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DEVELOPING METHODOLOGY FOR IDENTIFYING, EVALUATING, AND PRIORITIZING SYSTEMIC IMPROVEMENTS

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ACRONYMS

Acronym	Definition
AADT	Annual Average Daily Traffic
AASHTO	American Association of State Highway and Transportation Officials
ADOT	Arizona Department of Transportation
ADT	Average Daily Traffic
AusRAP	Australia Road Assessment Program
B/C	Benefit-Cost
CMF	Crash Modification Factor
CRF	Crash Reduction Factor
CRIS	Crash Records Information System
DOT	Department of Transportation
EuroRAP	Europe Road Assessment Program
FHWA	Federal Highway Administration
FM	Farm-to-Market
HSIP	Highway Safety Improvement Program
HSIPM	Highway Safety Improvement Program Manual
HSM	Highway Safety Manual
HWY	Highway
KABC	Fatal (K), Incapacitating Injury (A), Non-Incapacitating Injury (B), Possible Injury (C)
KYTC	The Kentucky Transportation Cabinet
MnDOT	Minnesota Department of Transportation
MoDOT	Missouri Department of Transportation
NCHRP	National Cooperative Highway Research Program
NYSDOT	New York State Department of Transportation
PDO	Property Damage Only
PWD	Public Works Department
ROR	Run-Off-Road
SH	State Highway
SHSP	Strategic Highway Safety Plan
SII	Safety Improvement Index
SVROR	Single Vehicle Run-Off-Road
TMUTCD	Texas Manual on Uniform Traffic Control Devices
TRB	Transportation Research Board
TRFW	Total Risk Factor Weight
TTI	Texas A&M Transportation Institute
TxDOT	Texas Department of Transportation
usRAP	United States Road Assessment Program
VDOT	Virginia Department of Transportation
Unit: ft (feet), mi (mile), and mph (mile per hour)	

EXECUTIVE SUMMARY

Traditional safety improvements have typically been applied in areas based on the number of crashes (i.e., hot or black spot approaches). However, this traditional approach has caused several negative externalities, such as more safety improvement projects are selected at crash condensed urban areas rather than sporadic rural areas. According to TxDOT crash statistics, fatal crashes in rural areas accounted for 55 percent of total fatal collisions in 2011 and 2012. Additionally, there were 1,679 fatal crashes in rural areas in 2012—a 9 percent increase from those reported in 2011. The systemic approach to highway safety improvements focuses on high-risk roadway features, rather than specific high-crash locations, and thus is more effective at reducing fatal/severe injury crashes on rural highways. This report proposes two systemic approaches for the State of Texas, one to project selection and one to roadway characteristic classification. The systemic approach to project selection focuses on reducing the number and severity of target crashes occurring on the TxDOT roadway network, and the approach to roadway characteristic classification deals with developing systemic improvements that focus on a particular countermeasure to have a positive impact on safety.

Both approaches include the task to identify the types of preventable crashes that represent the greatest opportunities for reduction. For systemic approach to project selection, those crash types usually represent the greatest number of crashes across the system being analyzed. For the approach to roadway characteristics, those crash types represent the crashes that can prevented by the countermeasure selected. The next task deals with the identification of risk factors associated with preventable target crash types. In the risk assessment, risk factors are evaluated using the weighting criteria based on the percentages of total crashes and the crash over-representation when compared to the proportion of highway mileage in a particular risk category (e.g. 10ft lane width). A total risk factor weight calculated based on the total crashes and the crash over-representation is used to prioritize the roadway network locations for countermeasure implementation.

The approach to project selection includes a benefit-cost analysis for selecting low-cost, effective countermeasures to remove/alleviate risk factors on roads by adding safety features. This systemic approach is beneficial for addressing not only rural crashes but also crash types less likely clustered in urban areas, particularly those involving pedestrians, bicyclists, and motorcyclists.

The systemic approach to roadway characteristic involves identifying low-cost countermeasures for preventable crash types and candidate locations on high-risk rural roadways, as well as defining potential risk factors for preventable crash types. The researchers recommend that countermeasures associated with preventable crash types and roadway risk factors be considered as safety improvements on new highway construction as well as existing highways.

CHAPTER I
LITERATURE REVIEW

This chapter summarizes the breadth of literature pertaining to systemic methods for improving safety. The review covers four core topics:

- A systemic approach to safety.
- Existing systemic methods used by highway safety stakeholders and agencies.
- Countermeasures and effects.
- Project prioritization methods.

1.1 OVERVIEW

The objective of the systemic approach to safety is to identify countermeasures that address high-risk roadway factors through system-wide analysis of specific target crash types. The traditional approaches used in the Highway Safety Improvement Program (HSIP) are mainly based on hotspot identifications. Sites with promise or identified as high risk (experiencing more crashes than expected) are identified through network screening, and investments are then decided based on the crash frequencies (Hauer et al. 2004). These sites could be defined as intersections or short or long segments (e.g., sharp curve, narrow lane width).

Recently, the nature of the HSIP has grown to focus on severe crashes, especially those that lead to fatalities. According to national crash figures, many fatal crashes occur in rural areas of the state. Based upon crash data obtained from the Federal Highway Administration (FHWA), rural crashes account for more than 50 percent of all fatal collisions (FHWA 2012b). At the same time, the length of rural highways is much longer than that of urban highways. According to the FHWA (2013b) national highway statistics, the length of public rural highways was about three times that of urban highways in 2012. These crashes are significantly affected by the random nature of the crash process, compared to those that occur in urban areas (Hasson 1999, FHWA 2012b). Scattered crashes over long highways make it much more difficult to efficiently predict or estimate the locations where fatal (or very severe) crashes will occur on rural highways. Thus, in short, transportation agencies will continue to experience difficulties when using traditional approaches to implement an HSIP (Preston et al. 2013). Interestingly, fatal crashes occurring on rural roadways are virtually identical in collision types. These types mainly include run-off-the-road, rear-end, and head-on crashes, all of which tend to occur on roadways with similar characteristics. Since systemic improvements focus on high-risk roadway features rather than specific locations, it is possible to use the roadway characteristics that are associated with specific crash types to estimate which locations are most likely to experience fatal or severe crashes (FHWA 2012b).

The advantages of a systemic approach are obvious. A systemic approach needs less data once the process is established, and countermeasures are usually categorized as low cost and generally can be implemented quickly (Julian 2011).

It is important to point out that a systemic approach does not replace the traditional site analysis but instead complements it. While a systemic approach suggests safety treatments based upon roadway system characteristics, the more traditional site analysis suggests safety countermeasures based on operator crash cause and type. Regardless of approach or process, FHWA recommends that sites with large numbers of severe crashes still be addressed using traditional crash analysis methods (FHWA 2012b).

1.2 SYSTEMIC METHODS USED BY AGENCIES

This section introduces systemic safety methods used by three agencies: FHWA, the American Association of State Highway and Transportation Officials (AASHTO), and the AAA Foundation for Traffic Safety.

1.2.1 FHWA Method and Practice

The FHWA developed a tool for systemic safety project selection based on the current practices for identifying roadway safety problems and developing the HSIP. The FHWA Systemic Tool provides a step-by-step process for conducting a roadway system safety evaluation. It involves three basic elements: (a) Element 1—the systemic safety planning process; (b) Element 2—a framework for balancing systemic and traditional safety investments; and (c) Element 3—an evaluation of a systemic safety program. The framework of the FHWA Systemic Tool is shown in Figure 1-1.

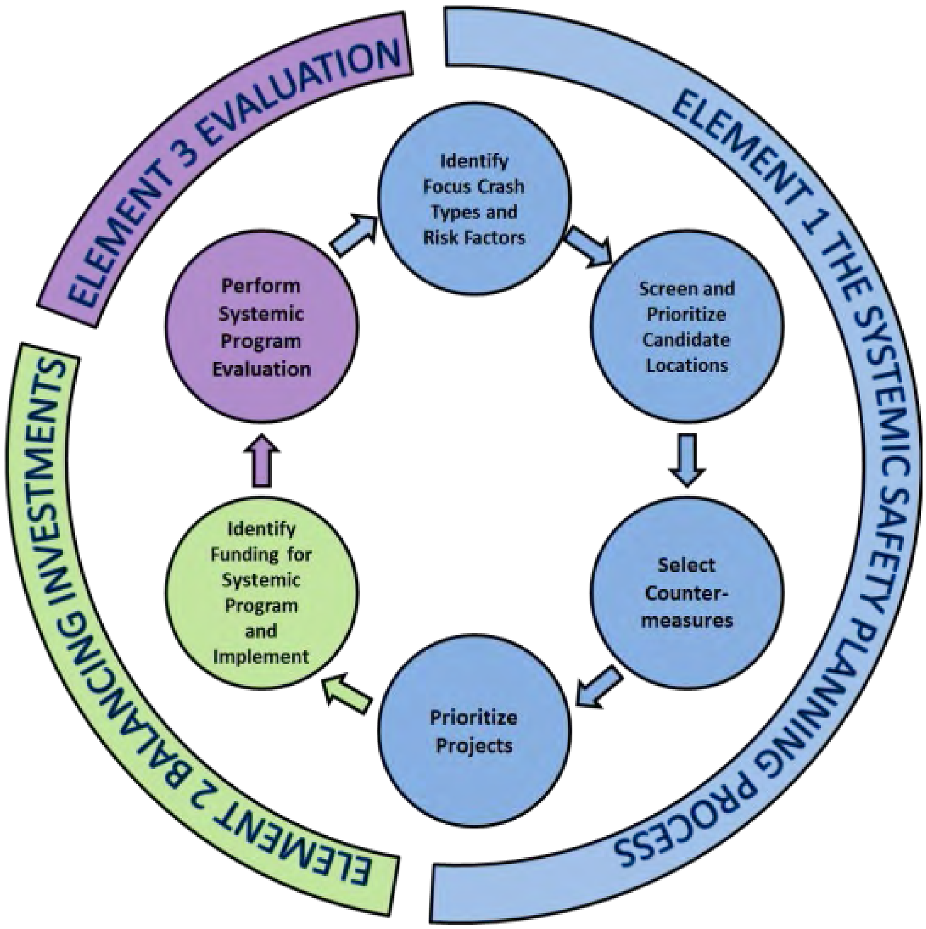


Figure 1-1 Framework of the FHWA Systemic Tool (Preston et al. 2013).

Each element contains one or more steps, as detailed below.

Systemic Approach Method

Element 1: Systemic Safety Planning Process

Systemic safety planning includes four steps: (1) identify target crash types and risk factors, (2) screen and prioritize candidate locations, (3) select countermeasures, and (4) prioritize projects. The process of the systemic safety planning is shown in Figure 1-2.

Figure 1-2 Process of Systemic Safety Planning (Preston et al. 2013).

Each step in the element of systemic safety planning has three tasks. The objectives and tasks of each step are summarized in Table 1-1.

Element 2: Framework for Balancing Systemic and Traditional Safety Investments

Balancing the investments between the systemic approach and the traditional site analysis is important. Since the systemic approach is not a replacement of the traditional site analysis, both methods are necessary when considering safety improvements. This framework helps agencies determine the safety investments between systemic and traditional analysis approaches.

The main components of the framework are (1) review the historical funding investments; (2) apply the funding determination framework to balance the two methods; and (3) assess the possible benefits from the systemic improvement based on the determined funding (Preston et al. 2013).

Table 1-1 Objectives and Tasks of Each Step in the Systemic Safety Planning Process.

Steps	Objective	Tasks
Identify target crash types and risk factors	To identify risk factors commonly associated with each focus crash type experienced across a system.	Task 1: select focus crash types
		Task 2: select focus facilities
		Task 3: identify and evaluate risk factors
Screen and prioritize candidate locations	To develop a prioritized list of potential locations on the roadway system (segments, curves, intersections, etc.) that could benefit from systemic safety improvement projects.	Task 1: identify network elements to analyze
		Task 2: conduct risk assessment
		Task 3: prioritize focus facility elements
Select countermeasures	To assemble a small number of low-cost, highly effective countermeasures to be considered for project development at candidate locations.	Task 1: assemble comprehensive list of countermeasures
		Task 2: evaluate and screen countermeasures
		Task 3: select countermeasures for deployment
Prioritize projects	To identify and develop a list of high-priority safety improvement projects for implementation.	Task 1: create decision process for countermeasure selection
		Task 2: develop safety projects
		Task 3: prioritize safety project implementation

Note: Objectives are adopted from Preston et al. (2013).

Element 3: Evaluation of a Systemic Safety Program

Evaluation provides valuable feedback on the systemic safety planning process. The effectiveness of the implemented countermeasures can be evaluated, and the results are useful to agencies for modifying or predicting future safety projects. Positive results obtained from evaluation, such as target types of crashes being reduced and treatments proving to be effective, support the usefulness of the systemic approach (Preston et al. 2013).

The evaluation process recommended by FHWA includes three levels: (1) short-term output, which consists of checking the implementation of the planned systemic program, including the general outputs, the finishing time, and the countermeasures; (2) long-term performance, which focuses on finding out if the focused crash types have been effectively reduced; and (3) specific countermeasure evaluation, which assesses the performance of the deployed countermeasures.

Evaluation in this phase will not focus on crashes at individual sites but instead at a system level. Since crashes are rare events, it is important that the evaluation include an adequate timeframe. Previous analyses on crash history duration revealed that 3 or more years of crash data provide significantly greater improvements than do data from 1 or 2 years; thus, researchers suggested that 3 years should be the shortest period when analyzing crashes (Cheng and Washington 2005). At least 3 years of crash data after the implementation of systemic countermeasures are usually required for conducting the evaluations.

Systemic Approach in Practice

The FHWA systemic approach to safety is presently being used in some states. Texas A&M Transportation Institute (TTI) researchers evaluated the systemic process for these states to determine the best practice for recommending a similar approach for Texas. This section introduces applications of the systemic approach in several states.

Minnesota

The state of Minnesota has taken the systemic approach through the development of safety plans for each of the state's 87 counties (FHWA 2013e). Following the procedure of the FHWA's systemic approach to safety, the Minnesota Department of Transportation (MnDOT) first identified the crash types and risk factors. MnDOT analyzed severe crashes (fatal (K) and incapacitating injury (A) crashes) on all public roads. The results suggested that the focus crash types were lane-departure crashes and intersection-related collisions. A crash tree diagram was created and indicated the focus facility types were rural segments and curves, rural intersections, and urban signalized intersections. MnDOT reviewed published research to identify roadway features strongly related to these crash experiences and compared these findings to available data. MnDOT then selected average daily traffic (ADT), access density, horizontal curvature, intersection skew, speed, and a few other factors as potential risk factors, as shown in Table 1-2 (Preston et al. 2013, FHWA 2013e).

Table 1-2 Potential Risk Factors for Facilities Selected by MnDOT (Preston et al. 2013).

