14	120.16
Rural Minor Arterial	1566.74	109.713	14306	2044	263	915	2.40	8.34	130.40
Rural Collector	1623.43	70.055	10368	1481	159	641	2.27	9.15	148.00

Table 20: Collision Rates and Severe Injury Collision Rates by Functional Class for Different Speed Limit Categories for 1999 to 2005

State Functional Class	Posted Speed Category	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
Rural Principal Arterial	Less than 40-mph	51.8	8.471	1718	245	10	51	1.18	6.02	202.81
	40-mph to less than 50-mph	214.88	36.920	5554	79	74	324	2.00	8.78	150.43
	55-mph and higher	1443.71	154.876	16792	2399	322	1055	2.08	6.81	108.42
Rural Minor Arterial	Less than 40-mph	71.05	9.189	2109	301	5	45	0.54	4.90	229.52
	40-mph to less than 50-mph	280.56	26.320	3582	512	53	233	2.01	8.85	136.09
	55-mph and higher	1215.13	74.20	8615	1231	205	637	2.76	8.58	116.10
Rural Collector	Less than 40-mph	164.32	10.19	1891	270	14	69	1.37	6.77	185.53
	40-mph to less than 50-mph	572.48	30.015	4918	703	74	292	2.47	9.73	163.85
	55-mph and higher	886.63	29.85	3559	508	71	280	2.38	9.38	119.24

RESULTS OF MEASURES OF CONTEXTS FOR THE ASSESSMENT OF TWO-LANE RURAL HIGHWAYS

As described earlier, the project evaluated surrogates (indicators) to distinguish between different contexts. This particular section describes the results of the assessment of each of the surrogates and the insights each provided in terms of differences in safety characteristics. First, a discussion of results for a surrogate for transition areas is presented, and then a description of a surrogate to distinguish between more developed contexts and those with limited development follows.

For the purpose of these discussions, the term 'rural town centers' are used to indicate developed rural contexts. The discussion of results for the various contexts follows.

Assessment of Surrogate for Identifying Transition Areas

The research team identified segments within 2 miles (in half-mile increments) of urban boundaries. These segments were assessed to determine whether higher collision rates and proportion of collisions are found on these segments compared to the rest of the two-lane rural highway network.

Overall Results for Using Proximity to Urban Boundaries as Surrogate

The analysis included collisions and segment collisions occurring in close proximity to urban boundaries (population 5,000 or larger). The results show that annual frequencies of fatal and disabling injury collisions within the 2-mile area from urban boundaries are relatively low. Because of the low frequency, the analysis was extended to cover a seven-year period (1999-2005). The observed results were similar over the 7-year period. Table 21 summarizes the results (1999 – 2005).

The region from a half to one mile from urban boundaries exhibit slightly higher overall fatal injury severity rates, for both the year 2005 and the 7-year period of 1999 to 2005.

Run-off-the-Road Collisions and Proximity to Urban Boundaries

As a major collision type of two-lane rural roads, run-off-the-road collision rates were also evaluated across the different categories of proximity to urban boundaries. The results, shown in Table 22, indicate that collision rates and severities are higher outside the 2-mile boundary area from urban areas. This is consistent with the expectation that run-off-the-road collisions are usually associated with environments with very little development, if any.

Crossover Collisions

As an extension of the evaluation of the safety characteristics of crossover collisions in terms of shoulder width and terrain type (Table 6), the project also assessed safety in terms of different categories of proximity to urban boundaries. Table 23 summarizes the centerline crossover collision rates across urban boundary proximity category, shoulder width, and terrain type.

Segments with the highest crossover collision rates. In reviewing Table 23 it is necessary to consider the frequencies of collisions reported for the groupings of segments with reference to proximity of urban boundaries provided in Table 23.

The highest overall frequencies were reported for segments located more than 2 miles from urban boundaries. In terms of collision rates for these particular segments, the highest rates (in descending order) were recorded for rolling, mountainous, and level terrain. However, the highest collision rate was recorded for segments with shoulders of 5-ft or more in mountainous areas. So while the researchers determined earlier that level segments with shoulder widths less than 5-ft exhibits the highest collision and severe injury collision rates, this surrogate identified another trend: that there are a subgroup of segments with shoulder widths greater than 5-ft experiencing higher collision and severe injury collision rates. In terms of assessment of fatal and disabling collision rates, the reader should note that in some cases frequencies are low, suggesting caution in terms of interpretation.

Table 21: Extent of the Two-Lane Rural Highway Network by Proximity to Urban Boundaries and Associated Collision Frequencies for 1999 to 2005

Category	Proximity to Urban Boundary	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
All Collisions	*0 to 0.5mi*	106.8	23.783	3193	456	36	155	1.51	6.52	134.26
	0.5 to 1mi	66.35	14.412	1795	256	33	114	2.29	7.91	124.55
	1 to 2mi	125.92	21.247	2808	401	43	168	2.02	7.91	132.16
	Not within	4601.49	320.592	40942	5849	716	2549	2.23	7.95	127.71
Segment Collisions	*0 to 0.5mi*	106.8	23.783	2189	313	30	121	1.26	5.09	92.04
	0.5 to 1mi	66.35	14.412	1209	173	19	78	1.32	5.41	83.89
	1 to 2mi	125.92	21.247	1951	279	32	116	1.51	5.46	91.82
	Not within	4601.49	320.592	33187	4741	636	2202	1.98	6.87	103.52

Table 22: Extent of the Two-Lane Rural Highway Network in Proximity of Urban Boundaries and Associated Run-Off-the-Road Collision Frequencies and Rates for 2002 to 2005

Proximity to Urban Boundary	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
0 to 0.5mi	106.8	13.980	597	85	10	31	0.72	2.22	42.71
0.5 to 1mi	66.35	8.446	354	51	6	26	0.71	3.08	41.91
1 to 2mi	125.92	12.446	603	86	11	40	0.88	3.21	48.45
Not within	4601.49	184.902	10466	1495	242	853	1.31	4.61	56.60

* TDO introduced the run-off-the-road collision indicator in 2002, therefore only allowing for analysis of this particular collision category from 2002 to 2005.

Table 23: Collisions Involving Centerline Crossover by Shoulder Width Category, Terrain Type, and Proximity to Urban Boundaries - Extent of the Network and Collision Frequencies for 1999 to 2005

Urban Proximity Category	Shoulder width	Terrain Type	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
0 to 0.5mi	*5 ft or more*	*Level*	25.47	5.186	14	2	0	1	0.00	0.19	2.70
		Rolling	41.39	12.380	61	9	0	3	0.00	0.24	4.93
	less than 5-ft	*Level*	12.52	1.552	11	2	1	1	0.64	0.64	7.09
		Mountainous	1.99	0.036	0	0	0	0	0.00	0.00	0.00
		Rolling	25.43	4.629	28	4	0	0	0.00	0.00	6.05
0.5 to 1mi	*5 ft or more*	*Level*	14.22	2.541	16	2	0	0	0.00	0.00	6.30
		Mountainous	0.79	0.374	0	0	0	0	0.00	0.00	0.00
		Rolling	28.12	7.984	37	5	0	2	0.00	0.25	4.63
	less than 5-ft	*Level*	5.65	0.648	3	0	0	0	0.00	0.00	4.63
		Mountainous	2.13	0.038	1	0	0	0	0.00	0.00	26.26
		Rolling	15.44	2.828	20	3	0	2	0.00	0.71	7.07
1 to 2mi	*5 ft or more*	*Level*	36.35	5.916	33	5	0	2	0.00	0.34	5.58
		Mountainous	0.98	0.464	0	0	0	0	0.00	0.00	0.00
		Rolling	38.4	9.057	38	5	2	5	0.22	0.55	4.20
	less than 5-ft	*Level*	16.12	1.338	13	2	0	1	0.00	0.75	9.71
		Mountainous	1.41	0.018	0	0	0	0	0.00	0.00	0.00
		Rolling	32.66	4.453	35	5	0	2	0.00	0.45	7.86
Not within	*5 ft or more*	*Level*	411.53	41.979	292	42	6	24	0.14	0.57	6.96
		Mountainous	94.02	6.133	93	13	0	0	0.00	0.00	15.16
		Rolling	1396.7	134.614	984	141	19	88	0.14	0.65	7.31
	less than 5-ft	*Level*	351.31	30.605	248	35	6	20	0.20	0.65	8.10
		Mountainous	342.46	12.221	121	17	4	11	0.33	0.90	9.90
		Rolling	2005.47	95.040	968	138	22	84	0.23	0.88	10.19

Assessment of Surrogate for Identifying Developed Areas - Proximity to School Locations

As discussed earlier, one would expect that the proximity to certain land-uses might indicate more developed contexts. This is because the proximity to these developments may likely be correlated with locations with higher vehicular volumes (exposure) with increased pedestrian and driveway related activity. The evaluation included different categories of proximity to K12 schools to determine whether it may be useful as a surrogate to identify the more developed characteristics of a rural town center (population less than 5,000).

Table 24 summarizes the results for 2005 and for the 7-year period from 1999 to 2005. The annual reported number of fatal and disabling injury collisions is relatively low in the 2-mile radius from K12 schools, indicating caution in drawing conclusions based on annual results. The results also include rates for segment collisions, allowing us to assess the relative difference in rates that could be related to the more developed contexts.

The research found that annual frequencies of collisions within 2 miles of K12 schools were low and across several years exhibited the highest collision rates because of relatively low exposure.

Results therefore would suggest that proximity to K12 schools might provide way to identify segments near rural town centers. The observed differences in rates indicate that these sections have a higher observed likelihood of collisions involving pedestrians and a lower observed overall injury severity. This would be consistent with safety characteristics of rural town centers where speeds are low (lower severity collisions) and where pedestrian exposure is higher than on the rest of the network (higher levels of involvement of pedestrians).

Table 24: Collision Occurrence and Severity in Different Categories of Proximity to Schools Across Different Collision Categories

Category	Proximity to K12 Schools	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
1999 - 2005										
All Collisions	0 to 0.5mi	135.52	21.616	4035	576	27	123	1.25	5.69	186.67
	0.5 to 1mi	193.31	29.199	3943	563	55	192	1.88	6.58	135.04
	1 to 2mi	416.23	58.739	7748	1107	107	452	1.82	7.70	131.91
	Not within	4155.5	270.480	33012	4716	639	2219	2.36	8.20	122.05
Segment Collisions	0 to 0.5mi	135.52	21.616	2133	305	17	71	0.79	3.28	98.68
	0.5 to 1mi	193.31	29.199	2536	362	40	139	1.37	4.76	86.85
	1 to 2mi	416.23	58.739	5593	799	94	351	1.60	5.98	95.22
	Not within	4155.5	270.480	28274	4039	566	1956	2.09	7.23	104.53
Pedestrian Collisions	0 to 0.5mi	135.52	21.616	40	6	4	14	0.19	0.65	1.85
	0.5 to 1mi	193.31	29.199	29	4	4	9	0.14	0.31	0.99
	1 to 2mi	416.23	58.739	43	6	3	15	0.05	0.26	0.73
	Not within	4155.5	270.480	119	17	21	55	0.08	0.20	0.44
2002 - 2005										
Run-Off-the-Road Collisions	0 to 0.5mi	135.52	12.573	392	98	6	15	0.48	1.19	31.18
	0.5 to 1mi	193.31	16.978	642	161	14	40	0.82	2.36	37.81
	1 to 2mi	416.23	34.215	1627	407	38	130	1.11	3.80	47.55
	Not within	4155.5	156.008	9359	2340	211	765	1.35	4.90	59.99

When reviewing the 7-year data for 1999 to 2005, the results indicated that segments further than 2 miles from K12 schools experience higher severe collision rates than segments located closer to K12 schools. When reviewing segments within two miles of schools, the team determined that the segments within a mile of the schools exhibited even lower rates. This would be consistent with lower operating speeds in these developed contexts, i.e. confirm that this measure holds promise in terms of distinguishing between different contexts.

For 2005, fatal injury collision rates are higher in the half mile to 1 mile from K12 schools compared to any other segments on the network, but this trend did not hold when reviewing the 7-year data. Overall, fatal injury collision rates for the half mile to 1-mile region from K12 schools are higher when comparing it to the other two distance categories within the 2-mile region around K12 schools.

Results suggest that proximity to K12 schools, particularly the three categories within 2 miles of these developments, is a suitable surrogate for the more developed character of two-lane rural highways in town centers. This measure does not imply correlation with the nature of the particular development. In other words, the mere presence of schools does not increase collision rates.

Pedestrian Collisions and Proximity to School(s)

In developed contexts, pedestrian exposure is likely higher. Generally, provision is made for pedestrian movements in these contexts. It would therefore be useful to assess whether the surrogate for development would generate results that are consistent with the fact that pedestrian exposure in this context is higher. Table 24 also shows the results of an analysis of all pedestrian collisions and non-intersection related pedestrian collisions for 2005 and the seven-year period 1999 to 2005.

Note that annual and 7-year frequencies of these collisions are very low, suggesting caution in interpretation. The differences in rates suggests that segments within 2 miles of K12 schools experience higher rates of pedestrian-related collisions, particularly within half a mile of the schools.

The results indicate that proximity to K12 schools could provide a surrogate for the identification of higher levels of development. However, the results do not suggest that the K12 schools are the cause of the collisions or higher collision rates found near the locations; rather, that they are an indication of a more developed land use.

Run-Off-the-Road Collisions and Proximity to School(s)

The run-off-the-road collision type is of particular relevance when considering strategies to improve safety on two-lane rural highways. It would therefore be beneficial to determine whether the surrogate for development would be consistent with our expectation of the incidence of run-off-the-road collisions – that these collision types will be associated with areas with little or no development. The results are included in Table 24.

The results indicate that rural two-lane segments outside a 2-mile radius of K12 have the highest run-off-the-road collision rate when compared to the segments in all other locations. This finding is consistent with the fact that run-off-the-road collisions tend to occur in environments that are less developed. The results indicate that the K12 school locations as surrogates successfully identified the more developed context of rural town centers. One may also consider that other factors may influence severe run-off-the-road collision rates for these locations (such as lower levels of enforcement and emergency response as distance increases from the town center).

Proximity to Urban Boundaries and Proximity to School(s)

Results using the surrogate proximity to urban boundaries seem to hold promise in identifying transitions of rural two-lane highways into the urban areas. However, there is not a surrogate for identifying transitions from high-speed two-lane rural segments into rural town centers. Based on the results discussed earlier, one would then expect that the combination of the two surrogate measures might be helpful in identifying transition areas into rural town centers. Table 25 shows the results.

The findings indicate that the frequencies of fatal and disabling collisions are relatively low for areas within two miles from urban boundaries and within a two-mile radius from K12 schools. In terms of segment categories with fatality frequencies higher than 10 over the 7-year period, the highest overall collision frequencies were recorded for segments outside the two-mile perimeter of urban boundaries. Outside the two-mile perimeter of urban boundaries, the highest collision rates were recorded within half a mile from K-12 schools, which may be indicative of highways through less developed areas but with more localized speed reduction because of adjacent land use. When assessing severe collisions, another pattern emerges; the highest fatality rates were recorded for segments 1 to 2 miles from urban boundaries but not within 2 miles of K12 schools. This is consistent with the expected higher severe rates associated with a rural context without development (generally associated with higher speeds).

Table 25: Collision Rates per 100 Million VMT by Different Categories of Both Proximity to Urban Boundaries and School(s) for 1999 to 2005

Proximity to Urban Boundary	Proximity to K12 Schools	Total Miles	100 million VMT	Total Collisions	Average Annual Number of Collisions	Fatal Collisions	Fatal and Disabling Collisions	Fatal Collision Rate	Fatal and Disabling Collision Rate	Collision Rate
0 to 0.5mi	0 to 0.5mi	6.5	1.927	326	47	1	8	0.52	4.15	169.15
	0.5 to 1mi	20.09	4.890	600	86	12	29	2.45	5.93	122.69
	1 to 2mi	46.43	11.256	1606	229	18	89	1.60	7.91	142.68
	Not within	33.78	5.710	661	94	5	29	0.88	5.08	115.77
0.5 to 1mi	0 to 0.5mi	1.31	0.251	55	8	1	2	3.99	7.98	219.33
	0.5 to 1mi	6.88	2.157	333	48	5	20	2.32	9.27	154.41
	1 to 2mi	27.52	5.861	694	99	11	44	1.88	7.51	118.42
	Not within	30.64	6.144	713	102	16	48	2.60	7.81	116.04
1 to 2mi	0 to 0.5mi	4.97	1.351	209	30	7	18	5.18	13.33	154.73
	0.5 to 1mi	4.73	0.989	200	29	2	11	2.02	11.12	202.26
	1 to 2mi	23.3	4.845	562	80	7	31	1.44	6.40	115.99
	Not within	92.92	14.062	1837	262	27	108	1.92	7.68	130.64
Not within	0 to 0.5mi	122.74	18.087	3445	492	18	95	1.00	5.25	190.46
	0.5 to 1mi	161.61	21.163	2810	401	36	132	1.70	6.24	132.78
	1 to 2mi	318.98	36.777	4886	698	71	288	1.93	7.83	132.85
	Not within	3998.16	244.564	29801	4257	591	2034	2.42	8.32	121.85

Proximity to Locations with Liquor Licenses

The research team also evaluated safety characteristics in close proximity of locations with liquor licenses. It had limited success in distinguishing between contexts when compared to the promising results of the other two surrogates (discussed earlier). Segments outside the two-mile radius from schools and within a mile of an establishment with a liquor license had the highest fatal collision rate and fatal and disabling collision rate. The highest collision rates were recorded for segments within half a mile of K12 schools and within one mile of an establishment with a liquor license. While the results are limited, consideration of this variable in the development of multivariate models and safety performance functions would be appropriate.

Other

The analysis included reviewing speed limit categories and proximity to school(s). The results were inconclusive.

DISCUSSION OF ANALYSIS RESULTS

This chapter presented the results of an extensive and systematic analysis of safety on two-lane rural state highways in Washington. The research team provided several summaries of results that provide comparisons of collision frequencies and rates for collisions and more severe injury collisions (fatal injury severity and fatal and disabling injury severity collisions). These results are presented by collision type, safety characteristics across different features such as horizontal curves and shoulder widths, and different contexts.

This analysis identified particular segments with higher collision and/or severe collision rates. The emphasis of the evaluation was on the more severe collision categories: fatal injury collisions, and then the grouping of fatal and disabling injury collisions.