Facility	Potential Risk Factors
Rural Segments	ADT, curve density, access density, edge rating
Rural Curves	ADT, radius, intersection, visual trap
Rural Intersections	ADT, geometry, railroad crossing, commercial development, distance from previous stop
Urban Signals	Speed, geometry, commercial development

After identifying potential risk factors for facilities, MnDOT evaluated each of the factors using descriptive statistics. The results suggested using the following specific elements for systemic network screening: 600-1,200 ADT, access density, roadside condition of no usable shoulder, and presence of fixed objects. Figure 1-3 illustrates the evaluation of ADT as a potential risk factor by MnDOT.

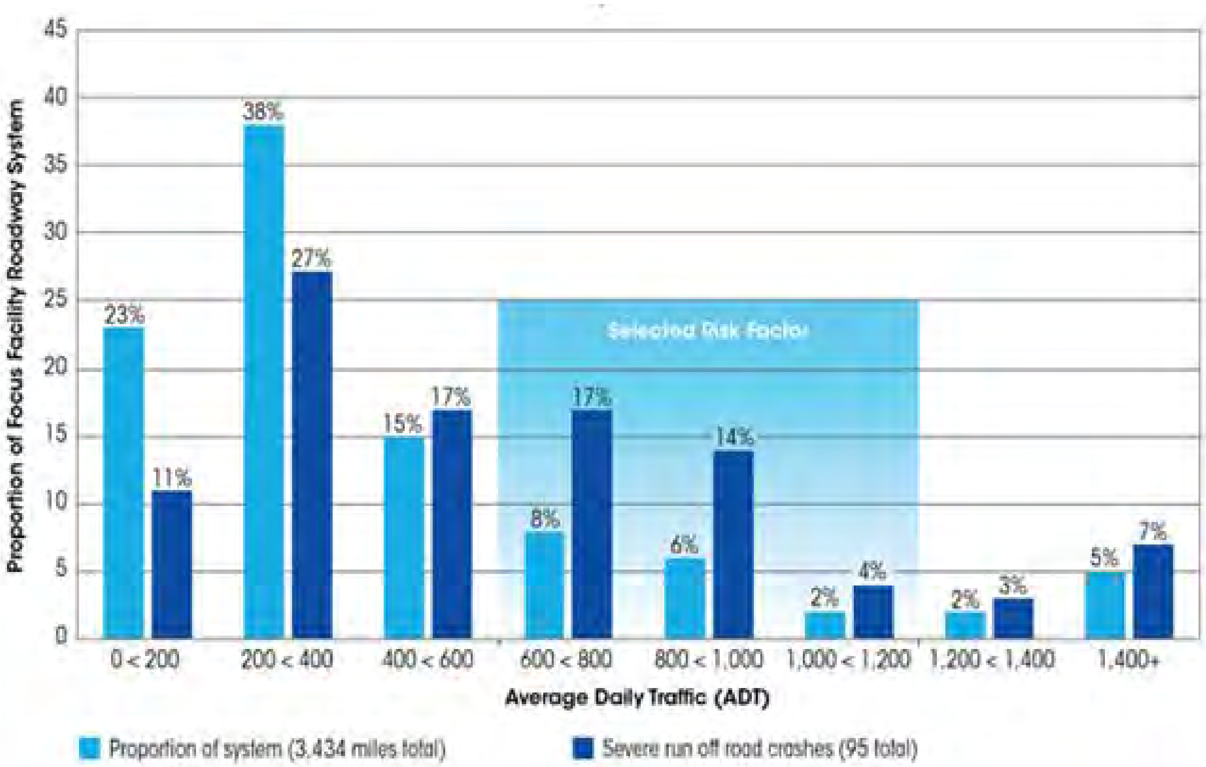


Figure 1-3 Evaluation of ADT as a Potential Risk Factor by MnDOT (Preston et al. 2013).

MnDOT screened the roadway network and prioritized candidate locations. Roadway networks were divided into segments that contained homogeneous roadway characteristics, such as consistent lane and should widths and ADT. Each segment was issued a score (varying from one star to five stars, indicating lower to higher risk) based on the number of selected screening elements it possessed. MnDOT summarized the scores and crashes within these segments. The results indicated that severe crash density and severe lane-departure crash density increased as more risk factors were present. MnDOT selected three stars as the minimum scoring threshold for selecting candidate locations for systemic safety projects. Figure 1-4 illustrates summary scoring for roadway segments considered for improvement.

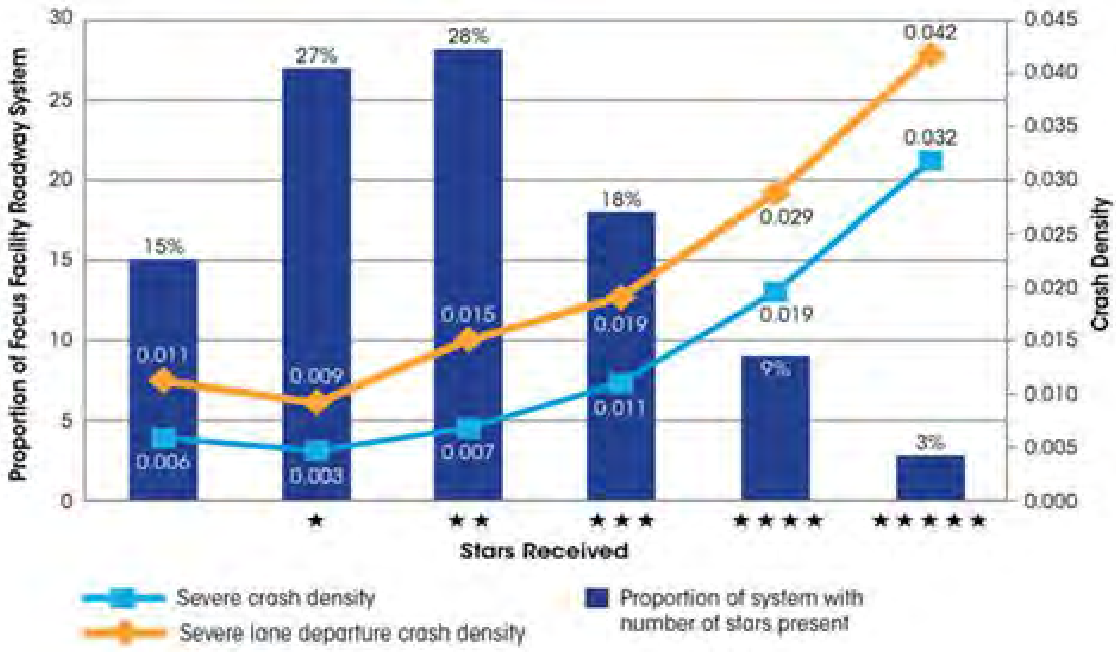


Figure 1-4 Summary of Segments by MnDOT (Preston et al. 2013).

A comprehensive list of countermeasures was assembled from the National Cooperative Highway Research Program (NCHRP) 500 Reports, the *Highway Safety Manual* (*HSM*), FHWA crash modification factor (CMF) Clearinghouse, and other recent research. When screening these countermeasures, MnDOT considered the crash data, effectiveness, cost, and agency policies and experience (Preston et al. 2013). MnDOT evaluated the initial list of countermeasures based on effectiveness of reducing the target crash types and consistency with the agency's policies, practices, and experiences. Countermeasures were then selected.

Finally, MnDOT created a decision tree for countermeasure selection and made a process for prioritizing projects for implementation. The prioritization considered not only the number of risk factors but also other factors, such as funding availability, other programmed projects, time required to develop project plans, and amount of public outreach needed (Preston et al. 2013).

Missouri

Presently, 77 percent of all roadway fatalities in Missouri occur on state-maintained roads (FHWA 2013f). As a result, the Missouri Department of Transportation (MoDOT) noted the need to apply a systemic approach to reduce fatal and serious injury crashes. MoDOT invested

HSIP funding into resurfacing projects on major roadways, where nearly half of all fatal crashes occurred (FHWA 2013f).

The concepts and procedure MoDOT adopted were similar to those used by MnDOT. However, MoDOT evaluated the effects of edgelines, which were installed on 570 mi of rural two-lane state highways. The evaluation results indicated that installing edgeline markings led to a 15 percent reduction in total expected crashes and a 19 percent reduction in severe expected crashes.

The results were used by decision-makers to determine whether or not to continue funding as normal or implement a particular countermeasure that focused on crash types on specific facilities. The findings strongly suggest that limited safety funding could be appropriately directed to projects and locations that produce safety benefits in terms of reduced crashes for the least investment (Storm, Bennett, and Wemple 2013).

Kentucky

The Kentucky Transportation Cabinet (KYTC) applied a systemic approach in five of the state's counties (FHWA 2013c). The application was based on the previously conducted systemic planning, which focused on roadway departure crashes on the state's highway system. A crash analysis showed that roadway departure crashes accounted for more than 60 percent of all traffic-related deaths and resulted in an average of 628 annual deaths between 2005 and 2009 (FHWA 2011). Based on this finding, KYTC chose roadway departure crashes as its target, concentrating specifically on rural county roads as the target facility.

KYTC identified and considered five potential risk factors: (a) horizontal curve density, (b) lane width, (c) shoulder type, (d) shoulder width, and (e) speed limit. Each risk factor was associated with a threshold value. Analysis indicated that the curve density and shoulder types were generally the determining factors for high-risk scores (FHWA 2013c). As a result of its analysis, KYTC implemented a set of cost-effective countermeasures on curves, as shown in Figure 1-5 (Chandler 2011).

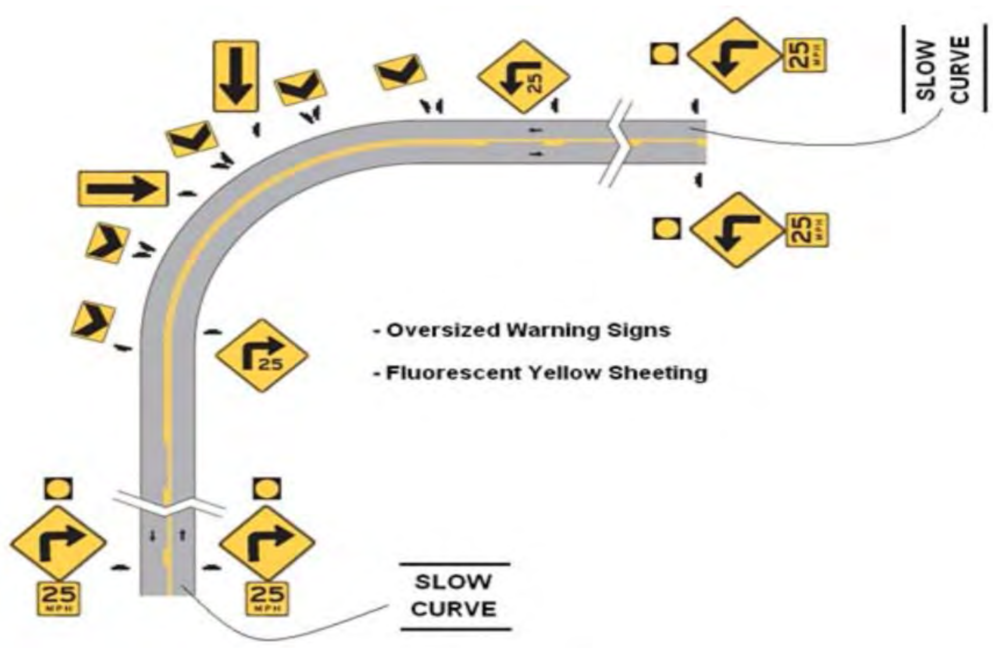


Figure 1-5 Strategy of Safety Treatments on Curves by KYTC (Chandler 2011).

Although effects of these countermeasures have not been evaluated, the systemic approach has been shown to be an easy-to-apply process to evaluate roadways in Kentucky. In addition, the systemic analysis conducted by KYTC was entirely based on available photo logs, so it did not require extra work for gathering additional data (FHWA 2013c).

New York

The New York State Department of Transportation (NYSDOT) used the systemic approach to identify sites where high-risk crashes could be reduced by implementing low-cost roadway countermeasures. NYSDOT started the systemic planning by analyzing crash data. The data suggested that road-departure and intersection-related collisions were the two primary types of crashes statewide. NYSDOT selected lane-departure crashes as the focus crash type.

The analysts merged the crash data with roadway inventory data to identify the target facilities. A crash tree diagram suggested that the most serious lane-departure crashes occurred on two-lane, rural state highways with a posted speed limit of 55 mph. NYSDOT compared the severity of crashes at locations with similar risk factors and discovered that three characteristics were over-represented: (a) annual average daily traffic (AADT) between 3,000 and 5,999, (b) curve radii between 100 and 300 ft, and (c) shoulder width between 1 and 3 ft.

Finally, NYSDOT assembled an initial, comprehensive list of countermeasures relative to lane-departure crashes (FHWA 2013d). Figure 1-6 shows an example of analyzing curve radius as a risk factor.

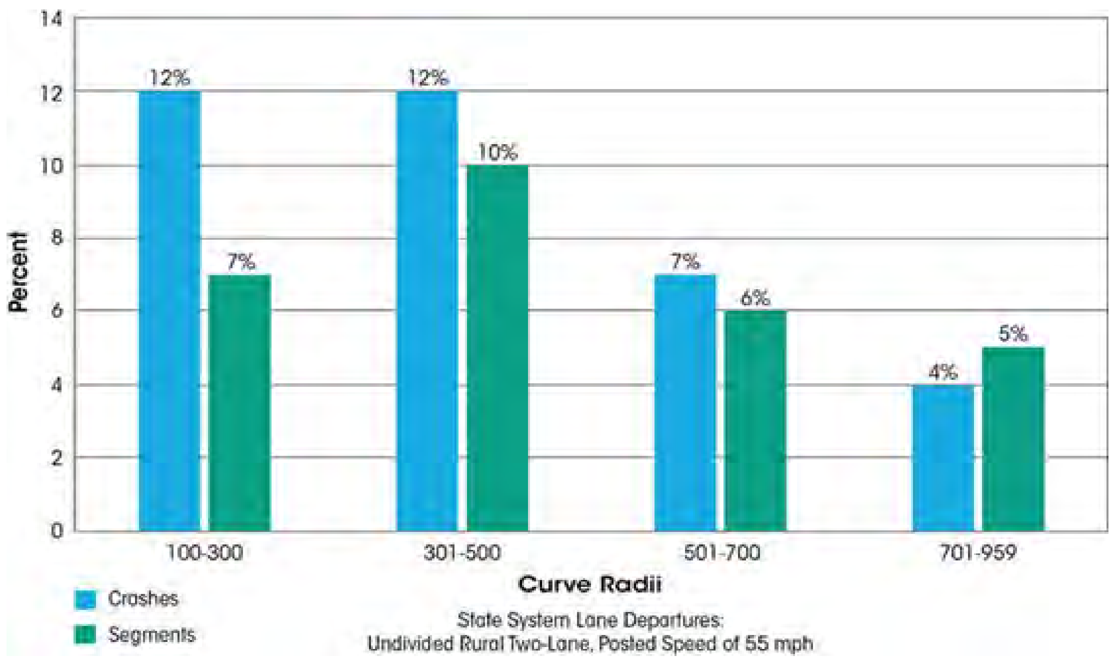


Figure 1-6 Analyzing Curve Radius as a Risk Factor (FHWA 2013d).

Thurston County, Washington

The Public Works Department of Thurston County, Washington, used a systemic approach to explore the potential benefits of proactive safety planning. The Public Works Department selected roadway departures in horizontal curves as the focus crash type because the assessment of crash data suggested that 81 percent of severe curve crashes occurred on arterial and collector roadways within the county (FHWA 2013h). The department identified nine risk factors from a list of 19 potential factors. Each factor was given an ordinal score based on the level of confidence. The evaluators then calculated the number of risk factors present for each of the segmented roadway curves. The department identified four low-cost, low-maintenance countermeasures that were systematically implemented at the curves. These included (a) traffic signs (chevron and large arrow signs), (b) pavement markings, (c) shoulder rumble strips, and (d) roadside improvements (object removal, guardrail, and slope flattening) (FHWA 2013h).

This section has presented the application of the systemic approach in several states. Since the systemic approach to safety is a new methodology, the actual benefits in terms of crash reduction have not yet been fully evaluated in all the locations described above. However, given the fact that the systemic approach uses treatments that have historically been shown to reduce target crashes, it is believed that a reduction will be observed where those treatments were installed.

1.2.2 AASHTO Method

AASHTO's adopted roadway safety management system is outlined in the *HSM* (AASHTO 2010a) and does not use a systemic approach. While the *HSM* does not use a systemic approach, some of the procedures developed in the document are closely related to this methodology. The *HSM* (AASHTO 2010a) outlines a six-step roadway safety management process that includes (1) network screening, (2) diagnosis, (3) countermeasure selection, (4) economic appraisal, (5) project prioritization, and (6) safety effectiveness evaluation. The six-step roadway safety management process is illustrated in Figure 1-7. Each step of the process will be further expanded upon below.

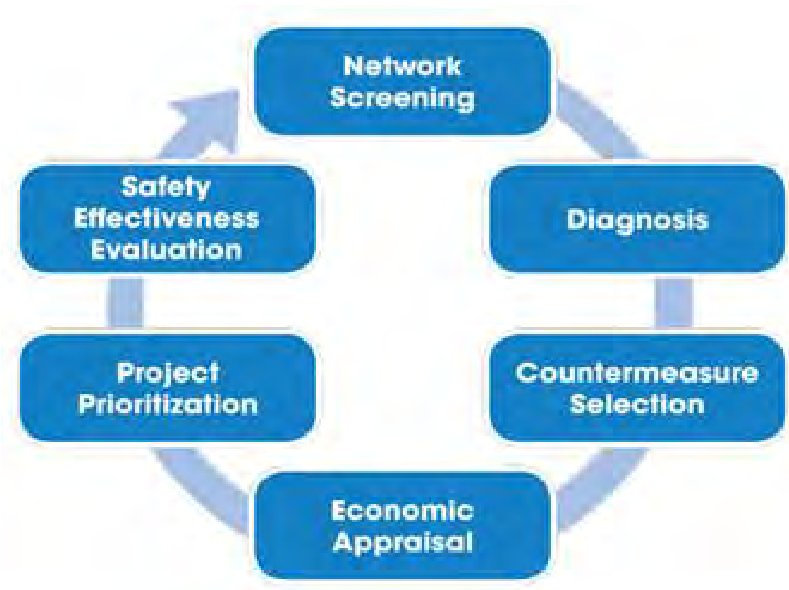


Figure 1-7 The Six-Step Roadway Safety Management Process (AASHTO 2010a).

Network Screening

In network screening, the transportation network is reviewed and sites are ranked based upon potential for crash reduction using countermeasures. Potential reductions, including collision types, contributing factors, and possible countermeasures, are then studied. Presently, there are five major steps for screening the network (AASHTO 2010a):

- *Step 1: Establish focus*. Identify the purpose or intended outcome of the network screening analysis. This decision influences the data needs, selection of performance measures, and screening methods that can be applied.
- *Step 2: Identify network and establish reference populations*. Specify the type of sites or facilities being screened (i.e., segments, intersections, at-grade rail crossings) and identify groupings of similar sites or facilities.
- *Step 3: Select performance measures*. Select the performance measure as a function of the screening focus and the data and analytical tools available. A variety of performance measures is available to evaluate the potential to reduce crash frequency at a site.
- *Step 4: Select screening method*. Select from three principle screening methods: sliding window, peak searching, and simple ranking. When screening a network, a selected method will be used to rank sites under consideration based on the performance measures. The sliding window and peak searching methods are used for segments, while the simple ranking method can be used for both segments and nodes, such as intersections.
- *Step 5: Screen and evaluate results*. Conduct the screening analysis and evaluate results. Using the ranked list generated in Step 4, countermeasures to reduce crash frequency can be applied, starting from the highest-ranked sites to the lowest, usually until the funds are depleted.

Diagnosis

Diagnosis is performed in order to identify the causes of the crashes and to discover potential safety concerns or crash patterns that can be evaluated further. The general steps of the diagnosis include (AASHTO 2010a):

- *Step 1*: *Safety data review*. Review crash locations, types, severities, and environmental conditions to develop summary descriptive statistics for pattern identification.
- *Step* 2: *Assess supporting documentation*. Review past studies and plans covering the site vicinity to identify known issues, opportunities, and constraints.
- *Step 3*: *Assess field conditions*. Visit the site to review and observe multimodal transportation facilities and services in the area, particularly how users of different modes travel through the site.

Countermeasure Selection

Sites and crash patterns are further evaluated to identify factors that contribute to particular crash types. Countermeasures are selected to specifically address the respective contributing factors that led to the collision.

Economic Appraisal

In this step, benefits of potential safety improvements are compared to the costs of implementing the improvements. The comparison is conducted after the highway network is screened. The selected sites are diagnosed and potential countermeasures for reducing crash frequency or crash severity are selected. Two main types of economic appraisals are a benefit-cost (B/C) analysis and a cost-effectiveness analysis. The B/C ratio is the ratio of the present-value benefits to the implementation costs. The benefits and costs are translated into monetary value. Cost effectiveness is expressed as the annual cost per crash reduced. The costs of countermeasures are divided by the estimated number of reduced crashes to estimate the cost of each crash reduced.

Project Prioritization

Countermeasures that have been identified for the crash sites and economic appraisals that have been conducted for the countermeasures allow for prioritization of projects in this step. The three prioritization methods recommended in the *HSM* involve ranking according to:

- Economic effectiveness.
- Incremental B/C analysis.
- Optimization methods.

Details of the three methods are introduced in Section 1.4.1.

Evaluation

Evaluation assesses the change in crashes resulting from implemented safety treatments, as well as how the treatment or a set of treatments affects the frequency and severity of crashes. The results can be used to estimate the CMF. Furthermore, safety effectiveness evaluations can be used to compare safety improvements to the invested funding. The results provide insight to agencies regarding future decision-making concerning allocation of funds for highway agency safety policies.

1.2.3 The AAA Foundation for Traffic Safety Method

The AAA Foundation for Traffic Safety's method is called the United States Road Assessment Program (usRAP). usRAP is a collaborative partnership with government and non-government traffic safety entities that:

- Encourages safety decisions in management of road networks based upon risk.
- Inspects roads and develops a ranking rating for safety investment planning.
- Provides support for building and sustaining national, state, and local capabilities.
- Tracks road safety performance so that funding agencies can assess benefits of their investments.

The purpose of the rating system is to assess the level of risk of fatal and serious injury crashes to road users based upon the characteristics of the roadway infrastructure. The usRAP is built on the successful EuroRAP and AusRAP programs already established in Europe and Australia. The primary objectives of usRAP are to (usRAP 2013):

- Reduce death and serious injury on United States (US) roads through a program of systematic assessment of risk that identifies major safety shortcomings that can be addressed by practical road improvement measures.
- Ensure that assessment of risk lies at the heart of strategic decisions on route improvements, crash protection, and standards of safety management.
- Forge partnerships among those responsible for a safe road system.
- Empower all highway authorities—even those that lack access to adequate crash data and other traditional tools for assessing risk—to make data-driven decisions using video logs

of roadway features known to be associated with crashes, as well as investment plans showing cost-effective solutions for the problems identified.

Risk mapping is the key tool used in usRAP to systematically assess risk and assist in identifying locations for potential safety impairments. The road sections on each risk map are color-coded to indicate the risk level for fatal and serious injury crashes on that particular road section. Figure 1-8 provides an illustration of the usRAP risk map.

The usRAP protocol includes four basic risk maps based on the following safety performance measures (usRAP 2013):

- Map 1: crash density (fatal and serious injury crashes per mile).
- Map 2: crash rate (fatal and serious injury crashes per 100 million veh-mi of travel).
- Map 3: crash rate ratio (ratio of the fatal and serious injury crash rate for an individual road section to the average crash rate for similar roads).
- Map 4: potential crash savings (annual number of fatal and serious injury crashes that would be reduced if the crash rate for an individual road section could be lowered to the average crash rate for similar road sections).

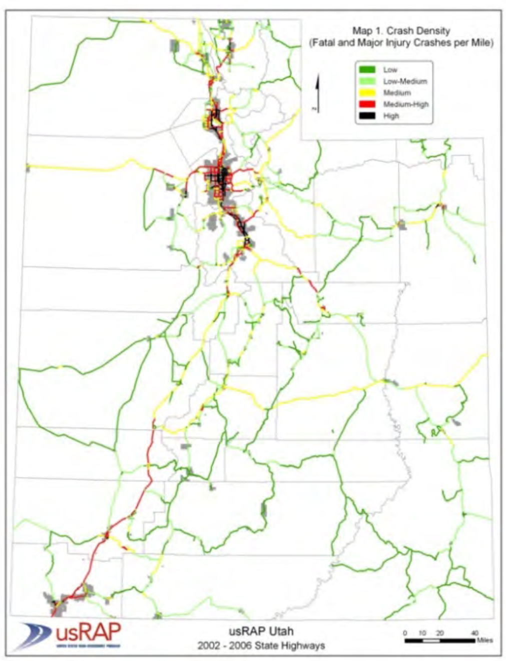


Figure 1-8 Example of usRAP Risk Map (usRAP 2013).

1.3 COUNTERMEASURES AND THEIR EFFECTS

Selecting countermeasures is a critical component of the safety management process. When proper countermeasures are selected and implemented, target crashes may be reduced. Numerous studies and evaluations have documented countermeasures and their effects on reducing crash frequency and severity. Some of the more robust include the National Cooperative Highway Research Program (NCHRP) Report 500 series, the Proven Safety Countermeasures, *HSM*, the FHWA CMF Clearinghouse and the TxDOT HSIP Work Codes.

1.3.1 NCHRP Report 500

The NCHRP has developed a series of guides to assist state and local agencies in reducing injuries and fatalities in target areas. The guides correspond to the emphasis areas outlined in the AASHTO Strategic Highway Safety Plan (SHSP). The series includes strategies in 22 key emphasis areas, all of which affect highway safety (TRB 2011). The series has been collectively published as NCHRP Report 500 and contains 23 volumes:

- Volume 1: A Guide for Addressing Aggressive-Driving Collisions.
- Volume 2: A Guide for Addressing Collisions Involving Unlicensed Drivers and Drivers with Suspended or Revoked Licenses.
- Volume 3: A Guide for Addressing Collisions with Trees in Hazardous Locations.
- Volume 4: A Guide for Addressing Head-On Collisions.
- Volume 5: A Guide for Addressing Unsignalized Intersection Collisions.
- Volume 6: A Guide for Addressing Run-Off-Road Collisions.
- Volume 7: A Guide for Reducing Collisions on Horizontal Curves.
- Volume 8: A Guide for Reducing Collisions Involving Utility Poles.
- Volume 9: A Guide for Reducing Collisions Involving Older Drivers.
- Volume 10: A Guide for Reducing Collisions Involving Pedestrians.
- Volume 11: A Guide for Increasing Seat Belt Use.
- Volume 12: A Guide for Reducing Collisions at Signalized Intersections.
- Volume 13: A Guide for Reducing Collisions Involving Heavy Trucks.
- Volume 14: Reducing Crashes Involving Drowsy and Distracted Drivers.
- Volume 15: A Guide for Enhancing Rural Emergency Medical Services.

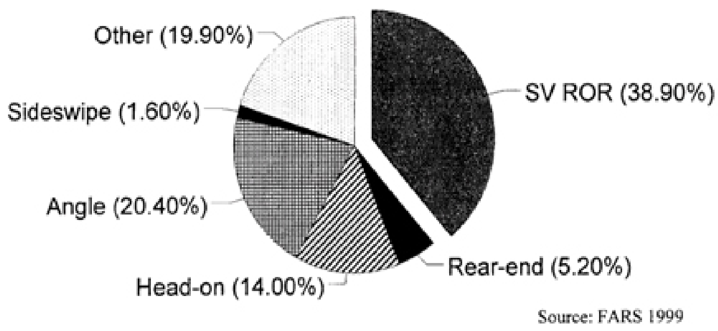
- Volume 16: A Guide for Reducing Crashes Involving Alcohol.
- Volume 17: A Guide for Reducing Work Zone Collisions.
- Volume 18: A Guide for Reducing Collisions Involving Bicycles.
- Volume 19: A Guide for Reducing Collisions Involving Young Drivers.
- Volume 20: A Guide for Reducing Head-on Crashes on Freeways.
- Volume 21: Safety Data and Analysis in Developing Emphasis Area Plans.
- Volume 22: A Guide for Addressing Collisions Involving Motorcycles.
- Volume 23: A Guide for Reducing Speeding-Related Crashes.

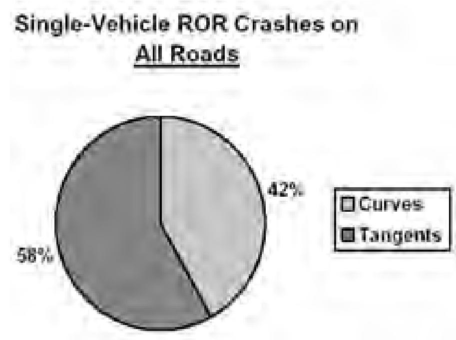
Each volume includes a brief introduction and a general description of a particular problem, strategies/countermeasures to address the problem, information regarding implementation cost, and what was known regarding effectiveness when the guide was published (TRB 2011). Taking Volume 6 as an example, the guide first presents a general description of the problem of single-vehicle run-off-road (SVROR) crashes, including the definition of SVROR crashes, the percentage among fatal crashes, and the distribution of SVROR fatalities on types of roadways and segments, as shown in Figure 1-9.