The results may be helpful when considering safety investments on two-lane rural state highways in Washington. It is important to note that while a particular group of segments may experience higher severe collision rates, appropriate countermeasures may not be available or that available countermeasures may not necessarily be compatible with site restrictions.

Comparing the Two-Lane Rural Highway System with the Rest of the State Network

When comparing the two-lane rural highways with the rest of the state network, a number of findings are of particular interest. Collisions on two-lane rural highways tend to be more severe. Dominant collision types include run-off-the-road collisions, roadside related collisions (hitting fixed objects), access related collisions, and collisions involving centerline crossovers. The assessment also indicated that the incidence of behavioral issues that impacts safety, such as the proportion of collisions involving drugs and/or alcohol, are more pronounced on these highways as well.

Terrain Types

Mountainous segments, when compared with those on level and rolling terrain experience the highest collision and severe collision rates. This may be the result of more demanding environments (particularly in extreme weather) and restricted clear zones (resulting from challenging topography and environmental-related restrictions).

Shoulder Widths

The biggest differences in collision rates were observed for two categories of right shoulder widths: those less than 5-ft wide and those of 5-ft or more. Segments with right shoulder widths less than 5-ft experiences higher collision and severe collision rates compared to those with shoulder widths of 5-ft or more.

Horizontal Curves

Collision and severe collision rates are higher on horizontal curves compared to straight segments. In particular, when only considering horizontal curves, results show that curves with shoulder widths less than 5-ft had higher collision and severe collision rates compared to curves with shoulder widths of 5-ft or more. This finding is consistent with the analysis results earlier that incorporated terrain type into the analysis. The curve segments in mountainous terrain, and curve segments with shoulder widths less than 5-ft on the other terrain types experiences similar rates.

When only considering horizontal degree of curvature, an increase in degree of curvature appears to be associated with higher collision and severe collision rates (although to a lesser extent for severe collision rates).

However, when comparing curve segments in eastern and western Washington, differences are detected in rates across different degrees of curvature. In eastern Washington, the severe collision rates tend to increase only substantially at degrees of curvature of 10 or more while in eastern Washington, it appears that rates steadily increase from degrees of curvature of six. A multivariate approach that incorporates differences in weather and pavement surface conditions may shed light on this difference.

Consideration of terrain type further identifies segments with higher rates: level and mountainous terrain for degree of curvature of eight or more (the differences in rates for mountainous terrain are more pronounced). It is therefore likely that these differences are indicative of more challenging environments (mountainous terrain) or areas where driver demand may be lower (level terrain).

WSDOT Regions

The Northwest, Southwest and Olympic Regions experience the highest collision rates while the highest fatal and disabling collision rates were observed in the Olympic and Southwest Regions. When reviewing different terrain types across region, the differences in collision and severe collision rates varied. The difference in rates between regions may relate to weather and other factors that could not be considered in this univariate assessment.

The results of assessment across curvature and region (eastern versus western) indicate that there may be a more complex underlying behavioral and contextual relationship between degree of curvature and region (eastern versus western). Multivariate modeling approaches that can account for weather, pavement, and vertical curvature differences, among others, could potentially shed light on this complex underlying behavior. Such analysis was outside the scope of this particular project.

Functional Class

Review of rates across the different functional classes alone renders similar rates across the different types. However, when considering different speed limit categories, another pattern emerges.

The highest severe collision rates were observed on rural minor arterials with speed limits of 40-mph and higher but less than 55-mph and rural collectors with speed limits of 55-mph and higher. The minor arterials would likely have lower design speeds and lower levels of access control than major arterials.

Run-Off-the-Road Collisions

Run-off-the-road collisions are the most common collision type for two-lane rural highways. Mountainous terrain segments have higher associated collision and severe collision rates than other terrain types. Segments on horizontal curves, particularly those with a degree of curvature of 10 or more experience the highest run-off-the-road collision and severe collision rate. It is likely that the higher rates indicate that run-off-the-road collisions are more likely on segments that present challenging conditions, such as mountainous terrain or segments with sharp horizontal curvature.

Collisions Involving Crossovers

The collision and severe collision rates for collisions involving crossovers were the highest for level highways with shoulder widths less than 5-ft.

Surrogates for Distinguishing Between Contexts

The analysis also included an evaluation of two possible surrogates to assist in distinguishing between contexts: first transition areas, and second more developed areas (such as rural town centers).

Surrogate for Identifying Transition Areas. The project evaluated proximity to urban boundaries as a surrogate for identifying transition areas. Results appeared to be promising. Segments half to a mile from urban boundaries exhibit slightly higher overall fatal injury severity rates – this region may therefore represent transitions. The incidence and rates of run-off-the-road collisions on segments located more than 2 miles from urban boundaries were higher. This may be indicative of environments with little or no development. This surrogate also allowed for the identification of a subgroup of segments with shoulders 5-ft or wider that are associated with higher crossover rates in mountainous terrain – those located half a mile to 1 mile from urban boundaries. This may seem contradictory to the anecdotal perception that crossover collisions are more likely where shoulder widths are restricted. However, this may be indicative of the reduced levels of risk perceived by drivers on mountainous segments that have shoulders of 5-ft or more and the higher speeds associated with transition areas.

When reviewing crossover collision rates for segments with shoulder widths of 5-ft and more, the observed rates were much higher. It likely reflects lower perceived risk responses by drivers (this was noted earlier for mountainous areas with shoulder widths of 5-ft or more). The highest frequency of fatal and disabling injury collisions occurred on rolling terrain with shoulder widths of 5-ft or more that are located more than 2 miles from urban boundaries.

Segments within half to 1 mile from urban boundaries, on mountainous terrain and with shoulder widths of 5-ft or had the highest crossover collision rates. Note that no fatal or disabling injury collisions were recorded over the 7-year period for these segments. This may reflect lower speed conditions where the resulting crossover collision severity would be much lower.

While the surrogate for the transition area did not necessarily identify transition areas (validation with site conditions are necessary), the surrogate did allow for the identification of a subgroup of segments that have higher crossover collision rates while having shoulder widths of 5-ft or more (i.e. those more than two miles from urban boundaries). This may be particularly helpful because of the relatively low incidence of this particular collision type.

Surrogate for identifying more developed contexts. Different categories of close proximity to K12 schools were tested as a surrogate to identify highways in more developed areas (such as rural town centers). The surrogate showed great promise. Results were consistent with the expected characteristics of more developed contexts. 5 different categories were evaluated (distance from K12 school): 0 to half a mile, half a mile to 1 mile, and 1 mile to 2 miles, 0 to 2 miles, more than 2 miles. Pedestrian-related fatal injury severity collision rates (particularly those that are intersection-related) are higher within the 2-mile area from schools (particularly within half a mile from the school location). Run-off-the-road collisions and associated severe injury rates tend to be higher on segments that are located further than 2 miles from K12 schools. The analysis also indicated that proximity to K12 schools provide more insight into different collision behavior. The differences in rates and severities across different collision types may be beneficial in the scoping of investment approaches and countermeasure selection process.

From these results, it is apparent that the relationships and collision behavior across different collision severities is complex. For this reason, it would be beneficial to investigate alternative safety modeling strategies. Alternative modeling methods would allow for the quantification of the more complex and underlying correlation between collision experience and the severe injury collision categories (fatal injury and fatal and disabling injury collisions). It would also allow for the inclusion of socio-demographic, weather, and other elements that may explain variations across segments.

CHAPTER 5 DECISION MATRIX FOR COUNTERMEASURES ON TWO-LANE RURAL HIGHWAYS

INTRODUCTION

The term "two-lane rural highways" describes any roadway that is located outside urban boundaries, with populations of 5,000 or more and that are WSDOT operated.

As discussed previously, WSDOT recognizes that the traditional ranking of high collision frequency locations does not necessarily reflect the full needs related to safety on two-lane rural highways and that these facilities requires an approach that addresses action(s) on a corridor and system-wide level. This project therefore first focused on identifying segments with particular characteristics or collision types or user groups through a systematic assessment. Segments with higher associated rates could be helpful in determining which parts of the network may have higher potential for safety related investments on two-lane rural highways.

Traditional countermeasure selection procedures focus on the identification of a particular site exhibiting particular target collision types. A set of alternative countermeasures are considered and a particular countermeasure is selected and implemented. Measures are implemented with the expectation that it has a high potential to reduce the collision severity and/or frequency at the particular site.

This chapter presents the policy and legislative framework for countermeasure implementation, and the process that was followed for the development of a decision-matrix for the selection of countermeasures on two-lane rural highways in Washington. The elements of the decision-matrix are presented and discussed.

LEGISLATION AND POLICIES

The improvement of safety on road networks has been part of the management of roadways for many years. The Highway Safety Improvement Program (HSIP) forms an integral part of safety improvement programs of state departments of transportation. The Hazard Elimination Program (HEP) and Highway-Rail Grade Crossings (HRGC) are part of the HSIP. These programs were established through the Highway Safety Act of 1973 with specific requirements set out in Section 130 and 152 of Title 23, *United States Code*. The primary objective of the Act was to reduce the frequency and severity of motor vehicle collisions (Epstein, Corino and Neumann 2002). In 1991, with the introduction of the Intermodal Surface Transportation Efficiency Act of 1991, the HEP and HRGC became part of the Surface Transportation Program (STP) (FHWA 2001). 23 CFR 924 specify that the HSIP "shall consist of components for planning, implementation, and evaluation of safety programs and projects" and allows states to develop their own processes with stakeholders in the particular state.

With the introduction of SAFETEA-LU, some legislative changes occurred that affects the funding levels and requirements for, among others, the HSIP. It defines a highway safety improvement project as a project that "*(i) corrects or improves a hazardous road location or feature; or (ii) addresses a highway safety problem*". Projects that would qualify as a highway safety improvement project are shown in Figure 20 (SAFETEA-LU, 23 U.S.C. Section 148 2005). SAFETEA-LU introduced a new federal requirement, the development of a Strategic Highway Safety Plan (SHSP) by each state.

The purpose of the SHSP is to state (and therefore facilitate) the goals, objectives, and key emphasis areas for a comprehensive statewide framework aimed at reducing the frequency and severity of collisions. In February 2007, the Governor of Washington State approved *Target Zero*, Washington's SHSP. *Target Zero* highlights the higher severity associated with collisions on rural highways and identifies run-off-the road collisions as a major collision type in terms of the resulting fatalities in Washington State. All the priority objectives and strategies in the SHSP relates to two-lane rural highways in some fashion, ranging from the behavioral to engineering to medical related aspects. The SHSP therefore supports activities towards the reduction of the frequency and severity of collisions on two-lane rural highways across different collision types and focus areas. The next section introduces decision-matrices, as a lead-in into the decision-matrix proposed for countermeasure selection on two-lane rural highways.

DECISION-MATRICES

Decision-matrices are widely used in the highway safety industry. A variety of decision-matrices were reviewed for the purpose of this project. These matrices varied greatly in terms of approach and content, suggesting that a decision-matrix can take many different forms. The variation also suggested that the format is largely dictated by the particular needs of the user(s).

A framework for the decision-matrix was presented to WSDOT in June 2007, and the proposed approach was supported in concept.

The proposed decision-matrix consists of two parts: Part A provides a summary of site characteristics suggesting higher potential for improvement for a master list of collision types and Part B provides a list of countermeasures and countermeasure groupings with detailed information pertaining to particular contexts, appropriate use, and impact of the particular measure where such information was readily available.

Highway Safety Improvement Projects

- "Intersection safety improvement.
- Pavement and shoulder widening
- Installation of rumble strips or another warning device
- Installation of a skid-resistant surface
- An improvement for pedestrian or bicyclist safety or safety of the disabled.
- Construction of any project for the elimination of hazards at a railway highway crossing
- Construction of a railway-highway crossing safety feature, including installation of protective devices.
- The conduct of a model traffic enforcement activity at a railway-highway crossing.
- Construction of a traffic calming feature.
- Elimination of a roadside obstacle.
- Improvement of highway signage and pavement markings.
- Installation of a priority control system for emergency vehicles at signalized intersections.
- Installation of a traffic control or other warning device at a location with high accident potential.
- Safety-conscious planning.
- Improvement in the collection and analysis of crash data.
- Planning, integrated interoperable emergency communications equipment, operational activities, or traffic enforcement activities (including police assistance) relating to workzone safety.
- Installation of guardrails, barriers (including barriers between construction work zones and traffic lanes for the safety of motorists and workers), and crash attenuators.
- The addition or retrofitting of structures or other measures to eliminate or reduce accidents involving vehicles and wildlife.
- Installation and maintenance of signs (including fluorescent, yellow-green signs) at pedestrian-bicycle crossings and in school zones.
- Construction and operational improvements on high risk rural roads."

Figure 20: Projects that Qualify as a Highway Safety Improvement Project (taken as is from (SAFETEA-LU, 23 U.S.C. Section 148 2005))

THE DEVELOPMENT OF A DECISION-MATRIX FOR COUNTERMEASURE SELECTION ON TWO-LANE RURAL HIGHWAYS

Figure 21 illustrates the four-phased approach that the research team took to develop the proposed decision-matrix. In the first phase, an extensive systematic assessment was undertaken, identifying particular collision types and site characteristics that would indicate higher potential for safety investment. In the second phase, the team used the results from this analysis for the development of a set of likely areas of potential highest benefit from safety investment. These included a) particular collision types, b) particular geometric and roadway features, c) different users, and d) particular contexts such as transition areas, and rural areas with urban features. Figure 22 shows the different areas investigated during the analysis. The analysis and prioritization focused on the more severe collision outcomes or collision types showing higher portions of fatal and disabling injury collisions when compared to others. The analysis also investigated segments with higher rates of fatal and disabling (higher severity) injury collisions.

During the third phase of development, a master list of collision types was generated. This list references the collision groups typical of two-lane rural highways. In the fourth phase a master list of countermeasures were developed. This list provides a detailed description of the context and appropriate use for each countermeasure (where available), along with demonstrated impact (where available).

The list of areas with higher associated rates allows the Department to evaluate system-wide strategies as part of an overall effort to improve safety. These strategies target parts of the network with the ultimate goal of investment to reduce fatalities. The intent of the master list of collision types, countermeasures, and the detailed countermeasure descriptions is to allow the user to identify and evaluate potential countermeasures that would have high potential in reducing severity or frequency of target collision types.

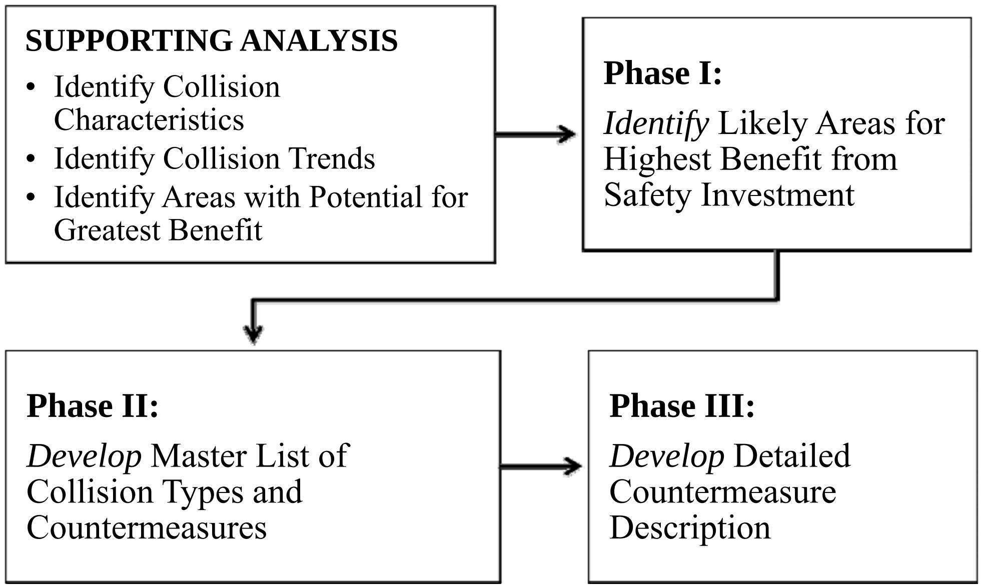


Figure 21: Process for the Development of a Decision-Matrix for Cost-Effective Countermeasure Selection on Two-Lane Rural Highways

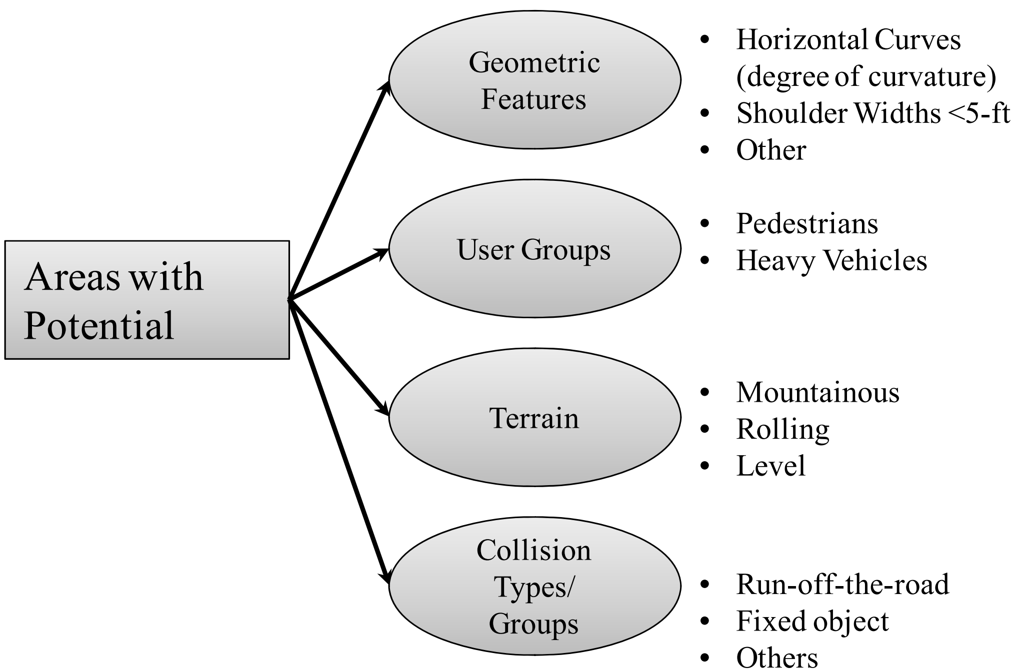


Figure 22: Approach to Systematic Assessments to Identify Areas with Possible Higher Potential for Safety Improvements on Two-Lane Rural Highways

As described earlier in Chapter 2, countermeasure related compendiums could take various forms. The proposed Decision-Matrix offers a compendium of measures as part of Part B of the matrix. Results shown in this compendium refers to individual study reports, provide some notes for each countermeasure, and do not include results from meta-analysis and expert panels that were recently developed as part of other research projects. Where possible, the team reported results specific to Washington State.