Then, the guide introduces the objectives of the emphasis area. In Volume 6, the three objectives for reducing SVROR crashes are (a) keep vehicles from encroaching on the roadside, (b) minimize the likelihood of crashing or overturning if the vehicle travels off the shoulder, and (c) reduce the severity of the crash.

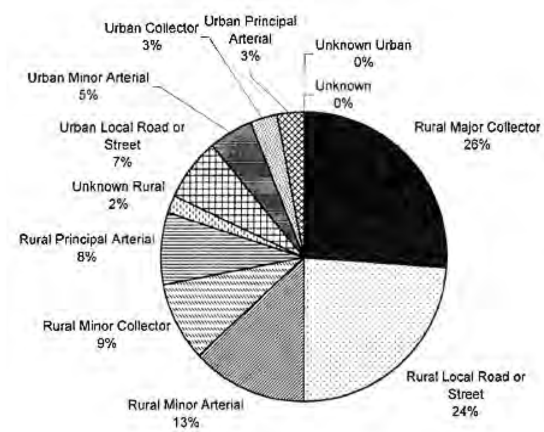
Third, the guide classifies the strategies according to the relative cost and the expected timeframe for this emphasis area. There are four qualitative levels of relative cost: low, moderate, moderate to high, and high. The implementation timeframes are short (less than 1 year), medium (1 to 2 years), and long (more than 2 years) (Neuman et al. 2003).

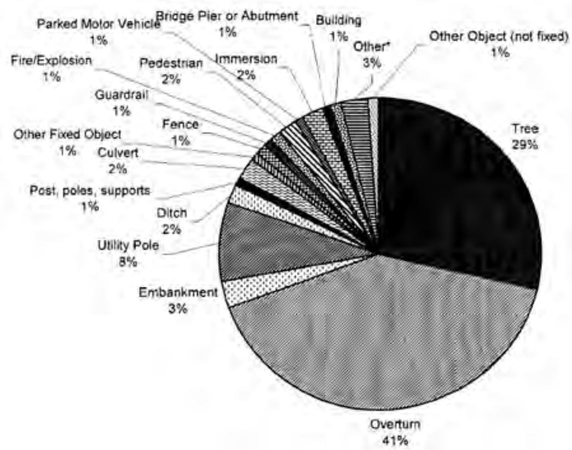
The guide provides a detailed description of each strategy, including the general introduction, the target, the expected effectiveness, and the potential difficulties or problems with implementation. Some of the strategies have also been presented with reported cost and effects. However, the cost varies across different districts, and the effects of countermeasures differ in different projects. Table 1-3 provides an example of SVROR-related objectives and strategies recommended by the NCHRP Report 500, Volume 6.





(a) SVROR Percentage **(b) Distribution between Sections**





(c) Distribution for Roadway Types **(d) Distribution for Harmful Event**

Figure 1-9 Description of SVROR Problems (Neuman et al. 2003).

Table 1-3 Objectives and Strategies for SVROR Collisions (Neuman et al. 2003).

Objectives	Strategies
Keep vehicles from encroaching on the roadside	• Install shoulder rumble strips • Install edgeline "profile marking," edgeline rumble strips, or modified shoulder rumble strips on section with narrow or no paved shoulders • Install mid-lane rumble strips • Provide enhanced shoulder or in-lane delineation and marking for sharp curves • Provide improved highway geometry for horizontal curves • Provide enhanced pavement markings • Provide skid-resistant pavement surfaces • Apply shoulder treatments • Eliminate shoulder drop-offs • Widen and/or pave shoulders
Minimize the likelihood of crashing into an object or overturning if the vehicle travels off the shoulder	• Design safer slopes and ditches to prevent rollovers • Remove/relocate objects in hazardous locations • Delineate trees or utility poles with retroreflective tape
Reduce the severity of the crash	• Improve design of roadside hardware (e.g., light poles, signs, bridge rails) • Improve design and application of barrier and attenuation systems

1.3.2 FHWA's Proven Safety Countermeasures

In 2012, the FHWA issued "Guidance Memorandum on Promoting the Implementation of Proven Safety Countermeasures." This guidance represents low-cost countermeasures appropriate for system-wide implementation (FHWA 2013g). These countermeasures have been shown by research to have significant value toward improving safety. FHWA strongly encourages safety agencies to consider these proven countermeasures with the caveat that not all are widely applied on a national level (FHWA 2012a).

Guidance includes nine safety countermeasures as shown below.

- Road safety audits.
- Rumble strips and rumble stripes.
- Median barriers.
- Safety edges.

- Roundabouts.
- Left and right turn lanes at stop-controlled intersections.
- Yellow change intervals.
- Medians and pedestrian refuge areas in urban and suburban areas.
- Walkways.

1.3.3 *HSM* and FHWA CMF Clearinghouse

Part D of *HSM* presents information about effects of various safety treatments. This information is used to estimate how effective a countermeasure or set of countermeasures will be in reducing crashes at a specific location (AASHTO 2010a). Treatments include the following:

- Roadway segments.
- Intersections.
- Interchanges.
- Special facilities and geometric situations.
- Road networks.

The *HSM* documents a large number of countermeasures under these five areas. For example, the roadway segment treatment contain 12 elements: roadways, roadsides, alignment, roadway signs, roadway delineation, rumble strips, traffic calming, on-street parking, roadway treatments for pedestrians and bicyclists, highway lighting, roadway access management, and weather issues. Each of the elements contains specific countermeasures, such as modifying lanes, adding paved shoulders, and providing medians under the roadway element.

Unfortunately, it has been difficult to quantify the effects of safety treatments. Historically, tools have been developed to quantify the safety benefits of countermeasure treatments. CMFs are tools that can be applied to better understand the safety impacts of treatments. They provide an estimate of the change in crashes expected after implementation of a countermeasure (FHWA 2010), and they are measures of safety effectiveness of a particular treatment or design element.

A value above 1 indicates that the treatment increased the number of crashes, a value below 1 implies that the countermeasure reduced crashes, and a value equal to 1 means that the treatment had no effects. The effects of countermeasures listed in the *HSM* are described as CMFs with specific conditions, including roadway types, AADT, and crash types. Most CMFs are presented in tables, while some are represented as curves. Presently, the CMFs for each treatment in the *HSM* are presented based on the best available research, which might be from a single study or an aggregate value based on multiple studies (AASHTO 2010b).

Regardless of development, CMFs play significant roles in roadway safety management's process of countermeasure selection. They represent candidate treatments that are associated with the greatest expectation for reducing crashes (FHWA 2013a). Many countermeasures have been developed and tested to improve safety. Each is unique and, as such, has value and merit as it relates to safety.

CMFs also vary by the very nature of the safety benefit they represent. While the first edition of the *HSM* has provided a large number of CMFs, research continues to uncover new safety improvements. As such, the *HSM* continues to improve based upon the newest literature and research findings.

In an effort to maintain all documented CMFs in a central location, the FHWA established the CMF Clearinghouse. The clearinghouse is a searchable database that can be easily used to identify CMFs for transportation professionals (FHWA 2010). The CMF Clearinghouse provides (a) a regularly updated, online repository of CMFs; (b) a mechanism for sharing newly developed CMFs; and (c) educational information on the proper application of CMFs. The CMF Clearinghouse summarizes published information on each CMF, including how it was developed (e.g., study design, sample size, and source of data) and what its statistical properties are (e.g., standard error) (FHWA 2010).

1.3.4 TxDOT HSIP Manual Work Codes

The TxDOT HSIP manual contains a complete list of work codes used in the safety improvement index (SII) calculation described in the HSIP manual (TxDOT 2013). The codes are grouped into five categories: (a) signing and signals, (b) roadside obstacles and barriers, (c) resurfacing and roadway lighting, (d) pavement markings, and (e) roadway work.

There are more than 100 countermeasures from the five engineering aspects of the HSIP manual. The countermeasures are listed by numbers within each group, with a brief definition, crash reduction factors (CRFs), service life, and preventable crashes. Figure 1-10 provides an example of the work code countermeasure table contained in the HSIP manual.

101	**Install Warning/Guide Signs**	
	Definition:	Provide advance signing for unusual or unexpected roadway features where no signing existed previously.
	Reduction Factor (%):	20
	Service Life (Years):	6
	Maintenance Cost:	N/A
	Preventable Crash:	(Vehicle Movements/Manner of Collision = 20–22 or 30) OR (Roadway Related = 2, 3 or 4)

Figure 1-10 An Example of TxDOT HSIP Manual Work Code Table (TxDOT 2013).

1.4 PROJECT PRIORITIZATION METHODS

Prioritization includes developing a list of high-priority safety improvement projects for implementation. The agency's final decisions will be made largely based on the prioritization list. This section presents the three commonly used prioritization methods and document-specific formulations used by some states.

1.4.1 Prioritization Methods in FHWA HSIP Manual

Several methods for prioritizing/ranking safety projects are presented in the FHWA HSIP manual (Herbel, Laing, and McGovern 2010), including B/C analysis, economic effectiveness, and optimization methods. Prioritization methods within the HSIP manual are consistent with those found in the *HSM*.

Benefit-Cost Analysis

The B/C analysis expresses the safety benefits of a countermeasure in monetary terms and calculates the ratio of those benefits to the cost of implementing the countermeasure. The B/C analysis provides a quantitative value that helps prioritize countermeasures or projects (AASHTO 2010a, Herbel, Laing, and McGovern 2010).

Economic Effectiveness

Ranking according to economic effectiveness is the simplest method for prioritizing countermeasures at a site or for prioritizing projects. Some economic effectiveness measures that can be used for ranking include:

- Project costs.
- Monetary value of project benefits.
- Total number of crashes reduced.
- Number of fatal and injury crashes reduced.
- Net present value.
- Cost-effectiveness index.

Optimization Methods

Optimization considers some constraints, e.g., budget, when prioritizing projects. Each project that is to be prioritized should be evaluated in terms of effectiveness. Common optimization methods include linear programming, integer programming, and dynamic programming. These methods can potentially be used for prioritization of safety projects as long as they are used to enhance effectiveness (AASHTO 2010a).

1.4.2 Prioritization Methods Used by Different States

Although several methods are presented in the FHWA HSIP manual, the B/C ratio is the most popular method used by states to qualify their funding and prioritize projects. Unfortunately, formulations used to calculate the B/C ratios vary from state to state, which is why it is important to remain consistent when selecting the B/C method as a prioritization method. The following section presents B/C formats used in the states of Texas, Alaska, and Virginia.

Texas

TxDOT uses the SII to prioritize safety projects. The SII formulation is as follows (TxDOT 2013, Singi Reddy 2007).

$$S = \frac{R(C_f F + C_i I)}{Y} - M \qquad (1)$$

$$Q = \left(\frac{A_a - A_b}{A_b} \div L \right) S \tag{2}$$

$$B = \frac{S + \frac{1}{2}Q}{1.06} + \sum_{i=2}^{L} \left[\frac{(S + \frac{1}{2}Q) + (i-1)Q}{1.06^i} \right] \tag{3}$$

$$SII = \frac{B}{C} \tag{4}$$

where:

S = annual savings in crash costs (equal to crash cost savings per year less annual maintenance costs),

R = percentage reduction factor,

F = number of fatal and incapacitating injury crashes (see following subheading for explanation),

C_f = cost of a fatal or incapacitating injury crash (see following subheading for explanation),

I = number of non-incapacitating injury crashes (see following subheading for explanation),

C_i = cost of a non-incapacitating injury crash (see following subheading for explanation),

Y = number of years of crash data,

M = change in annual maintenance costs for the proposed project relative to the existing situation,

Q = annual change in crash cost savings,

A_a = projected ADT at the end of the project service life,

A_b = ADT during the year before the project is implemented,

L = project service life (see following subheading for explanation),

B = present worth of project benefits over its service life, and

C = initial cost of the project.

Alaska

The State of Alaska considers crash severity when calculating the B/C ratio. Reductions of property damage only (PDO), major, minor, and fatal crashes are analyzed in the process, respectively. The B/C ratio is illustrated in the following equation (Gan et al. 2005, AlaskaDOT 2013):

$$\frac{B}{C} = \frac{CR + M_d}{C_c + M_i} \quad (5)$$

where:

CR = estimated annual reduction in crash cost,

M_d = decrease in annual maintenance cost,

M_i = increase in annual maintenance cost, and

C_c = annualized construction cost.

The Alaska Department of Transportation and Public Facilities also provide Excel spreadsheets for calculating the B/C ratio, which can be found in Alaska's HSIP handbook online at www.dot.alaska.gov/stwddes/dcstraffic/assets/pdf/hsip/20130321_hsip_hdbk.pdf.

Virginia

The Virginia Department of Transportation (VDOT) uses the following equations for calculating the B/C ratio and prioritizing safety improvement projects (VDOT 2008).

$$\frac{B}{C} = \frac{B_A \times f}{C_I + C_M} \quad (6)$$

$$f = (1+g) \times \frac{(1+g)^n - 1}{g \times n} \quad (7)$$

where:

B_A = sum of annul benefit from the reduction of each related injury type,

f = traffic growth factor,

g = annual traffic growth rate,

n = improvement action service life,

C_I = sum of the annualized initial cost for all improvement actions, and

C_M = sum of the annual maintenance cost for all improvement actions.

Excel spreadsheets for calculating B/C ratios are also available on the VDOT website at http://www.virginiadot.org/business/ted_app_pro.asp.

Although the B/C calculation formulations vary from state to state, the basic concepts are similar in that the benefits of reduced crashes are compared to the costs of countermeasures or projects. The benefits are usually estimated using CRFs, which are the most sensitive variable in prioritizing projects (Geedipally et al. 2011).

1.5 SUMMARY

The first section of this chapter presented the systemic method used by different agencies. Particularly, the review focused on the FHWA systemic approach, the *HSM* six-step roadway safety management approach, and the usRAP approach to safety. The FHWA systemic approach uses a detailed step-by-step procedure that has been successfully applied in several states and served as the foundation for the proposed systemic method documented in the next two chapters.

The second section summarized the literature about available safety treatments or countermeasures and their effects on safety. Several sources were reviewed, including the NCHRP Report 500, the *HSM*, and the FHWA CMF Clearinghouse. The second section also documented the characteristics of the treatments found within the TxDOT HSIP Work Codes Table. These treatments are used for the SII calculation that is part of the HSIP managed by TxDOT. All of these documents provide an extensive list of countermeasures that can be used with the systemic analysis. Finally, Section 2 provided a list of countermeasures and their related CMFs, target crashes, service life, and costs based on the documents described in the first part of the section.

The last section described different prioritization of methods used by a few state departments of transportation. The B/C analysis is the most frequently used method to prioritize projects or treatments. Although the equations vary from state to state, the basic formulation consists of calculating the ratio of the benefits related to the anticipated reduction in crashes and the costs of the projects or treatments. A large body of the literature has pointed out that CMFs play a significant role in B/C analysis.

By analyzing the information found in the literature, the TTI researchers were able to identify the strengths for different applications of the systemic approach, which were then used to govern proposed methods for the State of Texas. The next chapter presents the first of two proposed systemic approaches.

CHAPTER II
A SYSTEMIC APPROACH TO PROJECT SELECTION

This chapter presents the characteristics of a proposed systemic approach to project selection with a focus on reducing the number and severity of crashes occurring on the TxDOT roadway network. The proposed approach is mainly based on the steps documented by the FHWA but was adapted for the State of Texas, given the availability and the characteristics of the data.

This chapter provides information about the various steps of the systemic approach to project selection. Examples are provided using the data found in the TxDOT Crash Reporting Information System (CRIS) to better illustrate the approach.

2.1 STEP 1—IDENTIFY TARGET CRASH TYPES AND RISK FACTORS

Systemic problem identification involves the identification of target crash types and the commonly associated location characteristics experienced across the system. This process is a system-wide or macro-level review of the crash data and documentation of crash characteristics. Step 1 includes the following tasks.

2.1.1 Task 1—Identify Preventable Crashes

This task seeks to identify preventable crashes with the information related to contributing factors provided in crash reports. The TxDOT CRIS data provide contributing factors that may have influenced a crash. Crashes can be categorized as either preventable or non-preventable in relation to the implementation of roadway countermeasures provided in the TxDOT HSIP manual (TxDOT 2013). Appendix A presents the list of implementable countermeasures for preventable crashes and their crash reduction effects included in the manual. The countermeasures do not apply to non-preventable crashes. For example, countermeasures listed in Appendix A are not effective for reducing/preventing a crash due to a collision with a wild animal on the road because most countermeasures are related to the improvement of roadways, traffic control, and pavement and markings. Thus, a crash with the contributing factor "Animal on Road—Wild" would be categorized as non-preventable. Of the 73 contributing factors found in TxDOT crash reports (Table 2-1), TTI researchers decided that 36 factors were not related to risk factors and were thus less likely preventable with the countermeasures listed in Appendix A.

Table 2-1 Categorization of Contributing Factors.

Contributing Factor[1]	Preventable[2]	Non-Preventable[2]
Animal on Road—Domestic		√
Animal on Road—Wild		√
Backed without Safety		√
Changed Lane when Unsafe		√
Defective or No Head lamps		√
Defective or No Stop Lamps		√
Defective or No Tail Lamps		√
Defective or No Turn Signal Lamps		√
Defective or No Trailer Brakes		√
Defective or No Vehicle Brakes		√
Defective Steering Mechanism		√
Defective or Slick Tires		√
Defective Trailer Hitch		√
Disable in Traffic Lane		√
Disregard Stop and Go Signal	√	
Disregard Stop Sign or Light	√	
Disregard Turn Marks at Intersection	√	
Disregard Warning Sign at Construction	√	
Distraction in Vehicle	√	
Driver Inattention	√	
Drove without Headlights		√
Failed to Control Speed	√	
Failed to Drive in Single Lane	√	
Failed to Give Half of Roadway	√	
Failed to Heed Warning Sign	√	
Failed to Pass to Left Safely	√	
Failed to Pass to Right Safely	√	
Failed to Sign or Gave Wrong Signal		√
Failed to Stop at Proper Place	√	
Failed to Stop for School Bus	√	
Failed to Stop for Train	√	
Failed to Yield ROW—Emergency Vehicle		√
Failed to Yield ROW—Open Intersection	√	

[1] Listed factors in Texas Peace Officer's Crash Report (CR-3).
[2] Preventable if roadway countermeasures, provided in the TxDOT HSIP Manual, reduce the risk of a crash linked to the contributing factor. If not, they are categorized as non-preventable.

Table 2-1 Categorization of Contributing Factors (Continued).

Contributing Factor[1]	Preventable[2]	Non-Preventable[2]
Failed to Yield ROW—Private Drive	√	
Failed to Yield ROW—Stop Sign	√	
Failed to Yield ROW—to Pedestrian	√	
Failed to Yield ROW—Turning Left	√	
Failed to Yield ROW—Turn on Red	√	
Failed to Yield ROW—Yield Sign	√	
Fatigued or Asleep	√	
Faulty Evasive Action	√	
Fire in Vehicle		√
Fleeing or Evading Police		√
Followed too Closely	√	
Had Been Driving		√
Handicapped Driver (Explain in Narrative)		√
Ill (Explain in Narrative)		√
Impaired Visibility (Explain in Narrative)		√
Improper Start from Parked Position		√
Load not Secured		√
Opened Door into Traffic Lane		√
Oversized Vehicle or Load		√
Overtake and Pass Insufficient Clearance	√	
Parked and Failed to Set Brakes		√
Parked in Traffic Lane		√
Parked without Lights		√
Passed in No Passing Lane	√	
Passed on Right Shoulder		√
Pedestrian Failed to Yield ROW to Vehicle	√	
Unsafe Speed	√	
Speeding (Over Limit)	√	
Taking Medication (Explain in Narrative)		√
Turned Improperly—Cut Corner on Left	√	
Turned Improperly—Wide Right	√	
Turned Improperly—Wrong Lane	√	
Turned When Unsafe	√	
Under Influence—Alcohol		√
Under Influence—Drug		√
Wrong Side—Approach or Intersection	√	

[1] Listed factors in Texas Peace Officer's Crash Report (CR-3).
[2] Preventable if roadway countermeasures, provided in the TxDOT HSIP Manual, reduce the risk of a crash linked to the contributing factor. If not, they are categorized as non-preventable.

Table 2-1 Categorization of Contributing Factors (Continued).

Contributing Factor[1]	Preventable[2]	Non-Preventable[2]
Wrong Side—Not Passing	V	
Wrong Way—One-Way Road	V	
Cell/Mobile Phone Use		V
Road Rage		V

[1] Listed factors in Texas Peace Officer's Crash Report (CR-3).
[2] Preventable if roadway countermeasures, provided in the TxDOT HSIP Manual, reduce the risk of a crash linked to the contributing factor. If not, they are categorized as non-preventable.

2.1.2 Task 2—Select the Target Crash Types

This task identifies the types of preventable crashes that represent the greatest opportunities for reduction. Those crash types usually represent the greatest number of crashes across the system being analyzed. The crash types are categorized by drivers, special users, vehicles, and highways. Table 2-2 presents detailed information about the categorization and data availability for identifying target crash types.

Table 2-2 Variables and Their Availability for Identifying Crash Type.

Category	Variable	Data Availability
Severity	Fatal/Injury (KABC)	TxDOT CRIS (variable: CRASH_SEV_ID
Drivers	Age - Young Drivers (under 21) - Older Drivers	TxDOT CRIS (variable: PRSN_TYPE_ID, PRSN_AGE)
Special Users	- Pedestrian - Pedalcyclist	TxDOT CRIS (variable: HARM_EVNT_ID, PERSN_TYPE_ID)
Vehicles	- Motorcycle - Heavy Vehicles	TxDOT CRIS (variable: VEH_BODY_STYL_ID, PERSN_TYPE_ID)
Highways	Railroad Crossing	TxDOT CRIS (variable: HARM_EVNT, OBJECT STRUCK, CRASH RAILROAD RELATED FLAG ID)
	Roadway Departure	TxDOT CRIS (variable: COLLSN_ID, ROAD_RELAT_ID)
	Work Zone	TxDOT CRIS (variable: CRASH ROAD CONSTRUCTION ZONE FLAG_ID , CRASH ROAD CONSTRUCTION ZONE WORKER FLAG_ID, OTHR_ FACTR)
	Intersection	TxDOT CRIS (variable: INTRSCT_RELAT_ID)

Example Application of Task 2

TTI researchers identified target crash types by disaggregating fatal/incapacitating (KA) crashes that occurred between 2010 and 2013. As the bold text in Table 2-3 highlights, intersection/-related crash and SVROR crashes are the most frequent types and account for 34 and 35 percent of statewide KA crashes, respectively. The type of intersection/-related crash is predominant on local roads/streets. According to the TxDOT CRIS database, 50 percent of KA crashes on local streets occurred at intersection/-related areas. The SVROR crash type is predominant on state and county system highways. More specifically, more than half of KA crashes on county system highways are classified as SVROR. These results suggest that intersection/-related and/or SVROR crashes can be considered target crash type(s).

Table 2-3 Identification of Target Crash Types in Texas (2010–2013).

Emphasis Area		Statewide	Roadway System		
			State System	Local Roads/Streets	County Roads/Others
Total KA Crashes		61,530	35,854	21,550	4126
Drivers	Older Drivers	7193 (12%)	4562 (13%)	2380 (11%)	251 (6%)
	Young Drivers	10738 (17%)	5928 (17%)	3919 (18%)	**891 (22%)**
Vehicle Type	Motorcycle related	9179 (15%)	5474 (15%)	3285 (15%)	420 (10%)
	Large Truck related	3658 (6%)	3243 (9%)	311 (1%)	104 (3%)
Contributing Factor	DUI	**12,731 (21%)**	**7585 (21%)**	3738 (17%)	**1408 (34%)**
	Speeding	9463 (15%)	5547 (15%)	2264 (11%)	**1652 (40%)**
	Distracted Driving	11,246 (18%)	6560 (18%)	**4221 (20%)**	465 (11%)
Crash Type	SVROR	**21,447 (35%)**	**13,493 (38%)**	**5430 (25%)**	**2524 (61%)**
	Rearend	9683 (16%)	6632 (18%)	2742 (13%)	309 (7%)
	Sideswipe (SD)	2006 (3%)	1586 (4%)	361 (2%)	59 (1%)
	Head-on	3750 (6%)	2789 (8%)	775 (4%)	186 (5%)
	Intersection related	**20,913 (34%)**	**9368 (26%)**	**10,761 (50%)**	784 (19%)
Crash Location	Work Zone	2250 (4%)	1742 (5%)	440 (2%)	68 (2%)
Harmful Event	Pedestrian	5365 (9%)	2185 (6%)	2966 (14%)	214 (5%)
	Pedalcyclist	1298 (2%)	375 (1%)	880 (4%)	43 (1%)
	Train	228 (<1%)	76 (<1%)	109 (1%)	43 (1%)

Note: It is possible that some of the local roads/streets are state-maintained.

2.1.3 Task 3—Select Target Facilities

The objective of this task is to determine where and on what facilities the target crashes are occurring. Table 2-4 presents the variables that can be used for identifying the target facilities. This table includes but is not limited to representative variables selected from the TxDOT database. Depending on the agency's needs, additional variable(s) from the database can be selected for identifying target crash facilities.

Table 2-4 Sample Set of Variables for Identifying Target Facilities.

Variable	Subcategory	Data Availability
Roadway System	- Interstate - US highway - State highway - Farm to market - Ranch road - Ranch to market - Business interstate - Business US - Business state - Business FM - State loop - Toll road - Alternate - Spur - County road - Park road - Private road - Recreational road - Local road/street	TxDOT CRIS (variable: ROAD_SYS_ID)
Urban Rural Type	- Rural (Population: <5,000) - Small Urban (Population: 5,000-49,999) - Large Urban (Population: 50,000-199,999) - Urbanized (Population: 200,000+)	TxDOT CRIS (variable: RURAL_URBAN_ID)
Intersection Related	- Intersection (Signalized/Unsignalized) - Intersection Related - Driveway Access - Non-Intersection Related	TxDOT CRIS (variable: INTRSCT_RELAT_ID)
Speed Limit		TxDOT CRIS (variable: Crash_Speed_Limit)
Number of Lanes		TxDOT CRIS (variable: NBR_OF_LANE)
Shoulder Type	- Surfaced - Stabilized Surfaced with Flex - Combination—Surface/Stabilized - Earth—With or Without Turf	TxDOT CRIS (variable: SHLDR_TYPE_LEFT_ID, SHLDR_TYPE_RIGHT_ID)

Table 2-4 Sample Set of Variables for Identifying Target Facilities (Continued).

Variable	Subcategory	Data Availability
Shoulder Use	- Diagonal Parking - Parallel Parking - Bicycle - Bus - Emergency Only - Peak Only	TxDOT CRIS (variable: SHLDR_USE_LEFT_ID, SHLDR_USE_RIGHT_ID)
Roadway Alignment Type	- Normal curve - Point curve - Spiral curve	TxDOT CRIS (variable: CURVE_TYPE_ID)

Example Application of Tasks 2 and 3 Using Crash Tree Diagram

A crash tree diagram is an effective tool to illustrate the categorization of crashes. Figure 2-1 shows a crash tree identifying target crash types and facilities throughout the processes documented in Tasks 2 and 3 using crash data from 2010 to 2013. Categorizing statewide fatal/incapacitating crashes using four variables (highway system, urban and rural type, intersection/non-intersection-related type, and number of lanes) identifies target crash types and facilities. An angle crash is a predominant crash type at both signalized and unsignalized intersections on state highways in rural areas as well as urban areas. SVROR crashes are dominant in rural areas. In these areas, the target crash types and facilities are angle crashes at unsignalized intersections and SVROR crashes on two-lane US and state highways and farm-to-market (FM) roads.