SYSTEMATIC ASSESSMENT RESULTS: POSSIBLE AREAS FOR HIGHER POTENTIAL OF SAFETY IMPROVEMENT

The purpose of this section is to present the various diagrammatic presentations of analysis results from Chapter 5, the systematic assessment of the entire two-lane rural network of state maintained roads in Washington. Table 26 to Table 36 provide summaries by collision type. Part A of the Decision Matrix summarizes these tables (the decision-matrix is part of Appendix A).

Table 26: Target Collision Types and Contexts for Horizontal Curve Features

Geometric Feature	**Horizontal Curve**	
Target Collision Types	**All Collision Types**	**Run-off-the-Road Collisions**

Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	• Horizontal Curves on mountainous terrain (any shoulder width category)
	• Horizontal Curves with shoulder width less than 5-ft – all terrain types
	• Horizontal Curves with degree of curvature:
	  o Level terrain: degree of curvature of 8 or more
	  o Mountainous terrain: degree of curvature of 8 or more
	  o Rolling terrain: degree of curvature of 10 or more
	  o Eastern Washington: degree of curvature of 6 or more
	  o Western Washington:
	    ▪ degree of curvature of 5 or more but less than 6; and
	    ▪ degree of curvature of 10 or more
	• Horizontal Curves with shoulder width more than 5-ft in mountainous areas.
		Horizontal Curves with degree of curvature of 10 or more

Table 27: Target Collision Types and Contexts for Different Terrain Types

Context	**Terrain**		
Target Collision Types	**All Collisions**	**Run-off-the road**	**Centerline Crossovers**
Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	• Mountainous terrain • Horizontal curves with degree of curvature of 10 or more • Mountainous terrain: particularly Olympic, South Central, and Eastern Regions	• Mountainous terrain	In order of priority: • Mountainous terrain with shoulder width of 5-ft or more that are located more than 2 miles from urban boundaries • Rolling terrain with shoulder widths of 5-ft or more that are located more than 2 miles from urban boundaries • Level terrain, shoulders of 5-ft or more and located 1 to 2 miles from urban boundaries

Table 28: Target Collision Types and Contexts for Segments with Shoulder Widths of 5-ft or More

Geometric Feature	**Right Shoulder Widths 5-ft or More**		
Target Collision Types	**All**	**Run-off-the road**	**Centerline Crossovers**
Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	Horizontal curves in mountainous terrain with shoulder widths of 5-ft or more	Mountainous terrain segments with right shoulder widths of 5-ft or more	In order of priority: • Mountainous terrain and right shoulder width of 5-ft or more within half to 1 mile from urban boundaries • Rolling terrain with shoulder widths of 5-ft or more that are located more than 2 miles from urban boundaries • Mountainous terrain and right shoulder width of 5-ft or more located more than 2 miles from urban boundaries • Level terrain, right shoulders of 5-ft or more and located 1 to 2 miles from urban boundaries

Table 29: Target Collision Types and Contexts for Segments with Shoulder Widths Less than 5-ft

Geometric Feature	**Right Shoulder Widths Less than 5-ft**		
Target Collision Types	**All**	**Run-off-the Road Collisions**	**Centerline Crossovers**
Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	Horizontal curves in mountainous terrain with shoulder widths less than 5-ft	Shoulder widths less than 5-ft, particularly mountainous and rolling terrain	Mountainous terrain with right shoulder width of less than 5-ft that are located more than 2 miles from urban boundaries

Table 30: Target Collision Types and Context Characteristics for Transition Area Surrogate Measure

Context	**Transition Areas** Surrogate: half a mile to 2 miles from urban boundaries	
Target Collision Types	**All**	**Centerline Crossovers**
Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	Mountainous terrain	Level terrain, right shoulders of 5-ft or more and located 1 to 2 miles from urban boundaries

Table 31: Target Collision Types and Context Characteristics for Rural Areas Outside Transition Areas Using the Transition Surrogate Measure

Context	**Rural Areas outside Transition Areas** Surrogate: more than 2 miles from urban boundaries		
Target Collision Types	**All**	**Run-off-the road**	**Centerline Crossovers**
Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	Mountainous terrain	More than 2 miles from urban boundaries or K12 schools	In order of priority: • Mountainous terrain with shoulder width of less than 5-ft that are located more than 2 miles from urban boundaries • Rolling terrain with shoulder widths of 5-ft or more that are located more than 2 miles from urban boundaries • Mountainous terrain and shoulder width of 5-ft or more located more than 2 miles from urban boundaries

Table 32: Target Collision Types and Context Characteristics for the Level of and/or Presence of Urban Characteristics Using Surrogate Measure

Context	**Level of and/or Presence of Urban Characteristics** Rural with urban characteristics (surrogate: proximity to K12 schools)			
Target Collision Types	**All**	**Pedestrian Collisions**	**Pedestrian Collisions that are not intersection or intersection-related**	**Run-Off-the-Road Collisions**
Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	• Rural with urban characteristics, i.e. segments in small rural towns (surrogate measure: segments within half a mile of K12 schools) • Higher severity collisions: Rural character (no urban features) (surrogate measure: segments located more than 2 miles from K12 schools)	Order of priority: • Rural with urban characteristics, i.e. segments in small rural towns (surrogate measure: segments within half a mile of K12 schools) • Rural with some urban characteristics, i.e. segments in small rural towns (surrogate measure: half a mile to 1 mile from K12 schools)	Order of priority: • Rural with urban characteristics, i.e. segments in small rural towns (surrogate measure: segments within half a mile of K12 schools) • Rural with some urban characteristics, i.e. segments in small rural towns (surrogate measure: half a mile to 2 miles from K12 schools)	Rural with no urban characteristics (surrogate measure: segments more than 2 miles from K12 schools)

Table 33: Target Segment Collision Types and Context Characteristics Showing Highest Likelihood for Benefit

Specific Collision Group	***Segment Collisions***		
Target Collision Types	Run-off-the-road collisions	Centerline crossover collisions, particularly head-on and sideswipe opposite direction categories	Rear-end collisions • multiple vehicle collision where both vehicles were going straight and moving • multiple vehicle collision where both vehicles were going straight, one stopped and one moving

Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	• Rural environments (more than 2 miles away from K12 schools)
	• Segments with right shoulder width less than 5-ft
	  o Straight segments
	  o Segments on horizontal curves
	  o Mountainous terrain: particularly degrees of curvature of 3 or more
	  o Level terrain: particularly degrees of curvature of 3 or more
	  o Rolling Terrain: particularly degrees of curvature of 10 or more
	• Segments with right shoulder widths of 5-ft or more
		• Level terrain, where right shoulder widths < 5-ft and within 1/2 a mile to 1 mile from urban boundaries
		• Mountainous terrain, where right shoulder widths < 5-ft and more than 2 miles from urban boundary
		• Rolling terrain, where right shoulder widths < 5-ft and and a half to 2 miles from urban boundaries	

Special notes:	Severity of collisions where vehicle leaves the roadway are affected by roadside characteristics (clear zone width, fixed objects, and roadside features)		

Table 34: Major Target Intersection and Intersection-Related Collision Types

Specific Collision Group	**Intersection and Intersection-Related Collisions**		
Intersection Traffic Control	**STOP control**	**YIELD control**	**Unsignalized and not STOP or YIELD controlled**
Target Collision Types	• Hits Fixed Object • Entering at Angle • One Vehicle Leaving Driveway Access • From Same Direction, Both Going Straight, One Stopped, Rear end	• Entering at Angle • Hits Fixed Object • One Vehicle Leaving Driveway Access • From Opposite Direction, One Turning Left, One Straight • Vehicle Going Straight Hits Pedestrian • From Same Direction, Both Going Straight, One Stopped, Rear end • Vehicle Overturns • One Vehicle Entering Driveway Access • Bicycle • Vehicle Turning Left Hits Pedestrian • From Opposite Direction, All Others Category • From Same Direction, All Others Category	• One Vehicle Leaving Driveway Access • From Opposite Direction, One Turning Left, One Straight • Vehicle Going Straight Hits Pedestrian • Entering at Angle
Special notes: Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	Intersection collision rates were not calculated as part of this project. The intersection and intersection-related collisions are not associated with particular locations, making analysis particularly difficult. The abovementioned collision types represent the collision types that are the major collision types at each of the control types. Note that signalized intersections on two-lane rural roads are not included in this table because those intersections did not appear to be an area requiring particular attention in terms of focused efforts for safety improvement.		

Table 35: Major Target Collision Types Involving One or More Heavy Vehicles

Specific User Group	**Collisions Involving One or More Heavy Vehicles**
Target Collision Types	• From Opposite Direction, Both Going Straight, Sideswipe • From Opposite Direction, Both Moving, Head-On • From Opposite Direction, All Others • Hits Fixed Object • Vehicle Overturns • Entering at Angle • One Vehicle Entering Driveway Access • From Same Direction, All Others • From Same Direction, Both Going Straight, Both Moving, Rear end • One Vehicle Leaving Driveway Access • From Same Direction, Both Going Straight, One Stopped, Rear end

Table 36: Major Target Collision Types Involving One or More Pedestrians and Context Characteristics Showing Highest Likelihood for Benefit

Specific User Group	**Collisions Involving One or More Pedestrians**	
Target Collision Types	All Pedestrian Collisions • Vehicle Going Straight Hits Pedestrian • Vehicle Backing Hits Pedestrian • One Vehicle Parked, One Moving • Vehicle Turning Right Hits Pedestrian • Vehicle Turning Left Hits Pedestrian	Pedestrian Collisions that are intersection or intersection related
Specific contexts exhibiting higher injury severity collision rates and/or overall collision rates	Order of priority: • Rural with urban characteristics, i.e. segments in small rural towns (surrogate measure: segments within half a mile of K12 schools) • Rural with some urban characteristics, i.e. segments in small rural towns (surrogate measure: half a mile to 1 mile from K12 schools)	Order of priority: • Rural with urban characteristics, i.e. segments in small rural towns (surrogate measure: segments within half a mile of K12 schools) • Rural with some urban characteristics, i.e. segments in small rural towns (surrogate measure: half a mile to 2 miles from K12 schools)

MASTER LIST OF COLLISION TYPES AND POTENTIAL COUNTERMEASURES

Part A of the Decision Matrix (included as part of Appendix A) presents a master list of collision types and potential countermeasure groups. The table summarizes the major collision types for two-lane rural roads (as listed in Part A of the Decision-Matrix), with an emphasis on collision types resulting in fatal and disabling injuries. This table also presents an indication of the particular countermeasure group that can be considered to target the particular collision type/ group. Part B of the Decision Matrix (also provided in Appendix A) provides a countermeasure matrix, organized by countermeasure group and containing the expected benefits related to the particular countermeasure.

Appropriate Use of the Master List of Collision Types and Potential Countermeasures

The countermeasures presented in Part C of the Decision-Matrix represent result summaries from a comprehensive literature review with notes reflecting findings discussed in Chapter 4. It is not exhaustive in terms of presenting all possible countermeasures that may be appropriate for a particular site and reflects literature on particular measures. The benefits and associated consequences of each countermeasure reflect findings from the previously reviewed literature. The statistical and scientific rigor of the literature was not assessed and in some cases, analysis suggests benefits but could not be supported by statistical validation. This does not mean that the measure would not be effective, but the reported effect may be a direct result of small sample sizes or a limited number of sites evaluated. While it is recommended for use as a guide, it is not a replacement for WSDOT policy, engineering judgment and site-specific assessment and consideration. This included information does not constitute a standard or requirement.

CHAPTER 6 CENTERLINE RUMBLE STRIPS ON TWO-LANE RURAL HIGHWAYS

INTRODUCTION

Centerline rumble strips (CLRS) on two-lane rural roads alert drivers when their vehicles cross the centerline through provision of vibro-tactile information. The primary purpose of CLRS is the prevention of collisions with opposing traffic. This chapter briefly describes a basic literature review on centerline rumble strips in the U.S. and then provides results for the limited before-after study of centerline rumble strips.

CENTERLINE RUMBLE STRIPS – A LITERATURE REVIEW

The purpose of this section is to summarize the findings from a basic literature review of the safety benefits of CLRS installations on two-lane rural highways. First the target collision types for CLRS is discussed. Second, the experience of other DOTs, as reported by other research studies is described. Third, the documented benefits of CLRS are summarized. This is followed by a brief discussion of the findings of a study by Rasanen (2005) that is of particular interest when considering the installation of CLRS and the assessment of analysis results for these installations.

Target Collision Types for CLRS

A target collision type is defined as the particular collision type that one would expect that a specific countermeasure would impact (e.g. frequency, severity distribution). These particular collision types are closely reviewed in a before-after analysis of a countermeasure.

Zieba from Missouri Department of Transportation defined the target collision types for CLRS as "any cross- centerline (cross-over) crash that begins with a vehicle encroaching on the opposing lane". This cross-over collision definition by Zieba excludes "any crash that began by running off the road to the right and overcorrecting and any crash that began by a vehicle going out of control due to water, ice, snow, etc., prior to crossing the centerline" (Russel and Rys 2006). Rasanen (2005) points out that, although CLRS may not prevent a collision completely it can be expected to reduce collisions. He suggests that, from a human factors perspective, it offers the driver of a vehicle the opportunity to respond an errant maneuver with a timelier steering or braking response.

Experience from Departments of Transportation

A survey that Russel and Rys (2006) completed in 2003, determined that the use of CLRS is mostly limited to no-passing sections or curves. They found that CLRS were in use by at least 22 states (including Arizona, California, Connecticut, Colorado, Massachusetts, Missouri, Oregon, Pennsylvania and Washington). During the survey, Dorman (2000) indicated that CLRS may be beneficial on long straight sections when drivers fall asleep and drift across the centerline. They did not receive any negative feedback regarding the use of CLRS from the surveyed states. Concerns mentioned to Russel and Rys (2006) during their interview included: the visibility of centerline marking visibility, the deterioration of pavement, and the effect of CLRS on bicycles and motorcyclist on particularly narrow roadways. Their research did not find any conclusive evidence of negative effects of CLRS (2005).

Concerns regarding deterioration in the effectiveness of CLRS because of sand and debris have been brought forth anecdotally. Yet, Outcalt found that the accumulation of sand and debris in the grooves during winter did not appear to reduce the effectiveness of the rumble strips (2001).

Reported Benefits of CLRS

This section briefly summarizes results of the evaluation of CLRS in terms of collision reduction.

Table 37 shows the results of CLRS benefits from the literature review. It appears that few studies were able to identify statistically significant changes. It can be surmised that this inability resulted from small sample sizes used in the study and not from the effectiveness of the CLRS.

Table 37: Benefits of CLRS

Location	Benefit/ Collision Reduction	Notes
Delaware	B/C= 110 to 1	• Miles: 2.9 • Relatively short before-after periods (Russel and Rys 2006) • No information available regarding before-after study methodology
	Opposing injury collisions: 87% All opposing* collisions: 81%	• Miles: 2.9 • Sites: 1 • Empirical Bayes before-after study (Persaud, Retting and Lyon 2003)
California	All collisions: 14%	• Miles: 47.8 • Sites: 29 • Empirical Bayes before-after study (Persaud, Retting and Lyon 2003)
Colorado	All collisions: 11% All opposing* collisions: 13%	• Miles: 16.9 • Sites: 10 • Empirical Bayes before-after study (Persaud, Retting and Lyon 2003)
	Head-on Collisions: 34% Sideswipe Collisions: 36.5%	• Simple before-after study incorporating ADT (evaluation of rate change) (Outcalt 2001)
Maryland	All injury collisions: 38%	• Miles: 30.4 • Sites: 11 • Empirical Bayes before-after study (Persaud, Retting and Lyon 2003)
Oregon	All collisions: 46%	• Miles: 3.1 • Sites: 2 • Empirical Bayes before-after study (Persaud, Retting and Lyon 2003)
Washington	All injury collisions: 25% All collisions: 24%	• Miles: 43.5 • Sites: 21 • Empirical Bayes before-after study (Persaud, Retting and Lyon 2003)

* Opposing-direction collisions include head-on collisions and sideswipe opposite direction collisions.

<u>Lane Keeping Along Curves (Rasanen 2005)</u>

This subsection briefly summarizes the findings of a study by Rasanen at VTT in Finland (2005). Rasanen evaluated the effect of centerline rumble strips on the lane keeping behavior of drivers on curves. In his experiment, he tested the differences between a worn centerline, a repainted centerline, and a milled rumble strip barrier line.

Rasan found that with the milled barrier line, traffic did not encroach into opposing lanes when there was oncoming traffic. In free-flow conditions with no oncoming traffic, the centerline encroachment reduced from 9.2% with worn centerlines, to 2.5% with the repainted line. The rumble strip installation did not result in further changes.

The effect on trucks was much larger: with a worn barrier line, the encroachment was 16.4%. The encroachment reduced to 12.1% when the centerline was repainted and to 6.2% with the installation of centerline rumble strips. This finding suggests possible use in reducing collisions with heavy vehicles.

The researchers found that vehicles in a queue tended to encroach less when there was no oncoming traffic with centerline rumble strip as compared to a worn centerline condition (reducing from 9.2% with the worn line to 2.3% with the CLRS). They also found that changes in the centerline installation did not affect the free-flow speeds and compliance with no-passing restrictions improved. This implies that the application of CLRS effect both unintentional centerline crossovers (e.g., fatigue) and intentional encroachments (e.g. *cutting of curves* and encroachment by vehicles in queuing conditions).

This section summarized the major findings in the literature review. Findings of this review were used to refine the approach to the analysis of a selected number of sites where CLRS were installed between 2001 and 2003. The empirical setting and results from this analysis is described in more detail in the remainder of this chapter.

EMPIRICAL SETTING OF THE ANALYSIS

The WSDOT design office provided a list of rumble strip installations since 1995 to the research team. This data was parsed into individual segments based on rumble strip presence for the years 1995, 1996, and 1999-2005. In some cases, rumble strips were removed for a short time to allow for improvement and preservation construction and then re-installed as part of these projects. Since the removal of rumble strips was short lived, these segments were identified as having rumble strips starting with their initial installation date. The segmented rumble strip dataset was then combined with the data for two-lane rural roads for before-after analysis.