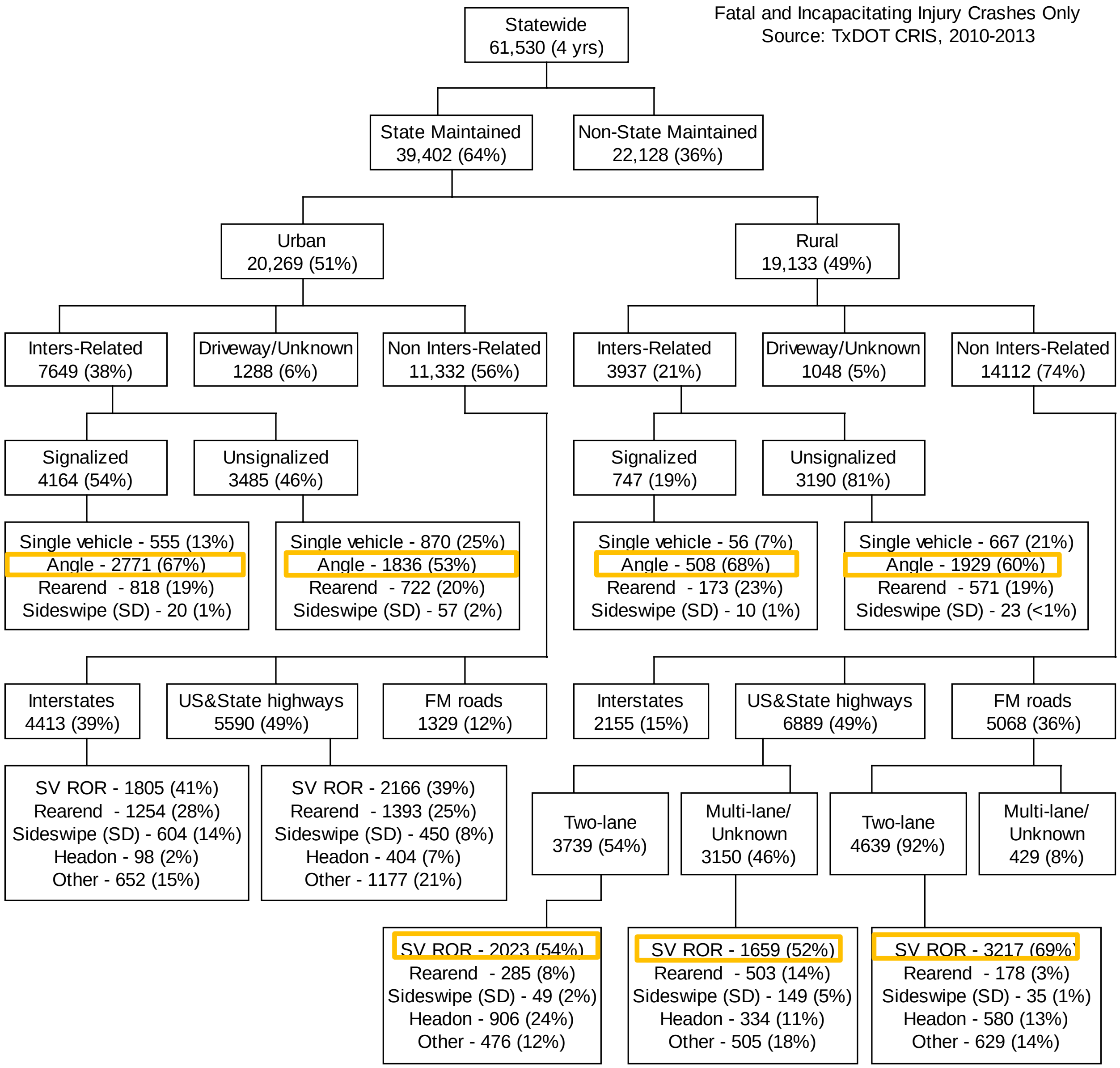


Figure 2-1 Crash Tree Diagram to Identify Target Crash Types and Facilities.

2.1.4 Task 4—Identify and Evaluate Potential Risk Factors

This task documents and evaluates the most common characteristics or risk factors for the locations associated with the crash types and facilities identified in Tasks 2 and 3. Table 2-5 presents the variables for identifying potential risk factors and data availability.

Table 2-5 Variables for Identifying Potential Risk Factors and Data Availability.

Category	Variable	Data Availability
Roadway and Intersection Features	Lane Width	TxDOT CRIS (variable: NBR_OF_LANE, SURF_WIDTH) and RHINO
	Number of Lanes	TxDOT CRIS (variable: NBR_OF_LANE) and RHINO
	Shoulder Type	TxDOT CRIS (variable: SHLDR_TYPE_LEFT_ID, SHLDR_TYPE_RIGHT_ID) and RHINO
	Median Width and Type	TxDOT CRIS (variable: Median_Type_ID, Median_Width) and RHINO
	Intersection Control Device Type	TxDOT CRIS (variable: TRAFFIC_CNTL_ID)
	Presence of Street Lighting	TxDOT CRIS (variable: LIGHT_COND_ID)
	Curve Length	TxDOT CRIS (variable: CURVE_LNGTH) and Geo-HINI
	Curve Radius	TxDOT CRIS (variable: based on Cd_Degr) and Geo-HINI
Traffic Volume	- ADT Counts - Truck AADT Percent	TxDOT CRIS (variable: ADT_ADJ_CURNT_AMT, TRK_AADT_PCT) and RHINO
Other Features	Posted Speed Limit	TxDOT CRIS (variable: Crash_Speed_Limit)
	Presence of Railroad Crossing	TxDOT CRIS (variable: POSCROSSING_ID,PHYS_FEATR_ID)
	Presence of Automated Enforcement (red-light running)	TxDOT CRIS (variable: TRAFFIC_CNTL_ID)

Example Application of Task 4 on Potential Risk Factors

After conducting Tasks 2 and 3, the TTI researchers identified the target crash types and facilities using TxDOT fatal/incapacitating crashes that occurred for the 2010-2013 period. The SVROR crash type on two-lane US and state highways and FM roads was found to be predominant in rural areas, as discussed above. The analysis of this target crash type provided information that helped identify and evaluate potential risk factors. For this evaluation, SVROR crashes on two-lane US and state highways and FM roads were categorized by variables, such as ADT, alignment, lane width, shoulder width, and truck percentage. In addition to these variables, it is important to note that these crashes are dependent on many other variables, such as edge treatments, sight distance, presence of traffic signs, advisory speeds, etc. These variables are not currently available in the TxDOT databases.

To identify the risk factors, the TTI researchers compared the proportion of KA crashes for a specific range or value of a variable with the proportion of existing highway mileage within the respective range or value. The analysis related to the ADT variable (Figure 2-2) shows that a large proportion of highway mileage occurs on highways with fewer than 1,200 vehicles per day, while a relatively higher proportion of SVROR crashes occurs on highways with over 3,200 vehicles per day. In fact, the proportion of the crashes exceeds the proportion of accounted highway mileage in all groups with ADT values of more than 1,200. This is expected because higher-volume roads tend to have more crashes. To remove the biased selection of higher-volume roads, the researchers divided the highways into three categories: low volume (<400 ADT), moderate volume (400 to 1,200 ADT), and high volume (>1,200 ADT).

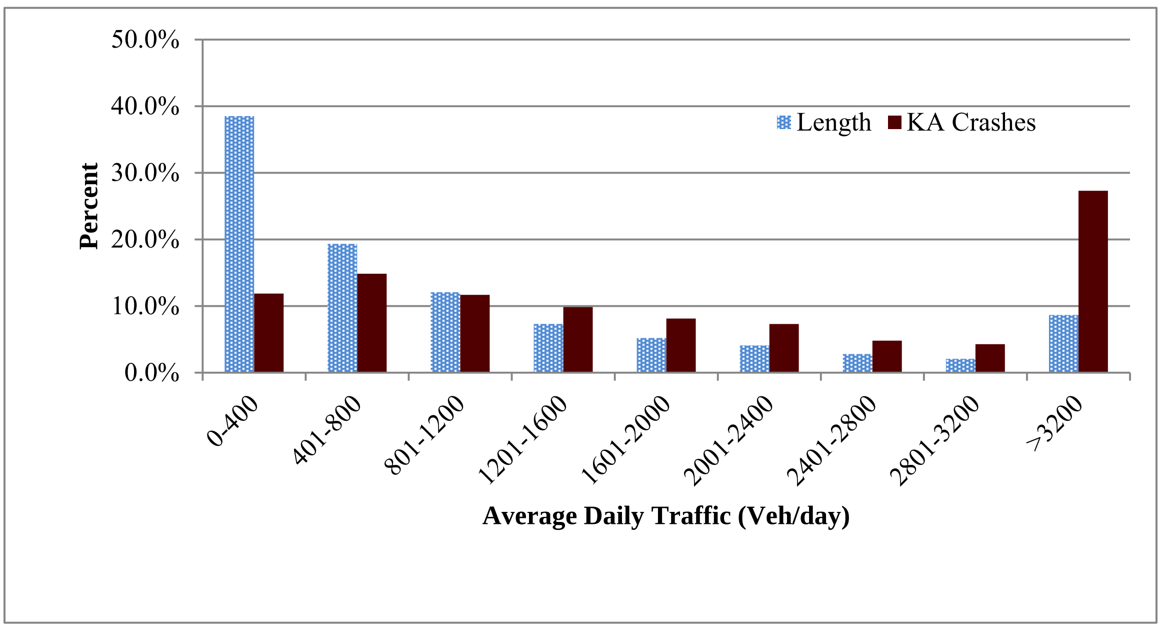


Figure 2-2 Categorization with ADT Volume.

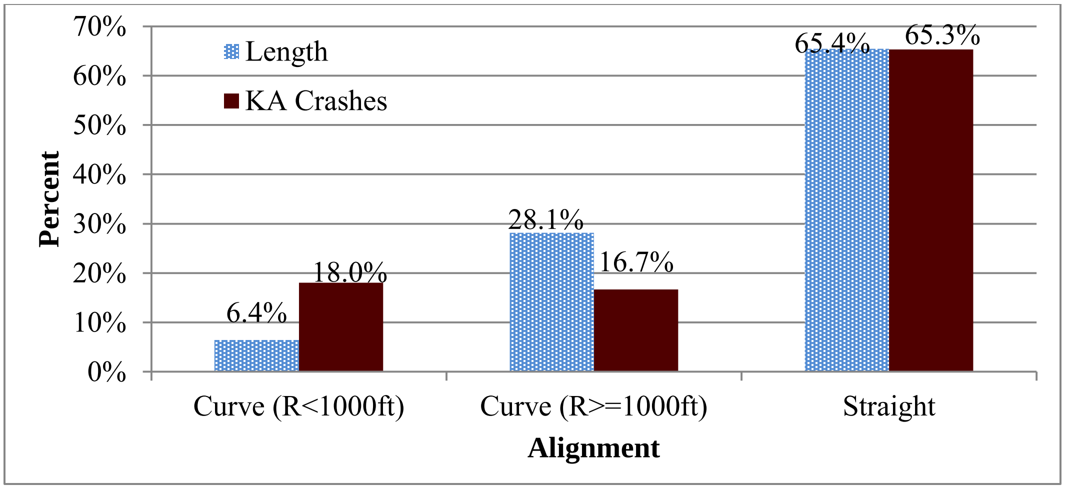
Figures 2-3 to 2-6 present the proportions of SVROR crashes by different variables (alignment, lane and shoulder widths, and truck percentage) for three traffic volume groups. SVROR crashes are over-represented at the horizontal curves when compared to the straight segments for all three ADT groups (Figure 2-3). For curves with low volumes, SVROR crashes account for about

35 percent of total SVROR KA crashes, while they constitute less than 20 percent of total highway mileage.

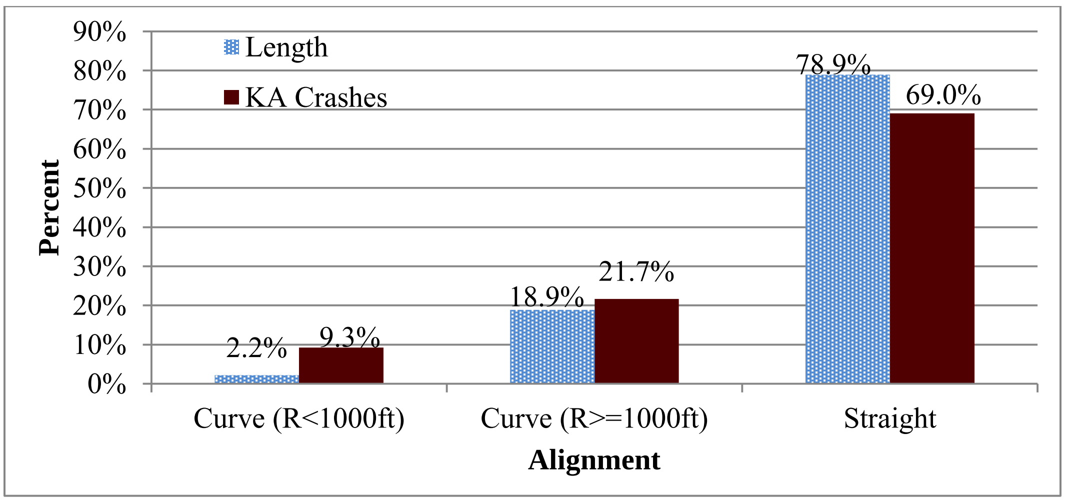
Figure 2-4 describes the proportions of SVROR crashes and highway mileage by lane width. In the low-volume highway group, about two-thirds of all segments have less than or equal to 10-ft lanes. The proportions of segments with less than or equal to 10-ft lanes decrease for higher traffic volume groups, while there is an increase in the proportion of segments with 12-ft lane widths. In other words, high-volume highways are initially constructed with wider lanes than the low-volume highways are. In terms of crash proportion, the crashes on highways with lane widths equal to 11 ft are over-represented for all traffic volume groups.

The analysis related to the shoulder width variable shows similar results as that associated with the lane width variable. In the low-volume group, most segments have shoulders less than 4 ft (Figure 2-5). In the high-volume group, more than half of the segments have shoulder widths of 7 to 10 ft. For all traffic volume groups, crashes are over-represented at segments having 0- to 2-ft shoulder widths.

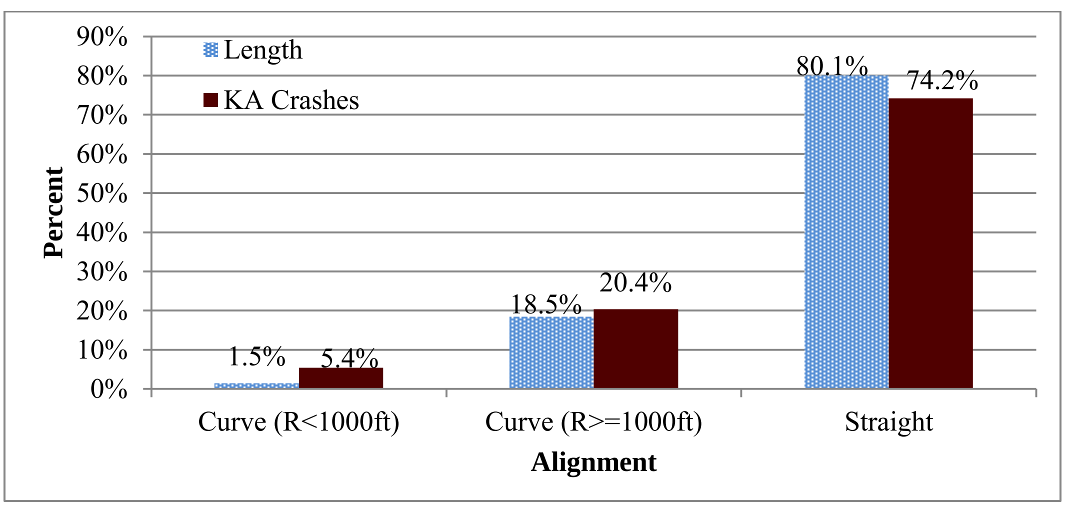
Finally, the analysis related to the truck percentage variable (Figure 2-6) shows that for all traffic volume groups, crashes are over-represented on the segments with low truck percentages. It is possible that the routes that trucks travel are constructed with high standard designs. Further investigation is needed to know the effect of truck volume on the SVROR crashes.