When identifying the data collection before and after periods, only full years were used, starting on January 1st and ending on December 31st. This is necessary because traffic volumes and other roadway related data records changes on an annual basis versus a monthly basis. It also allowed for the elimination of novelty effect and influences by construction/maintenance related activities on flow and safety experience. Installation records do not always contain information regarding the specific starting date of construction or maintenance, reducing the ability to eliminate periods for exclusion in the analysis.

A number of approaches are available for before-after analysis. The next section briefly describes each of these methodologies. Each method requires increasing levels of effort, input data, and all contain their own assumptions and limitations. The analysis approach used in this project is an expansion and mathematical formalization of the methods described by Hauer (1997). The reader can refer to the following two reports for a detailed description of the various methodologies (these reports also include derivation of formulas and statistical foundation of the various methodologies): *The Impact of Red Light Cameras (Automated Enforcement)* (Washington and Shin 2005) and *Evaluation of the Loop 101 Photo Enforcement Demonstration Program* (Washington, Shin and van Schalkwyk 2007).

Extent of the Centerline Rumble Strip Installations on State Highways

WSDOT installed approximately 318 miles of centerline rumble strips across the state. Approximately 151 miles of CLRS are in western Washington and 167 miles are in eastern Washington. In terms of shoulder width, approximately 197 miles were installed on roadways with right shoulder widths less than 5-ft. Approximately 84 miles of the installations are provided on horizontal curves. 207 miles of CLRS are installed on rolling terrain, 104 miles on level terrain, and 8 miles in mountainous terrain.

To perform a before-after study, the team needed traffic volume data and could only select sites where no other geometric changes (such as addition of turning lanes etc.) occurred. Using these criteria, the research team selected 46.6 miles of these segments with CLRS installed between 2001 to 2003. This would allow for control of changes to the network and ensure that at least two years of before and after data were available for the analysis. Ideally one would prefer to select only locations for which 3 years of data are available before and after installation, but this would have reduced the sample to only 22 miles of CLRS.

The 46.6 miles of CLRS that were evaluated as part of this before-after study, were all located in eastern Washington. 36 Miles of the CLRS are on straight segments where shoulder widths were 5-ft or more. The remaining 10.6 miles were installed on horizontal curves, consisting of 3.72 miles with a degree of curvature less than 1, and 2.63 miles with a degree of curvature of 2 or more but less than 3. The remainder of the horizontal curve segments was all in categories representing values less than 7 degrees of curvature. In terms of distribution across terrain types, 21.96 miles were located on level terrain and 24.65 on rolling terrain.

In the development of SPFs (safety performance functions) for the evaluation of these measures, the functions were developed using similar sites, i.e. sites with shoulder widths of 5-ft or more, horizontal curvatures of less than 7, level and rolling terrain, sites without rumble strips, and only segments located in eastern Washington. These conditions represent 1156 miles of two-lane rural highway.

The first step in any before-after study is the identification of target collision types. The next section provides a discussion of this process.

Target Collision Types

One installs CLRS with the expectation that it would reduce collisions and collision severity. As discussed earlier, one recognizes that countermeasures usually affect only a subset of the collisions. Also, that the measure may result in the shift of collision frequencies across severities and/or collision types. Therefore, as a first step in any before-after study one identifies the target collision type(s).

The research team selected several collision types for the analysis: centerline crossover collisions, head-on collisions, sideswipe-opposite direction, opposite direction (head-on and sideswipe opposite direction), nighttime collisions, injury collisions, and run-off-the-road collisions. Where the sample sizes were extremely small, the results were not included in the report. Table 38 provides a summary of the collision frequencies observed at the CLRS sites.

Table 38: Observed Collision Frequencies at the CLRS rumble strip sites by Collision Type and Injury Category

Collision Type	Injury Category	Observed Collisions in Before Period	Observed Collisions in After Period
All Types	All categories	247	253
	Injury Collisions	121	119
	PDO*** Collisions	126	134
Crossover*	All categories	43	32
	Injury Collisions	28	19
	PDO Collisions	15	13
Head-on	All categories	6	4
	Injury Collisions	6	3
	PDO Collisions	0	1
Nighttime	All categories	106	122
	Injury Collisions	44	54
	PDO Collisions	62	68
Opposite Direction**	All categories	8	7
	Injury Collisions	8	4
	PDO Collisions	0	3
Sideswipe Opposite Direction	All categories	2	3
	Injury Collisions	2	1
	PDO Collisions	0	2

* Crossover collisions likely include collision types that cannot be addressed through CLRS
** Opposite direction collisions include only head-on and sideswipe opposite direction collisions.
*** PDO refers to property damage only collisions (collisions without reported injuries)

The next section provides a brief overview of the evaluation methodology for the centerline rumble strip before-after analysis.

BEFORE-AFTER STUDY METHODOLOGY

In the assessment of safety performance, numerous methodologies are available for use. These range from naïve approaches used by many transportation agencies to more complex statistical approaches used in the Empirical Bayes analysis. The before-after analysis for this project included a simple before-after analysis, before-after analysis with traffic flow correction (using comparison sites) and Empirical Bayes before-after analysis.

Overview of the Different Before-After Study Methodologies

Naïve Before-After Analysis. In the naïve before-after analysis, collision frequencies before CLRS installation are compared with those after the installation. This method is easy to perform and does not require information other than collision counts. Unfortunately, it does not account for changes over time that can occur at these sites (e.g. changes in traffic volumes and weather). For example, if the site experiences growth in traffic, one would expect a natural increase in the collision frequency. Inclement weather such as snow could reduce the amount of travel while sunny days may be associated with higher flows (exposure). It also does not account for regression-to the mean (discussed as part of the empirical Bayes methodology).

Before-after analysis with traffic flow correction. In the before-after analysis with traffic flow correction, one determines the expected safety performance at the installations sites by using the relationship between flow and collisions at the comparison sites. The difference in the observed and expected safety performance represents the effect of the CLRS installation.

This methodology offers the ability to account for systematic changes over time on the network while allowing for a non-linear relationship between flow and safety outcomes. For example, changes in driver behavior may occur over time, which may influence network performance and traffic flow. Therefore, advantages to using this methodology compared to the basic before-after analysis are apparent. However, this methodology does not allow for variance of site characteristics in the estimation of safety outcomes and does not address regression-to-the-mean effects, as does the empirical Bayes.

Empirical Bayes Before-After Analysis. The empirical Bayes (EB) methodology uses volumes and site characteristics at comparison sites. This means that, while reviewing the safety effect over a relatively short period, it is important to make sure that the sites that are evaluated are not experiencing unusually low or high collision frequencies. Collisions are random events and one often observe unusually high frequencies at a site with an observed reduction in the next year without taking any corrective action. This is known as regression-to-the-mean. By accounting for regression-to-the-mean, we therefore attempt statistically to ensure that we are not under or overestimating the safety effect of the particular measure.

RESULTS

In this section, the team describes the results of each part of the before-after study. We first start by briefly introducing the notation used in these analyses and then shows a diagrammatic presentation of the evaluation process.

In the analysis, the team uses the following notation:

- π: Expected number of target crashes in the program period if the treatment had not been installed
- λ: Expected number of target crashes in the program period with the treatment in place
- $\delta = \pi - \lambda$: Change in safety due to the treatment
- $\theta = \lambda/\pi$: Index of the effectiveness of the treatment

The treatment is effective if either δ is greater than 1 or θ is less than 1. We estimate the parameters π, λ, δ, and θ.

Figure 23 shows how a basic before-after study works. It shows the observed collision frequencies in the before period, k_i, and the observed frequencies in the after period, l_i. π_i represents the estimated collision frequencies. The reduction in collision frequencies is the difference between π_i and l_i, i.e. the observed and expected collision frequencies in the after period.

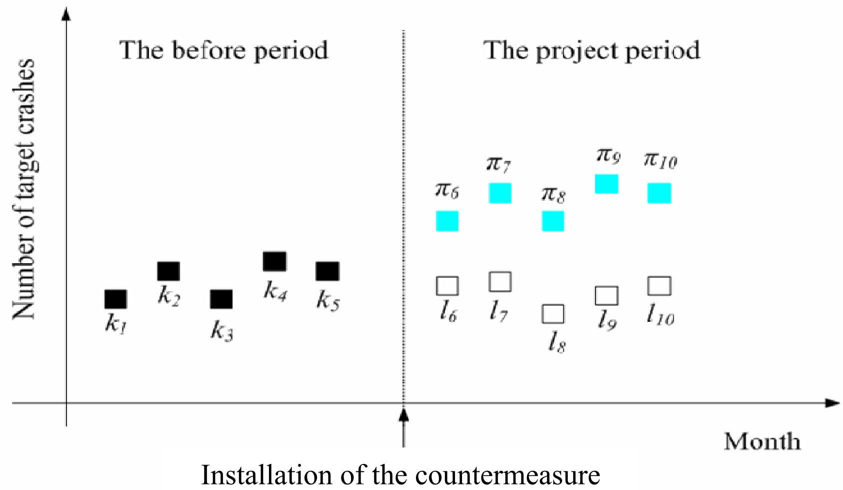


Figure 23: The Basic Concept of the Before-and-After Study (Washington, Shin and van Schalkwyk 2007)

Naïve Before-After Study

In the naïve before-after study we assume that there has not been a significant change at the site (traffic volume, geometry, road user behavior, weather, and any factors) that can affect collision occurrence. Table 39 summarizes the results of the naïve before-after study. Note that positive collision reductions indicate reduction in collisions while negative collision reductions indicate increases in collisions.

Table 39: Naïve Before-After Study – Measured Collision Reduction Percentage and 95% Confidence Interval for Each Collision Type and Injury Category

Collision Type*	Injury Category	Collision Reduction	Crash Reduction Confidence Interval**
All Types	All categories	15.1%	(-0.6%, 30.8%)
	Injury Collisions	18.5%	(-3.1%, 40.1%)
	PDO Collisions	12.7%	(-9.7%, 35.1%)
Crossover***	All categories	**42.9%**	(16.3%, 69.5%)
	Injury Collisions	**52.0%**	(24.2%, 79.8%)
	PDO Collisions	27.4%	(-25.4%, 80.2%)
Head-on	All categories	**55.6%**	(6.9%, 104.3%)
	Injury Collisions	**66.7%**	(26.9%, 106.4%)
	PDO Collisions	Sample sizes too small	
Nighttime	All categories	2.4%	(-24.5%, 29.3%)
	Injury Collisions	-7.2%	(-51.4% , 37%)
	PDO Collisions	10.6%	(-21.8%, 42.9%)
Opposite Direction****	All categories	39.4%	(-16.7%, 95.5%)
	Injury Collisions	**65.4%**	(28% , 102.8%)
	PDO Collisions	Sample sizes too small	
Sideswipe Opposite Direction	All categories	28.6%	(-55.3%, 112.5%)
	Injury Collisions	**76.2%**	(40.2%, 112.2%)
	PDO Collisions	Sample sizes too small	

Bold indicates collision reduction.
* Collision types only include non-intersection and non-intersection related collisions
** 95% Confidence Interval
*** Crossover collisions likely include collision types that cannot be addressed through CLRS
**** Opposite direction collisions include only head-on and sideswipe opposite direction collisions.

Under the assumptions of the naïve before-after study, the results suggest that (95% confidence intervals for reductions provided in parenthesis):

- CLRS reduced all crossover collisions by 43% (CI: 16% - 70%), injury crossover collisions by 52% (24% – 80%).
- CLRS reduced all head-on collisions by 56% (CI: 7% - 104%), injury head-on collisions by 67% (CI: 28 – 106%), and eliminate property damage only head-on collisions.
- CLRS reduced injury collisions for collisions involving vehicles travelling in opposite directions by 65% (28% , 102.8%).

- CLRS reduced injury sideswipe opposite direction injury collisions by 76% (CI: 40% - 112%) and eliminated property damage only sideswipe opposite direction collisions.
- In terms of the other collision types or injury categories, the results were inconclusive (it could have reduced or increased the particular category).

Before-after Study with Correction for Traffic Flow

In the naïve before-after study, we assumed that there were no changes at any of the rumble strip sites other than the installation of the centerline rumble strips themselves. However, volumes on roadways often change, reflecting growth in areas and shifts in traffic across the network.

This method therefore allows us to develop a function that describes the relationship between collision frequency and traffic volume, often referred to as a Safety Performance Function (SPF). Note that these functions determine the average expected collision counts and that the small sample of sites and associated collisions can affect results.

SPF Development. The SPFs were developed using comparison sites. In other words, if the site had rumble strips installed in 1993 to 1996, or 2004 to 2005, these sites were excluded from the dataset and only sites with similar features were included. The model form used for the SPFs is: $y = \propto (Segment\ Length)(Average\ Volume\ per\ Year\ from\ 1999\ to\ 2005)^{\beta}$ where y is the expected average number of collisions per year and α is the intercept. We specified the segment length as an offset.

Table 40: Before-After Study with Consideration of Changes in Traffic Volume – Measured Collision Reduction Percentage and 95% Confidence Interval for Each Collision Type and Injury Category

Collision Type*	Injury Category	Collision Reduction	Crash Reduction Confidence Interval**
All Types	All categories	23.9%	(-15.5%,63.2%)
	Injury Collisions	28.6%	(-17.7%,74.8%)
	PDO Collisions	24.6%	(-25%,74.1%)
Crossover***	All categories	**58.7%**	(18.9%,98.5%)
	Injury Collisions	**67.9%**	(33%,102.7%)
	PDO Collisions	**61.0%**	(16.4%,105.5%)
Head-on	All categories	**88.2%**	(71.1%,105.4%)
	Injury Collisions	**90.2%**	(72.4%,108%)
	PDO Collisions	Sample sizes too small	
Nighttime	All categories	18.7%	(-38.9%,76.2%)
	Injury Collisions	17.5%	(-54.3%,89.3%)
	PDO Collisions	31.1%	(-27.1%,89.4%)
Opposite Direction****	All categories	**81.2%**	(58.9%,103.4%)
	Injury Collisions	**88.7%**	(70.2%,107.3%)
	PDO Collisions	Sample sizes too small	
Sideswipe Opposite Direction	All categories	**90.6%**	(80.6%,100.5%)
	Injury Collisions	**96.9%**	(88.2%,105.6%)
	PDO Collisions	Sample sizes too small	

Bold indicates collision reduction.
* Collision types only include non-intersection and non-intersection related collisions
** 95% Confidence Interval
*** Crossover collisions likely include collision types that cannot be addressed through CLRS
**** Opposite direction collisions include only head-on and sideswipe opposite direction collisions.

Table 40 shows the results from the before-after study with correction for changes in traffic flow. Under the assumptions, findings suggest that (95% confidence intervals for reductions provided in parenthesis):

- CLRS reduces all injury categories of crossover collisions, the average expected reduction varies between 59% and 68% depending on the severity category.
- CLRS reduces opposite direction collisions: overall reduction of 81% (CI: 58.9%,103.4%) and reduction of injury collisions by 89% (CI: 70.2%,107.3%).
- CLRS reduces sideswipe opposite direction collisions: overall reduction of 91% (CI: 80.6%,100.5%) and reduction of injury collisions by 97% (CI: 88.2%,105.6%).

- Results for the other collision types and injury severity categories were inconclusive.

The Empirical Bayes Before-After Study

The empirical Bayes methodology (EB) offers the opportunity to account for regression to the mean. Unfortunately, we could not perform the EB methodology across all collision types because of small sample sizes. Results are therefore limited to the overall collision frequency (by injury category) and nighttime collision frequency (by injury category). Table 41 shows the steps in the EB methodology.

Table 41: Corrected 4-step for EB before-after study (Washington, Shin and van Schalkwyk 2007)

Step	**Goals**	**Formulas for before-and-after study with EB**
Step 1	Estimate λ and predict π	$\hat{\lambda} = L$ $\hat{\pi} = \hat{E}[\kappa \vert K] = \omega \cdot \hat{E}[\kappa] + (1 - \hat{\omega}) \cdot K$
Step 2	Estimate $\hat{\sigma}^2[\hat{\lambda}]$ and $\hat{\sigma}^2[\hat{\pi}]$	$VAR[\hat{\lambda}] = L$ $VAR[\hat{\pi}] = V[\kappa \vert K] = (1-\hat{w}) \cdot E[\kappa \vert K]$
Step 3	Estimate δ and θ	$\hat{\delta} = \hat{\pi} - \hat{\lambda}$ $\hat{\theta} \cong \dfrac{\left(\dfrac{\hat{\lambda}}{\hat{\pi}}\right)}{\left(1 + \dfrac{VAR[\hat{\pi}]}{\hat{\pi}^2}\right)}$
Step 4	Estimate $\hat{\sigma}^2[\hat{\delta}]$ and $\hat{\sigma}^2[\hat{\theta}]$	$\hat{\sigma}^2[\hat{\delta}] = \hat{\pi} + \hat{\lambda}$ $\hat{\sigma}^2[\hat{\theta}] \cong \dfrac{\hat{\theta}^2 \cdot \left[\dfrac{VAR(\hat{\lambda})}{\hat{\lambda}^2} + \dfrac{VAR(\hat{\pi})}{\hat{\pi}^2}\right]}{\left[1 + \dfrac{VAR(\hat{\pi})}{\hat{\pi}^2}\right]^2}$

w represents the weight used in the empirical Bayes before-after study.

SPF Development. The research team used SAS to develop the various count models for this part of the analysis. Poisson and negative binomial models are the most common used for segment-level safety prediction models. Where underdispersion was detected, Poisson models with a scaled deviance were used. The dataset used to develop the SPFs only included sites without rumble strips and those similar to the sites being evaluated.

A summary of the safety prediction models are provided as part of Appendix C. It is important to keep in mind that the sample sizes are relatively small and that the effect of roadside characteristics could not be incorporated into the analysis because it was not available at the time of the study.

Table 42 shows the results of the analysis. With the assumptions and limitations of the EB before and after study, results suggest that CLRS in the Eastern Region, on segments with a horizontal degree of curvature less than 7, and right shoulder widths wider than 5-ft is expected on average to increase: overall collision frequency, property damage only collisions, injury and property damage only nighttime collisions. It is important to point out that the short before-after periods and small sample sizes suggest caution in the use and application of these results.

Results regarding the effect on overall injury collision frequency and nighttime collision frequency were inconclusive.

Table 42: Empirical Bayes Before-After Study– Measured Collision Reduction Percentage and 95% Confidence Interval for Each Collision Type and Injury Category

Collision Type	Injury Category	Crash Reduction	Crash reduction Confidence Interval (95% level)
All Collision Types	All categories	-12.68%	(-24.2%,-1.2%)
	Injury Collisions	-4.58%	(-18.3%,9.1%)
	PDO Collisions	-22.40%	(-37.8%,-7%)
Nighttime	All categories	-9.32%	(-22.9%,4.2%)
	Injury Collisions	-25.61%	(-48.7%,-2.5%)
	PDO Collisions	-52.02%	(-77.5%,-26.5%)

CHAPTER 7 CONCLUSIONS AND RECOMMENDATIONS

The report presented results from a systematic assessment of two-lane highways in Washington State, along with a proposed decision-matrix for the selection of countermeasures for these facilities. In this chapter, the team first discusses the conclusions based on the findings of the study and then presents some recommendations.

CONCLUSIONS

A Contextual Surrogate to Identify Transition Areas

Initial assessment of two-lane rural highways indicated a benefit in the identification of transition areas, segments representing transitions from high-speed rural environments into lower speed urban environments. We tested a surrogate in the form of proximity to urban boundaries to identifying these segments. The surrogate measure shows promise in terms of identifying transition areas, suggesting that further analysis, investigation, and validation with field observations may be beneficial.

The result presented in Chapter 5 suggest that the specification of transition areas may vary between terrain types, with a region half a mile to a mile from urban boundaries as a possible region for transitions on level terrain; and half a mile to two miles for mountainous terrain. The surrogate measure did not adequately identify a particular transition area for rolling terrain segments. The surrogate measure was also unable to adequately identify transition areas into small rural towns, because of limitations in the data and the fact that urban boundaries only identify areas with populations of 5,000 or more. It is likely that a multivariate modeling approach to identify these areas may be possible through the investigation of other measures such as proximity to school locations, and socio-demographic information in combination with proximity to urban boundaries.

A Surrogate to Identify Rural Areas with Some Urban Features

The initial assessment of two-lane rural road facilities indicated that segments in a rural environment and those with urban characteristics (although still rural) differs in terms of features. The difference is described in this report as a change in context. The systematic assessment (refer to Chapter 5 and the findings provided below) suggests that the incidence of particular collision types are more likely in more developed areas than in the other or more likely in less developed areas. For example, pedestrian related collisions are more likely in rural environments with urban features while run-off-the-road collisions may be more likely in rural environments outside rural towns.

The project evaluated proximity to schools as a possible surrogate measure to identify rural segments with a more urban character (e.g. segments passing through small rural towns). The surrogate measure showed promise, with results consistent with expectations. For example, pedestrian collision rates were higher in close proximity to schools.

Evidence suggests that further investigation and the use of multivariate modeling approaches that would allow for the incorporation of other information such as demographics would likely improve the identification of segments with a more urbanized character.

Systematic Assessment of Two-Lane Rural Highways

An initial assessment of two-lane rural highways indicated that the features of two-lane rural freeways could vary substantially from location to location. These include aspects such as alignment, shoulder widths, roadside characteristics but also differences in contexts such as a two-lane rural highway that travels through a small rural town (i.e. a rural road with some urban features such as parking and higher driveway density) and transition areas (i.e. areas where higher speed two-lane rural roads transition into lower speed urban facilities).

The intent of the systematic assessment was to distinguish between these features and to develop a set of features associated with higher collision and severe collision rates (with a specific focus on the reduction of fatal and disabling injuries).

The systematic assessment indicates that there are particular segments, based on selected criteria that exhibit higher collision and severe collision rates. Sections within Chapter 5 summarize these results. It is expected that these findings would be helpful in identifying the overall approach to reduce fatalities on two-lane rural highways.

In terms of countermeasures such as changes to horizontal curvature (which can be particularly costly), the systematic assessment suggest that there may be particular segments that may benefit more from such a countermeasure than others, using criteria that would be more specific than the mere use of a particular degree of curvature.

Before-After Study of Centerline Rumble Strips

The results from the CLRS assessment indicate that the evaluation would benefit from the inclusion of a larger set of sites and associated collision data. The low observed collision frequency across collision types were of particular concern. In addition, the sites only represented a particular segment type: rolling and level terrain segments in eastern Washington with and without curvature (degree of curvature limited to less than 7) and shoulder widths of 5-ft or more. These segments are not necessarily typical of the rest of the two-lane rural highway network.

Given the assumptions of the naïve before-after study, results indicate that it reduces crossover and injury crossover collisions; head-on and injury head-on collisions; nighttime property damage only collisions; and sideswipe opposite direction collisions. The team did not detect any increases.

When the naïve before-after study is modified to account for changes in traffic flow, the team did not detect any increases. Under the assumptions of this methodology, the results suggest reductions in:

- Crossover collisions: all collisions, all injury collisions, and property damage only collisions.
- Head-on collisions: all collisions and injury collisions.
- Opposite direction collisions: all collisions and injury collisions.
- Sideswipe opposite direction: all collisions and injury collisions.

When accounting for regression to the mean, the empirical Bayes before-after study results suggests that CLRS may increase certain collision and severity categories. However, because of the small sample size and because roadside feature information could not be incorporated into the modeling process (omitted variable bias), the results may not accurately reflect the safety benefits of CLRS. The development of SPFs for two-lane rural highways in Washington that incorporates roadside feature information would of be particular benefit because the severity outcome of single vehicle and run-off-the-road collisions may be affected by these characteristics.

RECOMMENDATIONS

Based on the findings of the literature review, the systematic analysis, and the limited before-after study of a selection of CLRS sites, the team presents two recommendations. The first relates to the use of a decision-matrix for countermeasure selection and the second to future research.

The Use of a Decision-Matrix

The team recommends consideration of the use of the decision-matrix that are included as part of this project report. The use of a decision-matrix, such as the matrix proposed in this report, would allow the user to consider efforts on areas where analysis would indicate higher potential for improvement, while facilitating the selection of countermeasures for two-lane rural highways.

Future Research

Findings from the systematic assessment indicate that the underlying relationships between geometric feature, flow, and contexts (using surrogates and available information) may be more complex and that a multivariate approach that allows for the inclusion of socio-demographic and weather related factors could be beneficial. This approach may also assist in identifying particular segments that would have a high likelihood of being of relevance in identifying focus areas for safety investment. This includes use of the proximity to K12 school surrogate measure for identifying more developed areas, and the more recently collected roadside safety feature data from the WSDOT Transportation Data Office.

It can be expected that the development of Safety Performance Functions, models used in the Empirical Bayes before-after evaluation process, would be a beneficial next step in the process to evaluate measures applied on two-lane rural highways. Results from the systematic assessment confirm that there are Washington-specific and region-specific differences that would be of particular benefit to develop functions that are more appropriate.

The differences in the distribution of collision severity for different context and characteristics indicate that models that allow for prediction across severities would be of particular benefit to the department, although these models are extremely complex in development. Consideration of roadside features would be of particular relevance in this activity. The incidence and severity of outcome from run-off-the-road and hit fixed object collisions, the major collision types for two-lane rural roads, are substantially influenced by roadside character and features.

During the development of safety performance functions, consideration of the differences and benefits associated with the use of particular dataset development approaches (homogeneous segments, fixed segments) would be particularly beneficial. The literature review indicated that such comparisons have not yet been carried out.

An extended before-after study of CLRS installations across a larger number of sites would be beneficial as sample sizes of the limited effort in this report suggests caution in terms of interpretation. The development of safety performance functions that incorporates roadside characteristics would be of particular benefit to this analysis and the evaluation of other safety investments on two-lane rural highways.

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APPENDIX A: PROPOSED DECISION-MATRIX

PART A OF THE DECISION MATRIX – Summary of major collision types on two-lane rural roads and contexts identified in systematic analysis with higher potential benefit for improvement (summary of Table 26 to Table 36) with countermeasure references.

PART B OF THE DECISION-MATRIX – List of countermeasures, target collision types or conditions, and expected results (developed from extensive literature review and countermeasure summaries such as Dixon (1997), Monsere et al (2006), and Agent and Pigman (2005)).

Note: Appropriate Use

Part A is not exhausted in terms of presenting all possible collision types. Part B is not exhaustive in terms of presenting all possible countermeasures that may be appropriate for a particular site. While it is recommended for use as a guide, it is not a replacement for WSDOT policy, engineering judgment and site-specific assessment and consideration. This information does not constitute a standard or requirement.

PART A OF THE DECISION MATRIX – Summary of Major Collision Types on Two-Lane Rural Roads and Contexts Identified in Systematic Analysis with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)

Target collision type	**Target Collision Type Subcategory**	**Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)**	**Countermeasure Group & Number**
Run-off-the-road collisions	All	• Mountainous terrain • Horizontal Curves with degree of curvature of 10 or more • Mountainous terrain segments with right shoulder widths of 5-ft or more • Right shoulder widths less than 5-ft, particularly mountainous and rolling terrain • Specific Contexts: Rural environments with no urban features: locations more than 2 miles from urban boundaries or K12 schools	Delineation [1] – particularly [1.2], [1.5] Roadside features [2] (reduce severity of run-off-the-road collisions) Advisory speed sign [4.1] on sharp curves & high operating speeds Warning signs [4.3] for presence of sharp curves & lane reductions Chevron alignment sign [4.4] : horizontal curves with degree of curvature of 7 or more Post delineator [4.4] on horizontal curves with radius >820-ft where identification of curve would be difficult to identify Increase lane width [5.1] Shoulders [6] Roadway alignment [7] – particularly [7.1] and [7.2]

	Segment	• Specific Contexts: Rural environments (more than 2 miles away from K12 schools)
		• Segments with right shoulder width less than 5-ft
		  o Straight segments
		  o Segments on horizontal curves
		    ▪ Mountainous terrain: particularly degrees of curvature of 3 or more
		    ▪ Level terrain: particularly degrees of curvature of 3 or more
		    ▪ Rolling Terrain: particularly degrees of curvature of 10 or more
		• Segments with right shoulder widths of 5-ft or more	

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Centerline crossovers	All	• Mountainous terrain and right shoulder width of 5-ft or more within half to 1 mile from urban boundaries • Mountainous terrain with right shoulder width of less than 5-ft that are located more than 2 miles from urban boundaries • Rolling terrain with shoulder widths of 5-ft or more that are located more than 2 miles from urban boundaries • Mountainous terrain and right shoulder width of 5-ft or more located more than 2 miles from urban boundaries • Level terrain, right shoulders of 5-ft or more and located 1 to 2 miles from urban boundaries	Add/upgrade centerline markings [1.1] Add/upgrade no-passing zone pavement marking lines (supplemented by no-passing zone signs where appropriate) [1.3] Add raised pavement markings to centerline [1.4] Add centerline rumble strips [1.6] To select countermeasures targeted at reducing severity of centerline cross-over collisions also classified as run-off-the-road: refer to *Run-Off-the-Road Collisions* Increase lane width [5.1] Roadway Alignment [7]
	Segment	• Level terrain, where right shoulder widths < 5-ft and within 1/2 a mile to 1 mile from urban boundaries • Mountainous terrain, where right shoulder widths < 5-ft and more than 2 miles from urban boundary • Rolling terrain, where right shoulder widths < 5-ft and half to 2 miles from urban boundaries	

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Pedestrian related	All	• Rural with urban characteristics, i.e. segments in small rural towns (surrogate measure: segments within half a mile of K12 schools) • Rural with some urban characteristics, i.e. segments in small rural towns (surrogate measure: half a mile to 1 mile from K12 schools)	Parking management [3.1] Speed management [3.2] At intersections/crossing locations [3.3] Advisory speed sign [4.1] Warning sign [4.3] Differential speed limit signs [4.6] Improve sight distance [7.3] Pedestrian facilities [9] Lighting [14]
	Not intersection or intersection-related	• Rural with urban characteristics, i.e. segments in small rural towns (surrogate measure: segments within half a mile of K12 schools) • Rural with some urban characteristics, i.e. segments in small rural towns (surrogate measure: half a mile to 2 miles from K12 schools)	
Rear-end collisions	Rear-End Collisions where both vehicles were going straight and moving		Sight distance [7.3] Warning signs [4.3] if result of unexpected changes with reduced sight distance
	Segment collision where both vehicles were going straight, one stopped and one moving		Access management [12] Delineation [1] Traffic signs [4]

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Hits fixed object	Roadside collision, run-off-the-road collision	Rural environment with limited development	Roadside [2]
		Rural Town Center	Roadside [2] Alignment [7] Delineation [1] Speed management [3.2]
Vehicle overturns	• Roadside collision • Collisions involving crossing centerline		Roadside [2] Alignment [7] Roadside (if edge drop-off exists) [6.4], [6.5], [6.2] Also see *Run-off-the-road collisions, Collisions involving centerline crossover.*
Multiple vehicle collision where one vehicle from opposite direction, both moving, head-on	• Head-on collision • Collisions involving crossing centerline		Roadside [2] Alignment [7] Delineation [1]

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Multiple vehicle collision where one vehicle from opposite direction & all others	Collisions involving crossing centerline		Roadside [2] Alignment [7] Delineation [1]
Multiple vehicle collision where one vehicle was entering at an angle	Driveway and/or intersection related		Access management [12]
Multiple vehicle collision where one vehicle from opposite direction, where both going straight, and sideswipes	Collisions involving crossing centerline		Alignment [7] Lanes [5] Shoulders [6]

Target collision type	**Target Collision Type Subcategory**	**Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)**	**Countermeasure Group & Number**
Multiple vehicle collision where vehicles approached from same direction, where both were going straight, where one stopped, and any rear end collision	Driveway and/or intersection related		Access management [12]
	Collisions involving animals		Animals [11]
	Collisions involving pedestrians		Pedestrians [9]
	Collisions involving bicyclists		Bicyclists [10]
Multiple vehicle collision where one vehicle was entering or exiting a driveway access	Driveway and/or intersection related		Access management [12]

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Multiple vehicle collision: both from same direction, both going straight, both moving, and rear end	Driveway and/or intersection related		Access management [12]
	Collisions involving animals		Animals [11]
	Collisions involving pedestrians		Pedestrians [9] Warning signs [4.3] Signs to support driver expectancy [4]
	Collisions involving bicyclists		Bicyclists [10]
Vehicle going straight hits pedestrian	Collisions involving pedestrians		Pedestrians [9]
Vehicles colliding: from opposite direction where one vehicle was turning left, and the other going straight	Driveway and/or intersection related		Access management [12]: Lanes (exclusive turning lane) [12.2] Traffic signs [4] (where driver expectation is violated)

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Non domestic wildlife - deer, bear, bird, etc.	Collisions involving animals		Animals [11]
Multiple vehicle collision: both from same direction	Driveway and/or intersection related		Access management [12]
Collisions involving a bicyclist	Collisions involving bicyclists	All	Bicyclists [10]
		Rural town centers, small rural towns	Speed management [3.2]
		Rural town centers, small rural towns	Parking management [3.1]– evaluate parking configuration and bicycle movement
Vehicle hits other object (other than a fixed object)	• Roadside collision • Run-off-the-road collision • Collisions involving crossing centerline	Particularly where clear zones are restricted, shoulder widths less than 5-ft, mountainous areas, steep side slopes	Roadside [2] Lanes [5] Shoulders [6] Alignment [7]
	Vehicle avoiding animals		Animals [11]

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Multiple vehicle collision: Vehicles from same direction, or one turning left and other going straight	Driveway and/or intersection related		Access management [12] (incl. Exclusive turning lanes)
Multiple vehicle collision: Vehicles from same direction, both going straight, both moving, sideswipe	Collisions involving crossing centerline		Access management [12] (incl. Exclusive right turning lanes) Alignment [7] Lanes [5] Shoulders [6]
Multiple vehicle collision: One vehicle parked and one moving	• Parking-related • Driveway and/or intersection related		Access management [12] Urban environment [3]: Parking management [3.1] Collisions involving pedestrians (if one vehicle swerved away for a pedestrian) : [9]

Target collision type	**Target Collision Type Subcategory**	**Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)**	**Countermeasure Group & Number**
Head-on collisions & Single vehicle collisions			Delineation [1] Roadside [2] Lanes [5] Shoulders [6]
Hit Fixed Object collisions			Delineation [1] Roadside [2] Lanes [5] Shoulders [6]
Intersection and intersection-related collisions: stop control	Roadside: Fixed object collisions		Roadside [2] Shoulders [6] Lanes [5] Delineation [1]
	Driveway and/or intersection related (entering at an angle, rear-ends)		Access management [12] Sight distance [7.3] Lighting [14]

Target collision type	Target Collision Type Subcategory	Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)	Countermeasure Group & Number
Intersection and intersection-related collisions: yield control	Roadside: Hits fixed object		Roadside [2]
	Driveway and/or intersection related: • Entering at an angle, • Rear-end collision • One vehicle leaving driveway access • One vehicle entering a driveway access • Vehicles approaching from opposite direction, one turning left, and other going straight		Intersections (unsignalized) [13] Access management [12] Pedestrians [9] Lighting [14]
	Collision involving a bicycle		Bicyclists [10] Access management [12] Rural towns or rural town center environments
	Pedestrian-related: • Vehicle going straight hits a pedestrian • Vehicle turning left hits a pedestrian		Pedestrians [9] Sight distance [7.3] Lighting [14]
	Vehicles approaching from opposite direction: others (exclude head-on collisions, sideswipe collisions, and where one vehicle was turning left or right)		Delineation [1] Alignment [7] Roadside [2] Lanes [5] and Shoulders [6]

Target collision type	**Target Collision Type Subcategory**	**Contexts with Higher Potential Benefit for Improvement (Summary of Table 26 to Table 36)**	**Countermeasure Group & Number**
Intersection and intersection-related collisions: unsignalized intersection (excluding stop and yield controlled intersection)			Delineation [1] Alignment [7] Roadside [2] Lanes [5] Shoulders [6]
Intersection and intersection-related collisions: stop control	Hits Fixed Object		Roadside [2] Delineation [1]
	One vehicle entering at an angle		Sight distance [7.3] Traffic signs [4] Alignment: improve sight distance [7.3] Access management [12]: provision of turning lanes: [12.2], [12.3]
	One vehicle leaving/entering driveway access		Access management [12]: particularly, for vehicle entering driveway – exclusive right turn lane [12.3] or exclusive left turn lane [12.2]
	Multiple vehicle: both from same direction, both going straight, one stopped, rear-end		Access management [12]

PART B OF THE DECISION-MATRIX - Countermeasures, target collision types or conditions, and expected results (developed from literature review and countermeasure summaries such as Dixon (1997)**, Monsere et al** (2006)**, and Agent and Pigman** (2005)**)**

Appropriate Use of Countermeasure List:

- Benefits and associated outcomes for countermeasures represent likely average outcome for implementation at a large number of sites with specific site characteristics
- The use of any of the listed countermeasures do not imply that a pre-existing condition contributed to collision occurrence or severity
- The countermeasure list is used with engineering judgment and consideration of site-specific conditions. These conditions may indicate application of other countermeasures not contained on the countermeasure list.
- The list is not meant to present all available countermeasures and reflects only elements found in the literature review completed as part of this project.