(a) Low volume (ADT<400)

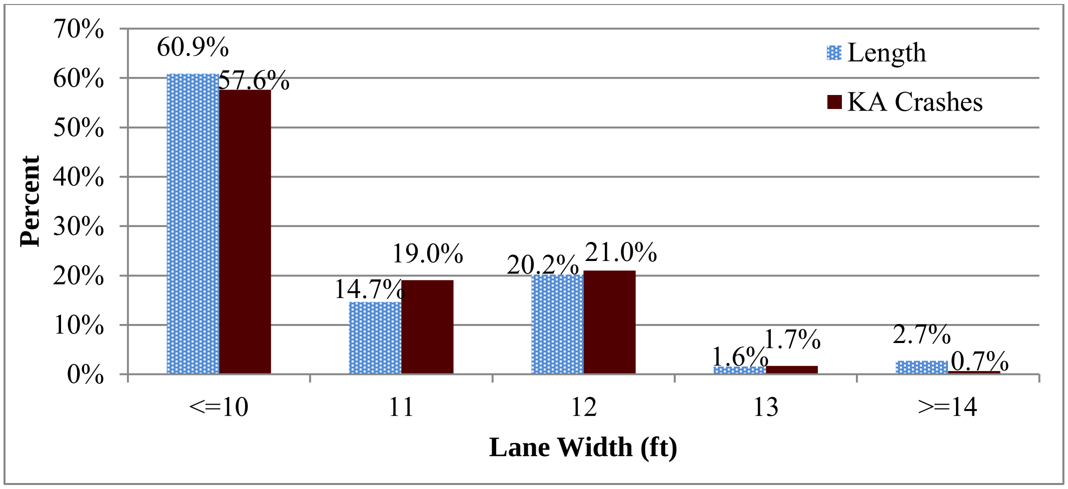


(b) Moderate volume (400≤ADT≤1,200)

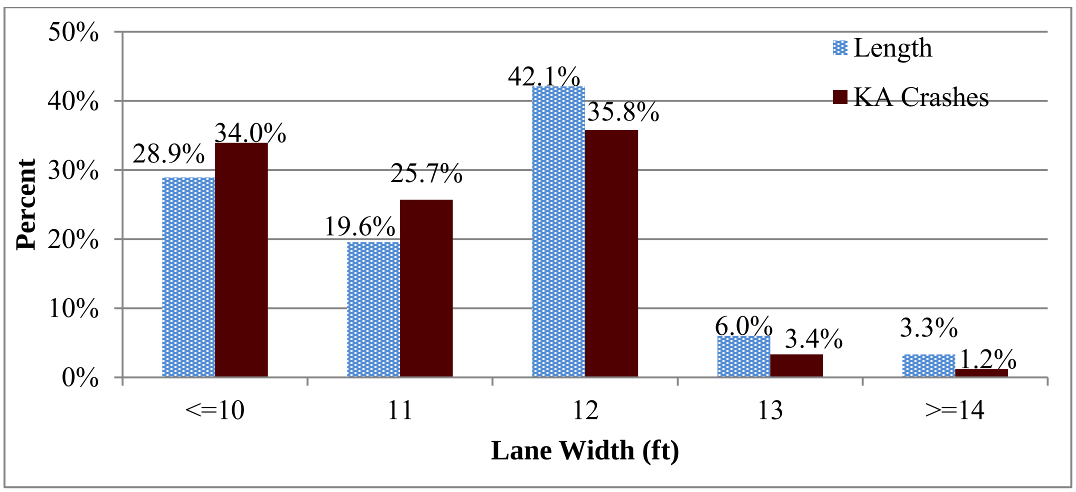


(c) High volume (ADT>1,200)

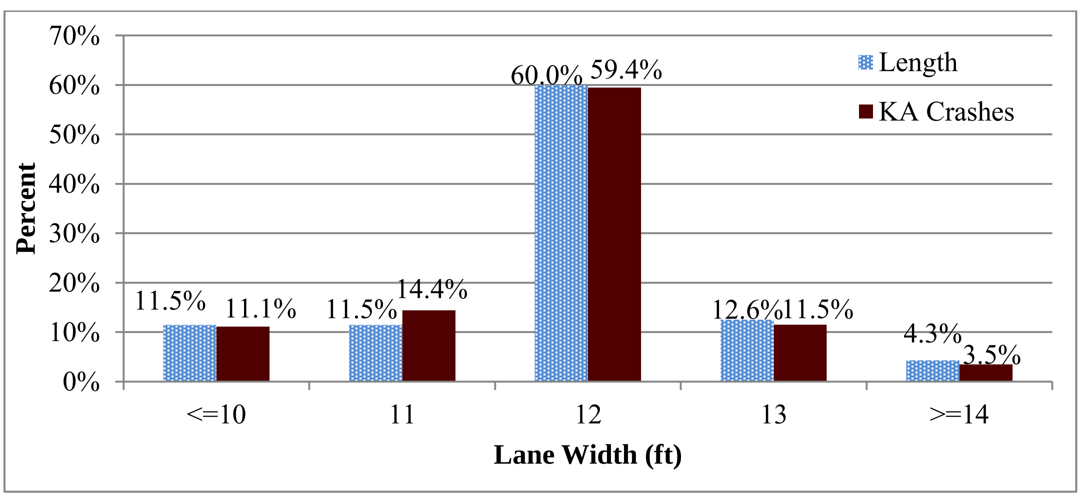
Figure 2-3 SVROR Crashes by Alignment on Two-Lane Highways.



(a) Low volume (ADT<400)

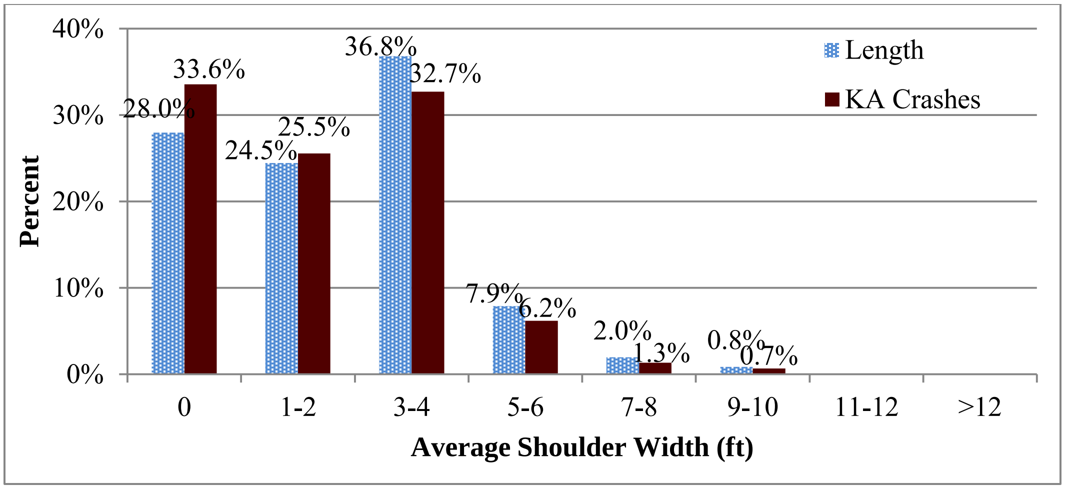


(b) Moderate volume (400≤ADT≤1,200)

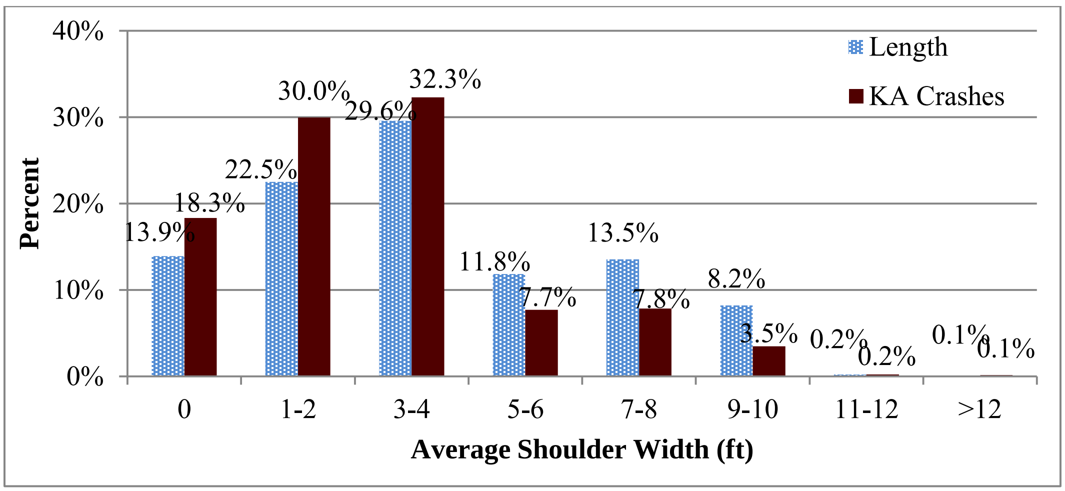


(c) High volume (ADT>1,200)

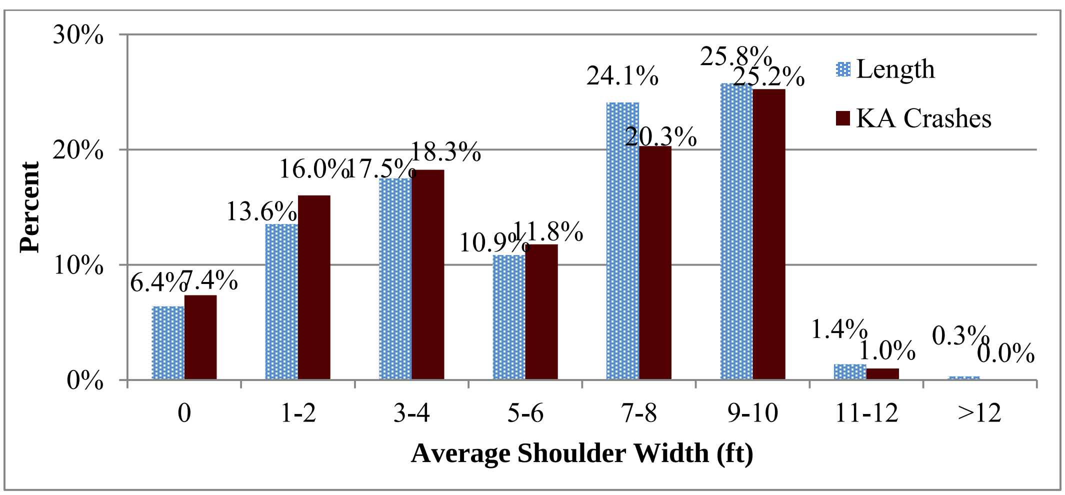
Figure 2-4 SVROR Crashes by Lane Width on Two-Lane Highways.



(a) Low volume (ADT≤400)

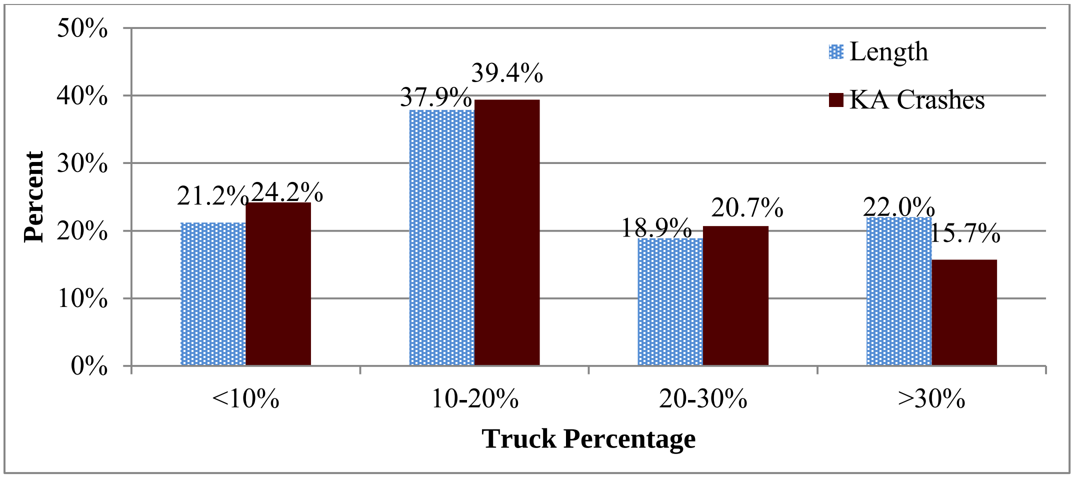


(b) Moderate volume (400≤ADT≤1,200)

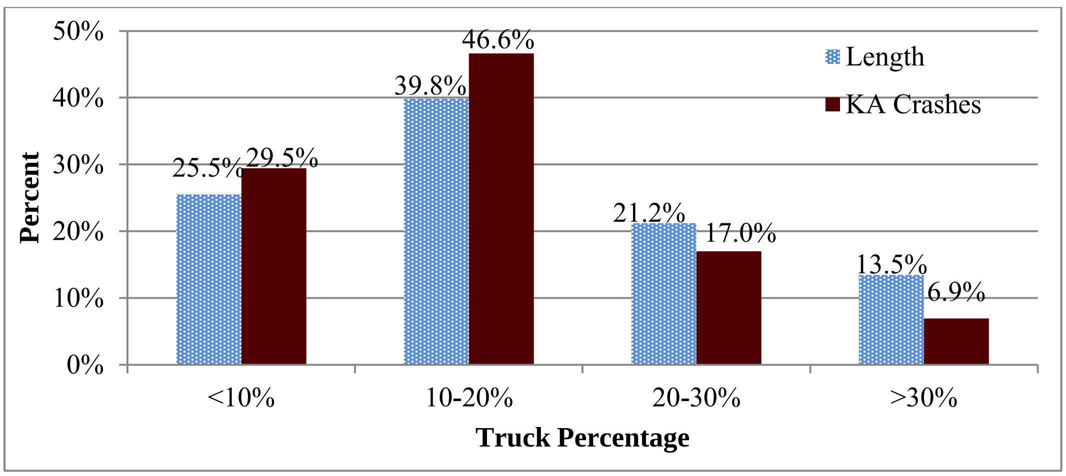


(c) High volume (ADT>1,200)

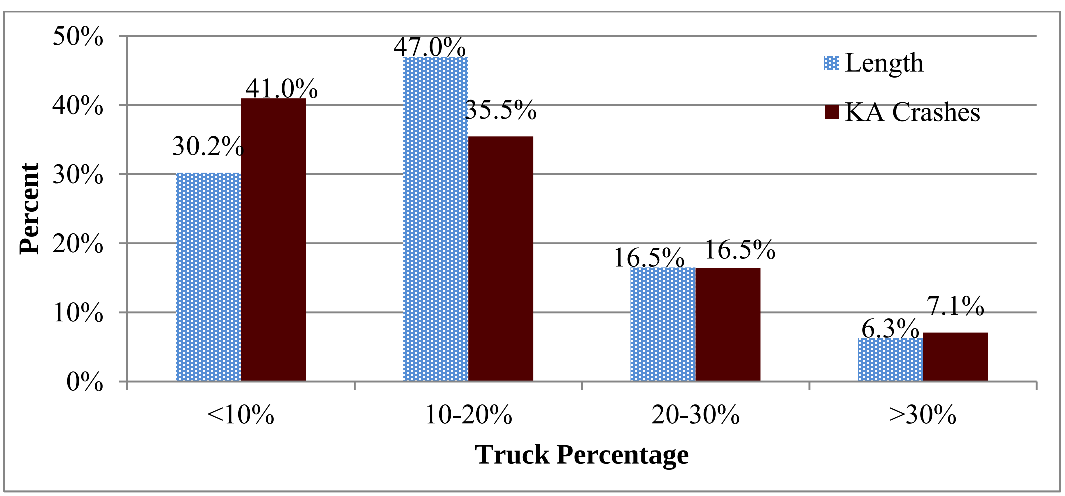
Figure 2-5 SVROR Crashes by Shoulder Width on Two-Lane Highways.