While it is recommended for use as a guide, it is not a replacement for WSDOT policy, engineering judgment and site-specific assessment and consideration. This information does not constitute a standard or requirement.

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td rowspan="2">1 - Delineation
(define roadway area for driver)
If targeting run-off-the-road collisions, apply in rural environments (more than 2 miles from schools, i.e. not in areas with urban features)

If targeting centerline crossover collisions, target segments with shoulder widths less than 5-ft and:
Level terrain within half to 1 mile from urban boundary
Mountainous terrain within half to 2 miles from urban boundary
Rolling terrain more than 2 miles from urban boundary</td>
<td>1.1
Add/upgrade centerline markings</td>
<td>All, particularly rural areas with limited development

Not appropriate for highways with road width less than 16 – 18 ft</td>
<td>Centerline crossover collisions
Head-on collisions
Sideswipe opposite direction collisions
Single vehicle collisions
Collision conditions: improve visibility at night-time and/or during wet weather</td>
<td>Agent et al (1996) estimates an average collision reduction of 35% for all collisions (from survey and literature review).

In a FHWA study (Smith, et al. 1983) the percentage collision reduction across collision severity levels for high collision locations were estimated as:
<table>
<tr><th rowspan="2">Location Type</th><th colspan="4">Collision Severity</th></tr>
<tr><th>All</th><th>Fatal</th><th>Injury</th><th>PDO</th></tr>
<tr><td>Tangent segment</td><td>7</td><td>0</td><td>5</td><td>10</td></tr>
<tr><td>Horizontal curve</td><td>10</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Vertical curve</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>At intersection</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>At bridge locations</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
</table></td></tr>
<tr><td>1.2
Add/upgrade edge line markings</td>
<td>Appropriate for: arterials with roadway width of 20-ft or more and 6,000 vpd ADT</td>
<td>Run-off-the-road collisions

Collision conditions: improve visibility at night-time and/or during wet weather</td>
<td>Agent et al (1996) estimates an average collision reduction of 15% for all collisions and 30% for run-off-the-road collisions (from survey and literature review).
In a FHWA study (Smith, et al. 1983) the percentage collision reduction across collision severity levels for high collision locations were estimated as:
<table>
<tr><th rowspan="2">Location Type</th><th colspan="4">Collision Severity</th></tr>
<tr><th>All</th><th>Fatal</th><th>Injury</th><th>PDO</th></tr>
<tr><td>Tangent segment</td><td>7</td><td>0</td><td>5</td><td>10</td></tr>
<tr><td>Horizontal curve</td><td>10</td><td>5</td><td>10</td><td>10</td></tr>
<tr><td>Vertical curve</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>At intersection</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
</table></td></tr>
</table>

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td rowspan="2">1 – Delineation (continued)</td><td>1.3
Add/upgrade no-passing-zone pavement marking lines (supplemented by no-passing zone signs where appropriate)</td><td>Appropriate for: locations with limited sight distance (crest vertical curves)
Maintain no-passing zone past isolated intersections where driver may not be expecting cross-traffic</td><td>Centerline crossover collisions occurring during passing maneuvers:
• Head-on collisions
• Side-swipe opposite direction collisions</td><td>Agent et al (1996) estimates an average collision reduction of 44% for passing related collisions (from survey and literature review).

Average total collision reduction estimates vary between 30% (Creasey and Agent 1985) to 40% (Ermer, Fricker and Sinha 1992)

In a FHWA study (Smith, et al. 1983) the percentage collision reduction across collision severity levels were estimated as: all (10%), fatal (20%), injury (15%), and PDO (10%)</td></tr>
<tr><td>1.4
Add raised pavement markings to centerline</td><td></td><td>• Head-on collisions
• Sideswipe opposite direction collisions

Collision conditions: improve visibility at night-time and/or during wet weather</td><td>Agent et al (1996) estimates an average collision reduction of 10% for all collisions, 25% for wet and night-time collisions, and 20% for night-time collisions (from survey and literature review).

In a FHWA study (Smith, et al. 1983) the percentage collision reduction across collision severity levels for high collision locations were estimated as:
<table>
<tr><th rowspan="2">Location Type</th><th colspan="4">Collision Severity</th></tr>
<tr><th>All</th><th>Fatal</th><th>Injury</th><th>PDO</th></tr>
<tr><td>Tangent segment</td><td>5</td><td>0</td><td>5</td><td>5</td></tr>
<tr><td>Horizontal curve</td><td>10</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>At intersection</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
</table>

Creasey and Agent (1985) provided an expert estimate of 5% reduction in total collisions, a 10% reduction for dry nighttime collisions, and 20% for wet pavement nighttime collisions.
Wattleworth, Atherly and Hsu (1988) estimated a 5% reduction in total collisions for installations in Florida.</td></tr>
</table>

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
1 – Delineation (continued)	***1.5*** ***Add shoulder/edge line rumble strips***		Run-off-the-road collisions where paved shoulders 2-ft or wider	Patel, Council and Griffith (2007) estimated the benefits of 23 treatment sites of shoulder rumble strips in Minnesota as: • All single vehicle run-off-the-road collisions: 13% reduction • All injury run-off-the-road collisions: 18% reduction
	1.6 ***Add centerline rumble strips***		• Centerline crossover collisions • Head-on collisions • Sideswipe opposite direction collisions *Collision conditions*: improve visibility at night-time and/or during wet weather	Persaud, Retting and Lyon (2003) noted that rumble strip installations vary in design and placement, and given the validity of the safety performance functions that were used in their study, that the following benefits are noted (WA results shown for 21 sites with total mileage of 43.5): • Reduction in injury collisions: 24% for WA • Reduction in collision frequency: 25% for WA • Reduction in opposing-direction collision frequency: 21% for WA • Reduction in injury opposing-direction collision frequency: 22% for WA. Specific considerations include: snow removal, maintenance requirements. Miles (2004) did not find any negative effects on passing maneuvers resulting from centerline rumble strips (15 mile installation, 70-mph speed limit). In a FHWA study (Smith, et al. 1983) the percentage collision reduction across collision severity levels for high collision locations were estimated as:

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td>1 – Delineation (continued)</td><td>1.6
Add centerline rumble strips (continued)</td><td></td><td></td><td><table>
<tr><th rowspan="2">Location Type</th><th colspan="4">Collision Severity</th></tr>
<tr><th>All</th><th>Fatal</th><th>Injury</th><th>PDO</th></tr>
<tr><td>Horizontal curve</td><td>30</td><td>60</td><td>40</td><td>25</td></tr>
<tr><td>Intersection</td><td>20</td><td>50</td><td>30</td><td>15</td></tr>
<tr><td>Bridge</td><td>30</td><td>60</td><td>40</td><td>25</td></tr>
<tr><td>Railroad grade crossing</td><td>10</td><td>10</td><td>10</td><td>10</td></tr>
</table></td></tr>
<tr><td rowspan="2">2.
Roadside features</td><td>2.1
Increase clear zone width (includes removal of fixed object(s) such as utility poles etc.)</td><td></td><td>• Hit fixed object collisions
• Run-off-the-road collisions</td><td>Zeeger et al (1991) estimated that:
• a 5-ft increase in roadside recovery distance expects to reduce horizontal curve collisions by 9% (assume no other improvements are made).
• a 15-ft increase in roadside recovery distance expects to reduce horizontal curve collisions by 23% (assume no other improvements are made).

Agent et al (1996) estimated that the removal of fixed objects could, on average, reduce overall collision frequency by 30%, fatal collisions by 50%, and injury collisions by 30%.

Smith et al (1983) estimates the following reductions for removal or relocation of fixed objects: overall collision frequency (60%), fatal collisions (65%), injury collisions (60%), and PDO collisions (55%).</td></tr>
<tr><td>2.2
Shield fixed objects</td><td>With the installation/ upgrading of a guardrail</td><td>Reduce severity of hit fixed object collisions</td><td>Potential to reduce injury severity, unlikely to affect collision frequency.
Agent et al (1996) estimated the mean percentage collision reduction for:
• guardrail installations: all collisions (5%), fatal collisions (65%), and injury collisions (40%)
• upgrading guardrail: all collisions (5%), fatal collisions (50%), and injury collisions (35%)</td></tr>
</table>

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
2. **Roadside features (continued)**	***2.3*** ***Upgrade/install end treatment for guard rail or impact attenuator***		Reduce severity of hit fixed object collisions	Potential to reduce injury severity, unlikely to affect collision frequency. Agent et al (1996) estimated the mean percentage collision reduction for installations of impact attenuators as: all collisions (5%), fatal collisions (75%), and injury collisions (50%). Creasey and Agent (1985) estimated that fatal collisions will, on average, reduce by 40% and injury collisions with 15%.
	2.4 ***Relocate fixed object*** ***(careful consideration if fixed object acting as lighting fixture as it may result in reduced lighting of the facility): includes utility poles, trees, mail boxes, etc.***			Potential to reduce injury severity and collision frequency. Agent et al (1996) estimated that the relocation of fixed object would render the following average collision reduction: all collisions (25%), fatal collisions (40%), and injury collisions (25%). Smith et al (1983) estimates that it would reduce overall collision frequency with 60%, fatal collisions by 65%, injury collisions by 60%, and PDO collisions by 55%.

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td>2.
Roadside features (continued)</td><td>2.5
Flatten side slope: flatter than 3:1 with 6:1 desirable</td><td>Appropriate where: vehicle stability affected by side slope in the event of a run-off-the-road collision</td><td>Improve recovery area and/or reduce injury severity of:
Run-off-the-road collisions
Single vehicle collisions
Some centerline crossover collisions</td><td>Depending on extent of flattening, Zegeer et al (1991) estimates that it can reduce collisions by between 3 – 15%.

Agent et al (1996) estimated that flattening of side slopes would on average reduce overall collision frequency by 30%.

A FHWA study (Smith, et al. 1983) estimates that the percentage collision reduction across collision severity levels for high collision locations where alignment changes are made:

<table>
<tr><td rowspan="2">Alignment Changes</td><td colspan="4">Mean Percent Crash Reduction</td></tr>
<tr><td>Total</td><td>Fatal</td><td>Injury</td><td>PDO</td></tr>
<tr><td>Flatten side or back slope</td><td>30</td><td>75</td><td>50</td><td>20</td></tr>
<tr><td>Round ditches</td><td>5</td><td>10</td><td>10</td><td>5</td></tr>
<tr><td>Remove pavement edge drop-offs (tangent section)</td><td>25</td><td>15</td><td>15</td><td>15</td></tr>
<tr><td>Remove pavement edge drop-offs (horizontal curve)</td><td>20</td><td>20</td><td>20</td><td>20</td></tr>
</table>
</td></tr>
</table>

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td rowspan="2">2.
Roadside features (continued)</td><td>2.5
Flatten side slope: flatter than 3:1 with 6:1 desirable (continued)</td><td></td><td></td><td>Zegeer et al (1988) estimated the average single vehicle collision frequency reduction for different side slope flattening conditions as:
<table>
<tr><td rowspan="2">Side Slope Ratio in Before Condition</td><td colspan="5">Side Slope Ratio in After Condition</td></tr>
<tr><td>3:1</td><td>4:1</td><td>5:1</td><td>6:1</td><td>7:1 or Flatter</td></tr>
<tr><td>2:1</td><td>2</td><td>10</td><td>15</td><td>21</td><td>27</td></tr>
<tr><td>3:1</td><td>0</td><td>8</td><td>14</td><td>19</td><td>26</td></tr>
<tr><td>4:1</td><td>---</td><td>0</td><td>6</td><td>12</td><td>19</td></tr>
<tr><td>5:1</td><td>---</td><td>---</td><td>0</td><td>6</td><td>14</td></tr>
<tr><td>6:1</td><td>---</td><td>---</td><td>---</td><td>0</td><td>8</td></tr>
</table></td></tr>
<tr><td>2.6
Add/ Upgrade guardrail to shield fixed object or drop-off</td><td></td><td>Reduce injury severity of:
• Run-off-the-road collisions
• Single vehicle collisions
• Centerline crossovers resulting in run-off-the-road collisions</td><td></td></tr>
</table>

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
2. **Roadside features (continued)**	***2.7*** ***Replace fixed object with breakaway feature, includes utility poles and traffic signs***		Reduce injury severity of: • Run-off-the-road collisions • Single vehicle collisions • Centerline crossovers resulting in run-off-the-road collisions	Use of breakaway poles could reduce severe fixed object collisions involving utility poles by as much as 60% (Zegeer and Cynecki, Determination of Cost-Effective Roadway Treatments for Utility Pole Accidents 1984) – note that collision frequency would not change. Agent et al (1996) estimated that the relocation of fixed object could render the following average collision reduction: all collisions (5%), fatal collisions (60%), and injury collisions (30%). Smith et al (1983) estimate that it would not reduce overall collision frequency and that it could reduce fatal collisions by 60%, injury collisions by 20%, and increase PDO collisions by 15%. Wattelworth (1988) estimated the overall average reduction in Florida for a number of sites as 35%.

Countermeasure Category (from Part B)	**Countermeasure with special notes**	**Context**	**Possible target collision type/condition**	**Potential impact of countermeasure (limited to research results for two-lane rural highways)**
3. **Rural environments with urbanized features/ small rural town environments**	***3.1*** ***Parking management***		Collisions involving parked vehicles or vehicles executing the parking maneuver	
	3.2 ***Speed management***		Incidence and severity of collision (impacts ability of driver to respond in a timely fashion and where it involves vulnerable road users, increase the likelihood of severe injuries)	
	3.3 ***Pedestrian facilities at intersections and/or crossing locations:*** • ***Sidewalks*** • ***Parking facilities*** • ***Crossing facilities*** • ***Sight distance at intersections & crossing locations*** • ***Lighting***		Collisions involving pedestrians, rear-end collisions where vehicles were braking for pedestrians	Refer to *Pedestrians*

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
4. **Traffic Signs**	***4.1*** ***Advisory speed sign***	Appropriate for: sharp curves with lower associated design speeds; sites requiring lower operating speeds (more urbanized environments, close proximity to pedestrian generators, work zones, etc.) Not appropriate: low speed facilities, tangent sections, locations with mild curvature		Agent et al (1996) estimated that advisory speed signs reduces collisions by an average of 30% Chowdhury et al (1998) noted that compliance to advisory speed limit signs on horizontal curves vary by posted advisory speed. Lower limits are associated with lower levels of compliance (35% compliance on average for advisory speeds of 45 - 50-mph; 5% for 35-40-mph; 8% for 25 - 30-mph; and 0% for 15 - 20-mph)
	4.2 ***Cross traffic does not stop sign***		Rear-end collisions where both vehicles were traveling in the same direction, one vehicle stopped, rear-end	

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr>
<td>4.
Traffic Signs (continued)</td>
<td>4.3
Warning signs (e.g. curve warning signs, etc.)</td>
<td>Appropriate for: locations with unexpected changes, such as presence of sharp curves; presence of pedestrians, animals, etc. ; reduced sight distance to upcoming intersections; lane reductions; etc.</td>
<td></td>
<td>Creasey and Agent (1985) provided an expert estimate of warning signs at high risk locations:

40% for all collisions after installation of warning signs at intersections
20% of all collisions after installation of warning signs at mid-block locations, and
30% of all collisions for warning signs on curves

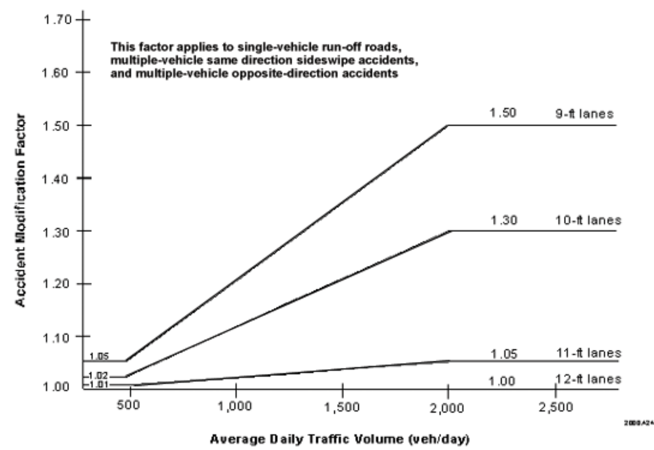
In a FHWA study (Smith, et al. 1983) the percentage collision reduction across collision severity levels for high collision locations were estimated as
<table>
<tr><th rowspan="2">Location Type</th><th colspan="4">Collision Severity</th></tr>
<tr><th>All</th><th>Fatal</th><th>Injury</th><th>PDO</th></tr>
<tr><td>Intersection</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Curve</td><td>10</td><td>15</td><td>10</td><td>10</td></tr>
<tr><td>Curve with advanced speed</td><td>20</td><td>30</td><td>25</td><td>20</td></tr>
<tr><td>Narrow bridge</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Route guidance</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Slippery when wet</td><td>1</td><td>1</td><td>1</td><td>1</td></tr>
<tr><td>Speed zone</td><td>5</td><td>15</td><td>10</td><td>5</td></tr>
</table>
Agent et al (1996) estimated that the collision reductions from warning signs are:

25% for general warning sign applications
30% for curve warning (run-off-the-road), intersection-related, railroad crossings
20% for pavement condition, and
15% for school zones.

</td>
</tr>
</table>

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
4. Traffic Signs (continued)	***4.4 Chevron alignment sign***	Not appropriate: tangent segments with good visibility, mild curvature with good visibility; particularly for horizontal curves with a degree of 7 or more (Jennings and Demetsky 1985)	• Run-off-the-road collisions • Single vehicle collisions	Wattleworth, Atherly and Hsu (1988) estimated that the installation of chevron signs in Florida resulted in a 35% reduction in total collisions Agent et al (1996) estimated that chevron installation reduces collisions by 30 to 55%.
	4.5 Post delineator	Appropriate for: horizontal curves with radius > 820-ft (degree of curvature of 7 or less) where identification of curve would be difficult; locations with unexpected lane reductions (Jennings and Demetsky 1985) Not appropriate: tangent segments with good visibility, mild curvature with good visibility	Collisions on horizontal curvature, including run-off-the-road collisions *Collision conditions*: inclement weather	Wattleworth, Atherly and Hsu (1988) estimated that the installation of post delineators reduces all collisions by 30% and fatal collisions by 25% Agent et al (1996) estimated that post delineators reduces nighttime collisions by 30%.

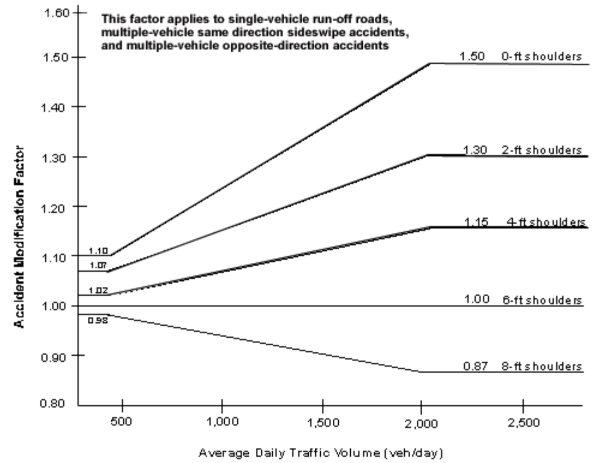
Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
4. **Traffic Signs (continued)**	***4.6*** ***Differential speed limit signs***	Integrate with speed management plan: particularly in transition areas from rural area with limited development into small rural town or rural town center		

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
5. **Lanes**	***5.1*** ***Increase lane width***	Appropriate for: locations with lane width less than 11-ft where narrow lane widths likely contribute to collisions Not appropriate: existing lane widths of 11-ft or greater	• Centerline crossover collisions • Run-off-the road collisions (incl. single vehicle collisions)	Harwood et al (2000) developed the following graph for determining the AMF for single-vehicle run-off-the-road and multiple-vehicle head-on, opposite-direction sideswipe, and same-direction sideswipe collisions:  Using the AMF for the abovementioned category (AMF_{ra}), the AMF for total collision frequency can be determined by using the following relationship: $AMF = (AMF_{ra} - 1.0) P_{ra} +1.0$ where P_{ra} refers to the proportion of collisions in the abovementioned category. Zegeer et al (1991) estimated that widening lanes from: • 10-ft to 12-ft: 4 – 33% reduction in collisions on horizontal curves • 8-ft to 12-ft: 21% reduction in collisions on horizontal curves Creasey and Agent (1985) estimated a 20% overall collision reduction resulting from lane widening.

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td rowspan="2">6.
Shoulders
Particular contexts to consider:
locations with shoulder widths less than 5-ft
Mountainous terrain
Degree of curvature 3 or more for level and mountainous terrain, and in particularly 9 to less than 10 for all terrain types</td><td>6.1
Increase shoulder width/ changes to surface</td><td>Appropriate for: locations with shoulder widths less than 5-ft or locations where reduced shoulder widths reduced the ability of a driver to recover from run-off-the-road collisions; locations where existing unpaved shoulder</td><td>Run-off-the-road collisions
particularly in level and mountainous terrain
Collisions on segments with shoulder widths less than 5ft where narrow shoulder width contributed to collisions.</td><td>Refer to countermeasures: widen existing shoulders (paved, unpaved)

Shoulder stabilization/paving
Agent et al (1996) estimated that the potential total collision reduction associated with shoulder stabilization and dropoff treatment is 25%, while paving shoulders could potentially on average, reduce all collisions by 15%

Smith et al (1983) developed the following collision reduction estimates for high collision locations:
<table>
<tr><th rowspan="2">Shoulder treatment and location</th><th colspan="4">Collision Severity</th></tr>
<tr><th>All</th><th>Fatal</th><th>Injury</th><th>PDO</th></tr>
<tr><td>Stabilize shoulders on tangent</td><td>5</td><td>0</td><td>5</td><td>10</td></tr>
<tr><td>Stabilize shoulders on horizontal curve</td><td>15</td><td>10</td><td>10</td><td>10</td></tr>
<tr><td>Stabilize shoulders at intersection</td><td>10</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Pave shoulders on tangent</td><td>5</td><td>5</td><td>10</td><td>10</td></tr>
<tr><td>Pave shoulders on horizontal curve</td><td>15</td><td>15</td><td>15</td><td>15</td></tr>
<tr><td>Pave shoulders at intersection</td><td>10</td><td>10</td><td>10</td><td>10</td></tr>
</table></td></tr>
<tr><td>6.2
Pave existing graded/stabilized shoulder</td><td>Where shoulders are eroded</td><td>Run-off-the-road collisions where outcome affected by shoulder condition or reduced traversability of shoulder</td><td>Zegeer et al (1991) estimated that widening shoulders between 1 – 10-ft reduce collisions from 3 – 29% (it was noted that side slopes steeper than 1:4 would increase rollover collisions and collision severity)</td></tr>
</table>

Countermeasure Category (from Part B)	**Countermeasure with special notes**	**Context**	**Possible target collision type/condition**	**Potential impact of countermeasure (limited to research results for two-lane rural highways)**
6. Shoulders (continued)	***6.3*** ***Widen and pave existing graded/stabilized shoulder***	Where shoulder is eroded or where shoulder width is less than 5-ft	Run-off-the-road collisions where outcome affected by shoulder condition or reduced traversability of shoulder and shoulder width less than 5-ft	Harwood et al (2000) estimates that, for ADT>2000, widening shoulders from: • 2-ft to 8-ft would reduce all collisions by 12% • 4-ft to 8-ft would reduce all collisions by 9% • 6-ft to 8-ft would reduce all collisions by 5%. For single-vehicle run-off-road and multi-vehicle opposite direction collisions, the following curve was developed by Harwood et al (2000):  Zegeer et al (1991) estimated that widening shoulders between 1 – 10-ft reduce collisions from 4 - 33% (it was noted that side slopes steeper than 1:4 would increase rollover collisions and collision severity) from: • 10-ft to 12-ft: 4 – 33% reduction in collisions on horizontal curves

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td rowspan="2">6.
Shoulders (continued)</td><td>6.3
Widen and pave existing graded/stabilized shoulder</td><td></td><td></td><td>
8-ft to 12-ft: 21% reduction in collisions on horizontal curves
Smith et al (1983) developed the following collision reduction estimates for high collision locations:
<table>
<tr><td rowspan="2">Pavement widening location</td><td colspan="4">Collision Severity</td></tr>
<tr><td>All</td><td>Fatal</td><td>Injury</td><td>PDO</td></tr>
<tr><td>Pavement widening on sections</td><td>0</td><td>-10</td><td>-5</td><td>5</td></tr>
<tr><td>Pavement widening on horizontal and vertical curves</td><td>5</td><td>-5</td><td>0</td><td>10</td></tr>
</table>
</td></tr>
<tr><td>6.4
Edge drop-off treatment: Beveled edge treatment during asphalt overlays</td><td>Appropriate for: locations where vehicles running off the road lost control when traversing a pavement drop-off (with presence of narrow shoulders); particularly in locations where pavement edge drop-offs are 4 inches or more with a roadway edge of 90 degrees</td><td></td><td>FHWA Safety Edge: 30-35 degree pavement wedge providing tapered transition between lane edge and edge of shoulder (http://safety.fhwa.dot.gov/roadway_dept/docs/sa05003.pdf).</td></tr>
</table>

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
6. **Shoulders (continued)**	***6.5*** ***Edge drop-off treatment: Provision of warning signs for shoulder drop-offs***	*Appropriate for*: locations where vehicles running off the road lost control when traversing a pavement drop-off (with presence of narrow shoulders); particularly in locations where pavement edge drop-offs are 4 inches or more with a roadway edge of 90 degrees		
7. **Roadway Alignment**	***7.1*** ***Realignment of geometry such as crests, sharp curves, locations with sight distance***	Appropriate for: Collision history indicates that geometry likely increased likelihood of collision; particularly for collisions involving heavy vehicles on horizontal curves with degree of curvature of 6 or more (Mohammedshah, Paniati and Hobeika 1993)	• Run-off-the-road collisions • Single vehicle collisions • Centerline crossover collisions	*Improvements to horizontal and vertical alignment* Agent et al (1996) and Creasey and Agent (1985) estimate that • An improvement in horizontal alignment on average would reduce collisions by 30% (Creasey and Agent 1985) to 40% (Creasey and Agent 1985) • An improvement in vertical alignment on average would reduce collisions by 40% (Creasey and Agent 1985) to 45% (Creasey and Agent 1985) • An improvement in both vertical and horizontal alignment would reduce collisions by 50% (Creasey and Agent 1985) *Improvements on horizontal curves for heavy vehicles* Miaou et al (1993) evaluated heavy vehicle collision rates on horizontal curves and estimated collision reductions as:

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td>7.
Roadway Alignment (continued)</td><td>7.1
Realignment of geometry such as crests, sharp curves, locations with sight distance (continued)</td><td></td><td></td><td>
<table>
<tr><td rowspan="2">Length of original curve (mi.)</td><td colspan="5">Horizontal Curvature (HC) in degrees / 100-ft arc: for 2° to 30° (percent reduction)</td></tr>
<tr><td>Reduce 1°</td><td>Reduce 2°</td><td>Reduce 5°</td><td>Reduce 10°</td><td>Reduce 15°</td></tr>
<tr><td>0.10</td><td>9.4 (±1.1)</td><td>18.0 (±2.0)</td><td>39.1 (±3.8)</td><td>62.9 (±4.6)</td><td>77.4 (±4.3)</td></tr>
<tr><td>0.25</td><td>10.0 (±1.8)</td><td>19.0 (±3.3)</td><td>41.0 (±6.1)</td><td>65.2 (±7.4)</td><td>79.5 (±6.8)</td></tr>
<tr><td>0.50</td><td>11.0 (±4.7)</td><td>20.7 (±8.4)</td><td>44.1 (±15.4)</td><td>68.7 (±20.2)</td><td>82.5 (±22.0)</td></tr>
<tr><td>0.75</td><td>11.9 (±7.6)</td><td>22.4 (13.6)</td><td>47.0 (±26.2)</td><td>71.9 (±42.6)</td><td>85.1 (---)</td></tr>
<tr><td>>1.00</td><td>12.8 (±10.6)</td><td>24.0 (±19.0)</td><td>49.7 (±39.6)</td><td>74.7 (---)</td><td>87.3 (---)</td></tr>
</table>

In a FHWA study (Smith, et al. 1983) the percentage collision reduction across collision severity levels for high collision locations were estimated as:
<table>
<tr><td rowspan="2">Location Type</td><td colspan="4">Collision Severity</td></tr>
<tr><td>All</td><td>Fatal</td><td>Injury</td><td>PDO</td></tr>
<tr><td>Horizontal realignment</td><td>40</td><td>40</td><td>30</td><td>25</td></tr>
<tr><td>Vertical realignment</td><td>40</td><td>40</td><td>40</td><td>50</td></tr>
</table>
An SDDOT study of 62 high collision sites found a 100% reduction for horizontal realignment and a 12% increase in collisions for realignment of vertical and horizontal features (South Dakota Department of Transportation 1998).

Reconstruction of highway with wider lanes, shoulders, high-speed alignment with full sight distance could potentially reduce both run-off-the-road and head-on collisions – may be cost prohibitive (Council, Head-On Crashes 2000).</td></tr>
</table>

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td>7.
Roadway Alignment (continued)</td><td>7.1
Realignment of geometry such as crests, sharp curves, locations with sight distance (continued)</td><td></td><td></td><td>Flatten horizontal curvature
Harwood et al (2000) developed the following AMF for total collision frequency on horizontal curves:
$AMF = \frac{1.55Lc + \frac{80.2}{R} - 0.012S}{1.55Lc}$, where Lc is the length of the curve in miles (exclude length of spiral curve), R is the curve radius in ft, and S is an indicator variable for the presence of a spiral transition (S=1 if a spiral transition is present, S=0 if it is not).

Zegeer et al (1991)estimated total collision reductions of up to 80% for curve flattening (factors affecting results include amount of flattening and curve central angle)

Improve Sight Distance without Geometric Realignment
Creasy and Agent (1985) estimated a total collision reduction of 30% for sight distance improvements.

Smith et al (1983) developed the following estimates for high collision locations:
<table>
<tr><td rowspan="2">Sight distance change location</td><td colspan="4">Collision Severity</td></tr>
<tr><td>All</td><td>Fatal</td><td>Injury</td><td>PDO</td></tr>
<tr><td>Sight distance on horizontal curve</td><td>5</td><td>5</td><td>5</td><td>5</td></tr>
<tr><td>Sight distance at intersection</td><td>50</td><td>60</td><td>50</td><td>40</td></tr>
<tr><td>Sight distance at railroad grade crossing</td><td>25</td><td>25</td><td>25</td><td>25</td></tr>
</table></td></tr>
</table>

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
7. Roadway Alignment (continued)	***7.2 Improve curve superelevation***	Appropriate for: horizontal curves with drainage concerns during wet weather; collisions on horizontal curves where superelevation not compatible with horizontal alignment	• Run-off-the-road collisions • Centerline crossover collisions	Harwood et al (2000) associated the improvement of a superelevation deficiency of greater than 2% with a total collision AMF: AMF = 1.06 +3 *(superelevation deficiency-0.02) Zegeer et al (1991)estimated that improvement of superelevation to AASHTO recommended values reduce collisions between 5 and 10%.
	7.3 Improve sight distance	• Removal of physical features restricting sight distance • Modification to geometry to improve sight distance (including moving stop bar at intersection(s))	• Centerline crossover collisions • Collisions where sight distance was restricted by physical features (incl. signing, vegetation)	
	7.4 Reduce grade			

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
8. Maintenance activities	***8.1 Removal of overhanging vegetation that are reducing visibility of signage***			
	8.2 Delineation: pavement markings and signage	• Worn Markings • Retroreflec-tivity of markings or signs limited		
9. Pedestrian facilities	• ***Provision/ upgrading of sidewalks*** • ***Enhancing crosswalks*** • ***Provision of pedestrian islands*** • ***Provision of raised median*** • ***Intersection improvements such as sight distance, stop line location.*** • ***Provision of shoulder/bicy***	*Specific contexts:* rural town environments, i.e. rural facilities with higher driveway density and retail development; (surrogate measure: within half mile from K12 schools), particularly intersection/intersec tion-related collision types		

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
9. Pedestrian facilities	***cle lane*** • ***Reducing curb radius (heavy vehicle needs may limit the use of this measure)*** • ***Provision of lighting*** • ***Installation of advance warning signs (for crossings, school zones, etc.)*** • ***Relocating on-street parking to off-street locations*** • ***Modify access provision: where a site has full frontal access, install curbing and restrict access to driveway***			

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
10. **Bicyclist facilities**	***Consider installation of bicycle lanes (include particular consideration of posted speeds, sight distances, and on-street parking provision)***	Rural town environments		
	• ***Consider improvement of shoulders (surfacing and width)*** • ***Evaluate restriction of use by bicycle (special consideration to ensure route continuity)***	Rural environments with little or no development		
11. **Countermeasures for collisions involving animals**	***11.1*** ***Fencing, and fencing combined with under- or overpasses***		Deer-related collisions	Countermeasures on deer collisions are limited and the literature review indicated that fencing, fencing combined with under- or overpasses were the only methods with scientific evidence of collision reduction. This measure may be cost prohibitive. A number of other methodologies are promising but needs further studies (Hedlund, et al. 2003).

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
12. Access Management: management of driveway/ access/ intersection locations to reduce likelihood of driveway related collisions when a vehicle enters or exit a driveway (including rear-end collisions) and collisions such as right angled and U-turn collisions	***12.1 All***	• Provision of left-turn lanes • Provision of right-turn lanes • Restricting turning movements (median installations) • Installation of two way left turn lanes • Access management strategies that will limit access provision within influence area of intersections • Replace full property frontage access with an access point	Rear-end collisions involving one vehicle that was turning left or right, involving a vehicle that was entering or exiting a driveway	Agent et al (1996) estimates that the addition of a frontage road would on average reduce overall collision frequency by 40%. Vogt and Bared (1988) determined that a reduction in driveway density would on average result in a reduction in overall collision frequency.

<table>
<tr>
<th>Countermeasure Category (from Part B)</th>
<th>Countermeasure with special notes</th>
<th>Context</th>
<th>Possible target collision type/condition</th>
<th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th>
</tr>
<tr>
<td>12.
Access Management (continued)</td>
<td>12.2
Add exclusive left turn lane</td>
<td>Appropriate for: locations involving collisions with vehicles turning left (including right-angled collisions and rear-end collisions involving one vehicle turning left); locations with reduced left turn opportunities; locations where higher speed through traffic would not have sufficient sight distance to respond to stopped left turning vehicle waiting for a gap.</td>
<td></td>
<td>Harwood et al (2000) estimated AMFs for installation of left turn lanes on two-lane rural highways:
<table>
<tr><th rowspan="2">Intersection Type</th><th rowspan="2">Control Type</th><th colspan="2">Number of major-road approaches on which left turn lanes are installed</th></tr>
<tr><th>One approach</th><th>Both approaches</th></tr>
<tr><td rowspan="2">3-leg intersection</td><td>STOP control</td><td>0.78</td><td>-</td></tr>
<tr><td>Traffic signal</td><td>0.85</td><td>-</td></tr>
<tr><td rowspan="2">4-leg intersection</td><td>STOP control</td><td>0.76</td><td>0.58</td></tr>
<tr><td>Traffic signal</td><td>0.82</td><td>0.67</td></tr>
</table>
The IHSDM for exclusive left-turn lane installations are (Council and Harwood 1999):
<table>
<tr><th rowspan="2">Intersection Type</th><th rowspan="2">Intersection Traffic Control</th><th colspan="2">Number of Major Road Approaches on Which Left-Turn Lanes are Installed</th></tr>
<tr><th>One Approach</th><th>Both Approaches</th></tr>
<tr><td rowspan="2">3-Leg Intersection</td><td>Stop Sign</td><td>0.78</td><td>---</td></tr>
<tr><td>Traffic Signal</td><td>0.85</td><td>---</td></tr>
<tr><td rowspan="2">4-Leg Intersection</td><td>Stop Sign</td><td>0.76</td><td>0.58</td></tr>
<tr><td>Traffic Signal</td><td>0.82</td><td>0.67</td></tr>
</table>
</td>
</tr>
</table>

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td>12.
Access Management (continued)</td><td>12.3
Add exclusive right turn lane</td><td>Appropriate for: locations involving collisions with vehicles turning right (rear-end collisions involving queuing resulting from right turning vehicles); locations where higher speed through traffic would not have sufficient sight distance to respond to slowing right turning vehicle.</td><td></td><td>Harwood et al (2000) estimated AMFs for installation of right turn lanes on major approaches to intersections on two-lane rural highways:
<table>
<tr><td rowspan="2">Control Type</td><td colspan="2">Number of major-road approaches on which left turn lanes are installed</td></tr>
<tr><td>One approach</td><td>Both approaches</td></tr>
<tr><td>STOP control</td><td>0.95</td><td>0.90</td></tr>
<tr><td>Traffic signal</td><td>0.975</td><td>0.95</td></tr>
</table>
The IHSDM for exclusive right-turn lane installations are (Council and Harwood 1999):
<table>
<tr><td rowspan="2">Intersection Type</td><td rowspan="2">Intersection Traffic Control</td><td colspan="2">Number of Major Road Approaches on which Right-Turn Lanes are Installed</td></tr>
<tr><td>One Approach</td><td>Both Approaches</td></tr>
<tr><td rowspan="2">3-Leg Intersection</td><td>Stop Sign</td><td>0.95</td><td>---</td></tr>
<tr><td>Traffic Signal</td><td>0.975</td><td>---</td></tr>
<tr><td rowspan="2">4-Leg Intersection</td><td>Stop Sign</td><td>0.95</td><td>0.90</td></tr>
<tr><td>Traffic Signal</td><td>0.975</td><td>0.95</td></tr>
</table>
</td></tr>
</table>

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
12. **Access Management (continued)**	***12.4*** ***Add two way left turn lane (TWLTL)***	Appropriate for: • locations involving collisions with vehicles turning left (including right-angled collisions and rear-end collisions involving one vehicle turning left); • locations with reduced left turn opportunities; • locations where higher speed through traffic would not have sufficient sight distance to respond to stopped left turning vehicle waiting for a gap. Not appropriate: locations where		Harwood et al (2000) estimated that the AMF for installing TWLTLs as : AMF=1-0.7P_DPLT/D), where • P_D = driveway-related crashes as a proportion of the total, which can be estimated by (0.0047DD +0.0024DD^2) / • (1.199 +0.0047DD +0.0024DD^2) where DD is driveways per mile; and • $P_{LT/D}$ = left-turn crashes correctable by the addition of a TWLTL, estimated as 0.5.

Countermeasure Category (from Part B)	Countermeasure with special notes	Context	Possible target collision type/condition	Potential impact of countermeasure (limited to research results for two-lane rural highways)
12. Access Management (continued)	***12.4 Add two way left turn lane (TWLTL) (continued)***	high density of driveways reduce effectiveness of two-lane left turn lanes.		
	12.5 Add passing lanes			Reduces passing related and head-on collisions. May be cost prohibitive. Harwood et al (2000) estimates that total collision frequency resulting from installing passing lanes for two-way traffic is 35% .
13. Unsignalized intersections	***13.1 Rumble strips/exposed aggregate on approach to minor approaches of intersections***		Right-angled collisions (incl. entering at angle)	A synthesis report for Wisconsin DOT indicated that this measure is likely to: • Reduce approach speeds (increase in speeds also reported) • Reduce rear-end collisions • Reduce frontal-impact collisions They also noted special considerations: inappropriate motorist behaviors such as entering opposing lanes to avoid the strips, loss of control by motorcyclists and bicyclists; and possible increase in speeds (CTC & Associates LLC, WisDOT Research & Library Unit 2007).
	13.2 Also see Lighting [14]			

<table>
<tr><th>Countermeasure Category (from Part B)</th><th>Countermeasure with special notes</th><th>Context</th><th>Possible target collision type/condition</th><th>Potential impact of countermeasure (limited to research results for two-lane rural highways)</th></tr>
<tr><td rowspan="2">14.
Lighting</td><td>14.1
Add segment lighting</td><td>Particularly beneficial for segments with higher driveway/access density, challenging geometry, presence of pedestrians where poor visibility contributed to collisions</td><td></td><td>Agent et al (1996) estimated that street lighting on roadway segments would on average reduce overall collision frequency by 25% and nighttime collisions by 50%.

Smith et al (1983) estimated the following collision reduction percentages for street lighting:
<table>
<tr><td rowspan="2">Lighting location</td><td colspan="4">Collision Severity</td></tr>
<tr><td>All</td><td>Fatal</td><td>Injury</td><td>PDO</td></tr>
<tr><td>Install street lighting on horizontal curve or at bridge</td><td>10</td><td>15</td><td>15</td><td>10</td></tr>
<tr><td>Install street lighting on tangent section</td><td>-</td><td>10</td><td>5</td><td>5</td></tr>
</table></td></tr>
<tr><td>14.2
Add lighting at intersections</td><td>Particularly beneficial for intersection with fixed islands/ channelization, users such as pedestrians, or challenging geometry where poor visibility contributed to collisions</td><td></td><td>Smith et al (1983) estimated the following collision reduction percentages for street lighting:
<table>
<tr><td rowspan="2">Lighting location</td><td colspan="4">Collision Severity</td></tr>
<tr><td>All</td><td>Fatal</td><td>Injury</td><td>PDO</td></tr>
<tr><td>Install street lighting at intersection</td><td>10</td><td>15</td><td>15</td><td>10</td></tr>
</table>

Wortman et al (1972) estimated that street lighting at rural at-grade intersections reduce the frequency of nighttime collisions. Preston and Schoenecker (1999) estimated that the overall frequency of nighttime collisions could potentially reduce by 40% with the installation of street lighting. A 49% reduction of nighttime collision frequency was estimated in a study by Walker and Roberts (1976).</td></tr>
</table>

APPENDIX B: BIBLIOGRAPHY FOR THE PROJECT

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APPENDIX C: SAFETY PERFORMANCE FUNCTIONS FOR LIMITED BEFORE-AFTER STUDY OF CENTERLINE RUMBLE STRIPS INSTALLED ON TWO-LANE RURAL HIGHWAYS FROM 2001 TO 2003 IN WASHINGTON STATE

LIST OF VARIABLES

Variable	Description
SEGMENTLENGTH	Length of segment
LOGLENGTH	Log(length of segment)
ROLLING	Rolling terrain
FUNC_R1	Functional Class R1
FUNC_R2	Functional Class R2
FUNC_R3	Functional Class R3
INTALL_DENSITY	Intersection Density
HORCURVE_LESS3	Horizontal curve degree of curvature less than 3
HORCURVE_LESS4	Horizontal curve degree of curvature less than 4
HORCURVE_LESS5	Horizontal curve degree of curvature less than 5
SCHOOL_DIST_0tohMI	Within half a mile of a K12 school
SCHOOL_DIST_hto1MI	Within half of a mile to 1 mile of a K12 school
SCHOOL_DIST_1to2MI	Within 1 to 2 miles of a K12 school
SCHOOL_1MI_IND	Within 1 mile of a K12 school
HU2005	Number of housing units in the particular census block group
NUM_RAINYDAYS_AV_9906	Average annual number of rainy days for 1999 to 2006
RIGHTSHLDWIDTH	Right shoulder width in ft
TOTAL_SNOWYDAYS_AV_9906	Average annual number of days with snow from 1999 - 2006
TOT_DAYSWITHWETPAVHRS_AV_9906	Average annual days with wet pavement (as defined by Van Schalkwyk et al, 2006)
TOT_PRECIP_AV_9906	Average rainfall per year from 1999 to 2005 (rain and ice but excluding snow)
ACCESSCONTROL_NONE	No access control
ACCESSCONTROL_1	Access control level 1
ACCESSCONTROL_2	Access control level 2
ACCESSCONTROL_3	Access control level 3
ACCESSCONTROL_4	Access control level 4
ACCESSCONTROL_5	Access control level 5
HCURVE_CAT_0	Segment with no horizontal curve
HCURVE_CAT_1	Segment on horizontal curve with a degree of curvature>= 1 and <2
HCURVE_CAT_2	Segment on horizontal curve with a degree of curvature>= 2 and <3
HCURVE_CAT_3	Segment on horizontal curve with a degree of curvature>= 3 and <4
HCURVE_CAT_4	Segment on horizontal curve with a degree of curvature>= 4 and <5
HCURVE_CAT_5	Segment on horizontal curve with a degree of curvature>= 5 and <6
HCURVE_CAT_6	Segment on horizontal curve with a degree of curvature>= 6 and <7
VBREAKNUM	Number of vertical breaks on segment
VOL_9905_AVERAGE	Average annual traffic volume (1999 - 2005)
LOGAVERAGEVOL	Log(VOL_9905_AVERAGE)

All Collisions

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	-2.1787	0.0624	-2.3009	-2.0564	1220.82	<.0001
LOGAVERAGEVOL	1	0.3061	0.0077	0.2910	0.3211	1584.07	<.0001
LOGLENGTH	1	0.3068	0.0053	0.2964	0.3172	3331.28	<.0001
ACCESSCONTROL_1	1	-0.0954	0.0147	-0.1242	-0.0667	42.25	<.0001
ACCESSCONTROL_2	1	0.0468	0.0131	0.0211	0.0724	12.78	0.0004
ACCESSCONTROL_3	1	-0.1161	0.0259	-0.1669	-0.0653	20.07	<.0001
ACCESSCONTROL_4	1	-0.2075	0.0471	-0.2999	-0.1152	19.40	<.0001
HCURVE_CAT_1	1	-0.1073	0.0196	-0.1457	-0.0689	30.00	<.0001
HCURVE_CAT_2	1	-0.0758	0.0209	-0.1167	-0.0349	13.21	0.0003
HU2005	1	0.0001	0.0000	0.0001	0.0001	26.76	<.0001
VBREAKNUM	1	0.0602	0.0086	0.0433	0.0770	49.00	<.0001
NUM_RAINYDAYS_AV_9906	1	0.0009	0.0002	0.0005	0.0013	16.20	<.0001
SCHOOL_DIST_0tohMI	1	-0.1357	0.0216	-0.1781	-0.0933	39.34	<.0001
SCHOOL_DIST_1to2MI	1	-0.0779	0.0183	-0.1137	-0.0421	18.18	<.0001
SCHOOL_DIST_hto1MI	1	-0.1239	0.0228	-0.1687	-0.0791	29.41	<.0001
Dispersion	1	0.2042	0.0041	0.1961	0.2123		

All Injury Collisions

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	-3.4972	0.0783	-3.6507	-3.3437	1994.53	<.0001
LOGAVERAGEVOL	1	0.3503	0.0096	0.3315	0.3690	1342.43	<.0001
LOGLENGTH	1	0.3558	0.0068	0.3425	0.3692	2720.06	<.0001
ACCESSCONTROL_1	1	-0.1014	0.0176	-0.1359	-0.0669	33.21	<.0001
ACCESSCONTROL_2	1	0.0487	0.0157	0.0179	0.0795	9.59	0.0020
ACCESSCONTROL_3	1	-0.1087	0.0327	-0.1727	-0.0446	11.05	0.0009
ACCESSCONTROL_4	1	-0.2408	0.0613	-0.3608	-0.1207	15.45	<.0001
HCURVE_CAT_0	1	-0.0468	0.0226	-0.0911	-0.0025	4.28	0.0386
HCURVE_CAT_1	1	-0.1571	0.0314	-0.2186	-0.0956	25.08	<.0001
HCURVE_CAT_2	1	-0.1192	0.0325	-0.1829	-0.0555	13.45	0.0002
VBREAKNUM	1	0.0497	0.0093	0.0315	0.0678	28.76	<.0001
POP_RURAL	1	0.0001	0.0000	0.0000	0.0001	38.69	<.0001
TOT_DAYSWITHWETPAVHRS_AV_9906	1	0.0018	0.0003	0.0011	0.0025	29.22	<.0001
SCHOOL_DIST_0tohMI	1	-0.1393	0.0278	-0.1938	-0.0847	25.02	<.0001
SCHOOL_DIST_1to2MI	1	-0.0756	0.0220	-0.1186	-0.0326	11.86	0.0006
SCHOOL_DIST_hto1MI	1	-0.1330	0.0287	-0.1893	-0.0767	21.43	<.0001
Scale	0	0.7070	0.0000	0.7070	0.7070		

All PDO Collisions

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	-3.3913	0.0819	-3.5518	-3.2308	1714.27	<.0001
LOGAVERAGEVOL	1	0.3245	0.0103	0.3042	0.3447	983.17	<.0001
LOGLENGTH	1	0.3526	0.0068	0.3393	0.3659	2698.78	<.0001
FUNC_R1	1	0.1309	0.0144	0.1026	0.1591	82.50	<.0001
HCURVE_CAT_0	1	-0.0455	0.0226	-0.0897	-0.0013	4.07	0.0437
HCURVE_CAT_1	1	-0.1590	0.0314	-0.2205	-0.0975	25.70	<.0001
HCURVE_CAT_2	1	-0.1225	0.0325	-0.1862	-0.0587	14.17	0.0002
POP_RURAL	1	0.0001	0.0000	0.0000	0.0001	40.61	<.0001
SCHOOL_DIST_0tohMI	1	-0.0947	0.0277	-0.1490	-0.0405	11.72	0.0006
SCHOOL_DIST_1to2MI	1	-0.0545	0.0220	-0.0976	-0.0113	6.13	0.0133
SCHOOL_DIST_hto1MI	1	-0.0975	0.0288	-0.1540	-0.0409	11.41	0.0007
VBREAKNUM	1	0.0492	0.0093	0.0310	0.0674	28.11	<.0001
NUM_WETPAVHRS_AV_990	1	0.0001	0.0000	0.0001	0.0002	25.31	<.0001
Scale	0	0.7079	0.0000	0.7079	0.7079		

Nighttime Collisions

Parameter	DF	Estimate	Standard Error	Wald 95% Confidence Limits		Chi-Square	Pr > ChiSq
Intercept	1	-6.0622	0.1581	-6.3720	-5.7523	1470.00	<.0001
LOGAVERAGEVOL	1	0.8289	0.0183	0.7931	0.8648	2051.56	<.0001
LOGLENGTH	1	0.8770	0.0141	0.8494	0.9047	3868.02	<.0001
ACCESSCONTROL_3	1	-0.5203	0.0775	-0.6721	-0.3685	45.13	<.0001
ACCESSCONTROL_4	1	-1.0428	0.1789	-1.3935	-0.6921	33.96	<.0001
ACCESSCONTROL_5	1	-1.0509	0.0809	-1.2095	-0.8923	168.61	<.0001
HCURVE_CAT_0	1	-0.4040	0.0563	-0.5145	-0.2936	51.41	<.0001
HCURVE_CAT_1	1	-0.5213	0.0694	-0.6573	-0.3852	56.39	<.0001
HCURVE_CAT_2	1	-0.4020	0.0714	-0.5419	-0.2621	31.74	<.0001
HCURVE_CAT_3	1	-0.2934	0.0845	-0.4590	-0.1277	12.05	0.0005
VBREAKNUM	1	-0.0710	0.0152	-0.1007	-0.0413	21.91	<.0001
Scale	0	1.6294	0.0000	1.6294	1.6294		

Nighttime Injury Collisions

Parameter	*DF*	*Estimate*	*Standard Error*	*Wald 95% Confidence Limits*		*Chi-Square*	*Pr > ChiSq*
Intercept	1	-7.2759	0.2174	-7.7020	-6.8498	1120.12	<.0001
LOGLENGTH	1	0.8455	0.0172	0.8117	0.8793	2409.05	<.0001
LOGAVERAGEVOL	1	0.8186	0.0259	0.7679	0.8693	999.61	<.0001
ACCESSCONTROL_3	1	-0.5061	0.1069	-0.7156	-0.2966	22.42	<.0001
ACCESSCONTROL_4	1	-1.0881	0.2466	-1.5714	-0.6048	19.47	<.0001
ACCESSCONTROL_5	1	-1.0772	0.1118	-1.2963	-0.8581	92.86	<.0001
SCHOOL_1MI_IND	1	-0.1290	0.0484	-0.2238	-0.0342	7.12	0.0076
HCURVE_CAT_0	1	-0.3983	0.0775	-0.5502	-0.2463	26.40	<.0001
HCURVE_CAT_1	1	-0.5045	0.0954	-0.6915	-0.3175	27.96	<.0001
HCURVE_CAT_2	1	-0.4082	0.0981	-0.6005	-0.2158	17.30	<.0001
HCURVE_CAT_3	1	-0.3099	0.1163	-0.5378	-0.0820	7.10	0.0077
TOT_PRECIP_AV_9906	1	0.0088	0.0021	0.0046	0.0130	16.85	<.0001
Scale	0	0.9146	0.0000	0.9146	0.9146		

Nighttime PDO Collisions

Parameter	*DF*	*Estimate*	*Standard Error*	*Wald 95% Confidence Limits*		*Chi-Square*	*Pr > ChiSq*
Intercept	1	-6.7672	0.2278	-7.2136	-6.3208	882.80	<.0001
LOGLENGTH	1	0.8904	0.0196	0.8521	0.9287	2072.47	<.0001
LOGAVERAGEVOL	1	0.7665	0.0294	0.7090	0.8240	681.99	<.0001
FUNC_R1	1	0.2151	0.0477	0.1216	0.3085	20.36	<.0001
FUNC_R2	1	-0.2027	0.0591	-0.3186	-0.0868	11.76	0.0006
HCURVE_CAT_0	1	-0.2874	0.0616	-0.4082	-0.1666	21.73	<.0001
HCURVE_CAT_1	1	-0.3907	0.0837	-0.5546	-0.2267	21.81	<.0001
HCURVE_CAT_2	1	-0.3154	0.0866	-0.4852	-0.1457	13.26	0.0003
HU2005	1	0.0002	0.0001	0.0001	0.0003	12.00	0.0005
INTALL_DENSITY	1	-0.0049	0.0017	-0.0082	-0.0016	8.26	0.0041
RIGHTSHLDWIDTH	1	-0.0255	0.0128	-0.0507	-0.0003	3.94	0.0472
VBREAKNUM	1	-0.0774	0.0211	-0.1187	-0.0361	13.50	0.0002
SCHOOL_DIST_0tohMI	1	-0.5031	0.1129	-0.7243	-0.2819	19.87	<.0001
SCHOOL_DIST_hto1MI	1	-0.3166	0.0897	-0.4924	-0.1407	12.44	0.0004
Scale	0	0.9145	0.0000	0.9145	0.9145		