(a) Low volume (ADT<400)



(b) Moderate volume (400≤ADT≤1,200)



(c) High volume (ADT>1,200)

Figure 2-6 SVROR Crashes by Truck Percentage on Two-Lane Highways.

2.2 STEP 2—SCREEN AND PRIORITIZE CANDIDATE LOCATIONS

The objective of this step is to develop a prioritized list of potential locations on the roadway system (segments, curves, and intersections) that could benefit from systemic safety improvement projects. This step requires two types of data: crash information and roadway characteristics for specific crash types. Those required data were already identified in Step 1. Detailed descriptions on the data and their availability can be found in the tables and figures included under Step 1.

2.2.1 Task 1—Identify Network Elements Analyzed

This task seeks to identify the network elements from the focus facility types selected in Step 1, Task 3, which represent the locations where the target crash types tend to occur for use in the network screening. In Task 4 of Step 1, the analysis related to ADT, lane and shoulder width, alignment, and truck percentage was conducted to identify where SVROR KA crashes frequently occur on two-lane rural highways. Those factors are used to identify at-risk highway network elements.

2.2.2 Task 2—Conduct Risk Assessment

This task evaluates the risk factors in order to rank/prioritize the at-risk locations previously selected based on roadway and traffic characteristics. In the risk assessment, roadway network elements are prioritized using risk factor weights. Risk factor weights are calculated using the total crashes and the crash over-representation of each element. The total risk factor weight is the sum of all risk factor weights of a highway for each element evaluated. Table 2-6 provides the weights based on the proportion of crash over-representation and crash total when compared to highway mileage, which is acquired from Task 4 of Step 1. When crashes at a specific element are over-represented by 10 percent or greater (which means a difference between the proportion of observed crashes and the highway mileage in a specific group), a weight of 10 points is assigned to the element. For example, for the low-volume ADT group, the proportion of SVROR crashes on curves and the related highway mileage are about 34 and 18 percent, respectively (Figure 2-3). The crashes on curves are over-represented by 16 percent. Thus, a weight of 10 point is assigned to low-volume horizontal curves. Additionally, 3 points are given to these curves because the proportion of SVROR crashes (i.e., crash total in Table 2-6) on these curves is about 34 percent. As a result, curve segments on two-lane rural highways with fewer than 500 vehicles per day are assigned a weight of 13 points, according to the weight criteria. Depending on lane and shoulder width, as well as truck percentage on the curves, additional points can be given to calculate a total risk factor weight.

Table 2-6 Risk Factor Weight Criteria.

Category	Weight (points)										
	0	1	2	3	4	5	6	7	8	9	10
Crash Total	≥0% and <10%	≥10 and <20%	≥20 and <30%	≥30 and <40%	≥40 and <50%	≥50 and <60%	≥60 and <70%	≥70 and <80%	≥80 and <90%	≥90 and <100%	100%
Crash Over-Representation	0%	>0% and <2%	≥2% and <3%	≥3% and <4%	≥4% and <5%	≥5% and <6%	≥6% and <7%	≥7% and <8%	≥8% and <9%	≥9% and <10%	≥10% and ≤100%

Example Application of Task 2

This weighting process should be applied for all identified risk factors. Table 2-7 summarizes the results of risk factor prioritization related to SVROR crashes on two-lane highways in rural areas. For example, 5 points are given to segments having a 12-ft lane width and ADT greater than 1,200 vehicles per day. If truck percentages are less than 10% at those segments, an additional 14 points will be given.

Table 2-7 Risk Factor Prioritization Results.

Risk Factor		Weight (points)		
		Low Volume (<400 ADT)	Moderate Volume (400 ≤ADT ≤1,200)	High Volume (>1,200 ADT)
Lane Width (feet)	≤10	5	8	1
	11	5	8	3
	12	3	3	5
	13	1	0	1
	≥14	0	0	0
Shoulder Width (Paved, feet)	0	8	5	1
	1-2	3	9	3
	3-4	3	5	2
	5-6	0	0	2
	7-8	0	0	2
	9-10	0	0	2
	11-12	0	0	0
	>12	0	1	0
Truck Percentage (%)	<10	4	5	14
	10-20	4	10	3
	20-30	3	1	1
	>30	1	0	1
Alignment	Curve (R<1000ft)	11	7	3
	Curve (R>=1000ft)	1	4	3
	Straight	6	6	7

2.2.3 Task 3—Prioritize Roadway Facilities

The prioritized lists of facility elements, such as segments, horizontal curves, and intersections, are generated based on the presence of the weighted risk factors—the more risk factors present, the greater chance of occurrence of the focus crash type and thus the higher probability of being considered as a candidate for safety investments.

Example Application of Task 3

Table 2-8 presents a sample list of selected prioritized locations ranked according to the weight criteria and the reported SVROR crashes that occurred during the 2010-2013 period. This list is generated with the application of the weighted risk criteria on roadway network facilities on two-lane US and state highways and FM roads in rural areas. The list of all evaluated network locations weighted over 30 points is provided in Appendix B.

Table 2-8 Selected Prioritized Locations Using Weight Criteria.

HWY	District	Curve ID	Radius (ft)	ADT (veh/day)	Truck Percentage (%)	Lane Width (ft)	Average Shoulder Width (ft)	Weight					SVROR Crash Freq. (Crashes/ 4 years)
								Align	Lane Width	Shoulder Width	Truck Percentage	Total	
FM0323	10	11934	573	770	16.5	10	2	7	8	9	10	34	6
FM0019	10	1922	954.9	870	15.4	10	2	7	8	9	10	34	4
FM0159	17	7121	573	460	13.6	11	1	7	8	9	10	34	4
FM0434	9	14482	954.9	460	16.3	10	2	7	8	9	10	34	4
SH0016	15	63353	286.5	850	10.6	10	2	7	8	9	10	34	4
FM0766	13	21787	573	930	17.1	10	1	7	8	9	10	34	3
FM0056	9	3177	818.5	420	13.7	11	2	7	8	9	10	34	2
FM0095	11	4658	286.5	640	19.5	11	1	7	8	9	10	34	2
FM0095	11	4659	573	640	19.5	11	1	7	8	9	10	34	2
FM0521	13	16520	573	1150	12.4	10	2	7	8	9	10	34	2
FM0902	1	24384	520.9	1000	12	11	1	7	8	9	10	34	2
FM0004	2	1221	573	590	10.6	10	2	7	8	9	10	34	1
FM0323	10	11934	573	770	16.5	10	2	7	8	9	10	34	6
FM0019	10	1922	954.9	870	15.4	10	2	7	8	9	10	34	4
FM0121	1	5536	636.6	780	13.5	11	1	7	8	9	10	34	1
FM0205	2	8573	477.5	550	10.9	10	2	7	8	9	10	34	1
FM0222	11	9152	954.9	1150	12	11	2	7	8	9	10	34	1
FM0230	11	9690	573	800	17.2	11	1	7	8	9	10	34	1
FM0250	19	10193	318.3	710	13.7	11	1	7	8	9	10	34	1
FM0323	10	11935	674.1	770	16.5	10	2	7	8	9	10	34	1
FM0531	13	16781	286.5	410	14.6	10	1	7	8	9	10	34	1
FM0121	1	5536	636.6	780	13.5	11	1	7	8	9	10	34	1
FM0205	2	8573	477.5	550	10.9	10	2	7	8	9	10	34	1
FM0222	11	9152	954.9	1150	12	11	2	7	8	9	10	34	1

2.3 STEP 3—SELECT COUNTERMEASURES

This step involves selecting a small number of low-cost, highly effective countermeasures to be considered for implementation at candidate locations. Step 3 includes the following tasks.

2.3.1 Task 1—Assemble Comprehensive List

The first task involves assembling a comprehensive list of the safety countermeasures associated with each of the targeted crash types and the identified risk factors from Step 1. Among the countermeasures provided in Appendix A, candidate countermeasures are selected with the greatest potential to address identified target crash type and facilities. In addition to the countermeasure information in the Texas HSIP manual (Appendix A), the *HSM* and FHWA CMF Clearinghouse both provide a good list of countermeasures and describe their effectiveness and associated cost. Table 2-9 lists effective countermeasures focused on reducing the number (and severity) of SVROR crashes.

Table 2-9 List of Countermeasures and Their Effectiveness for SVROR Crashes.

Treatment	Road Type	Crash Type (Severity)	CMF	App. Cost	Service Life (yr)
Install Combination Horizontal Alignment/Advisory Speed Signs	Unspecified	All (Injury)	0.87	$300 per unit [a]	6
Install Chevrons (Curve)	Unspecified	SVROR (All)	0.75	$3,000 per curve [b]	10
Install Changeable Speed Warning Signs for Individual Drivers	Rural Two-Lane Undivided	All (All) [d]	0.54	$300 per unit [c]	6
Install Post-Mounted Delineators	Rural Two-Lane Undivided	All (Injury)	0.70	$3,000 per curve	2
Place Standard Edgeline Markings (4 to 6 inches wide)	Rural Two-Lane	All (Injury)	0.75	$650 per mi [b]	2
Install Milled Rumble Strips	Unspecified	SVROR (All) [d]	0.5	$2640 per mi [b]	10
Flatten Side Slope (Provide an Embankment Side Slope of 6:1 or Flatter)	Unspecified	SVROR (All) [d]	0.54	$300,000 per mi [c]	20
Safety Treat Fixed Objects	Unspecified	SVROR (All) [d]	0.5	$300,000 per mi [b]	20
Install High-Friction Surface Treatment (Curve)	Unspecified	All (All) [d]	0.55	$20/sq. yd	5
Increase Superelevation	Unspecified	All (All) [d]	0.35	$200,000 per mi [c]	10

Note: [a] Idaho (2012); [b] Preston and Farrington (2011); [c] Estimated based on experience; [d] Determined based on their preventable crash types in the Work Code and other related studies.

2.3.2 Task 2—Evaluate/Screen Countermeasures

The second task is to evaluate and screen the initial list of countermeasures based on documented effectiveness (at reducing the target crash types), implementation and maintenance costs, and consistency with the agency's policies, practices, and experiences.

2.3.3 Task 3—Conduct Benefit-Cost Analysis

The objective of Task 3 is to conduct a B/C analysis with the expected crash reductions and implementation and maintenance costs during the service life. TxDOT provides the SII for a B/C analysis to prioritize safety projects and the cost-effective countermeasures. This B/C analysis using SII can be applied for all the network locations identified in Task 3 of Step 2 and for each countermeasure documented in Task 2 of Step 3.

Example Application of Task 3

Table 2-10 illustrates the B/C analysis using the SII on the curve having the highest weight and SVROR crash frequency (presented in Table 2-8) to identify the cost-effective countermeasures to address SVROR crashes on two-lane rural highways.

Table 2-10 B/C Analysis of Candidate Countermeasures on Prioritized Locations.

Roadway Data	
Type	FM Road
Number	
Urban/Rural	Rural
District	10
ADT	770 veh/day
Truck %	16.5
Facility Type	Two-Lane Rural Highway
Lane Width	10 ft
Shoulder Width	1 to 2 ft
Alignment	Curve
Radius	573 ft
Curve Length	586 ft
Rumble Strip	None
Crash Frequency	6 SVROR crashes (2010 to 2013)

Risk Factor Evaluation (Weight Criteria)				
Alignment	Lane Width	Shoulder Width	Truck Percentage	Total
7 points	8 points	9 points	10 points	34 points

Countermeasures Considered			
Type	CMF	Service Life	Cost
Install milled edgeline rumble strips	0.5	10 yr	$2,640 per mi
Install Post-Mounted Delineators	0.70	2 yr	$3,000 per curve
Install Advisory Speed Signs	0.87	6 yr	$300 per unit

SII (B/C) Evaluation			
Type	Benefit[1,2]	Cost	SII (B/C)
Install milled edgeline rumble strips	$ 1,009,085	$ 586	1,721
Install Post-Mounted Delineators	$ 134,435	$ 3,000	44
Install Advisory Speed Signs	$ 165,580	$ 600	276

[1] Crash cost: $158,200 (fatal & injury); [2] Annual 3% increase in ADT prediction.

2.3.4 Task 4—Select Countermeasures for Deployment

The objective of this task is to select countermeasures for each of the target crash types that comprise the short list of strategies used to develop safety projects at specific locations across TxDOT's road system. Selection of countermeasures for deployment should be determined based on best safety improvement and lowest cost to implement. Table 2-11 provides potential countermeasures by cost, effectiveness, and implementation timeframe for SVROR crashes.

Table 2-11 Potential Countermeasures for SVROR Crashes.

Countermeasure	Cost[1]	Effectiveness[2]	Timeframe for Implementation[3]
Install Combination Horizontal Alignment/Advisory Speed Signs	Low	Moderate	Short
Install Chevrons (Curve)	Low	Moderate	Short
Install Changeable Speed Warning Signs for Individual Drivers	Moderate	High	Short
Install Post-Mounted Delineators	Low	High	Short
Place Standard Edgeline Markings (4 to 6 inches wide)	Low	Moderate	Short
Install milled edgeline rumble strips	Low	High	Short
Flatten Side Slope (Provide an Embankment Side Slope of 6:1 or Flatter)	High	High	Short to Medium
Safety Treat Fixed Objects	High	High	Short to Medium
Install High-Friction Surface Treatment (Curve)	Moderate	High	Short
Increase Superelevation	High	High	Short to Medium

NOTE	
[1] Cost	Low: <$10,000 per mile or implementation
	Moderate: $10,000 to $100,000 per mile or implementation
	High: >$100,000 per mile or implementation
[2] Effectiveness	Low: CMF >0.9
	Moderate: 0.7 < CMF ≤0.9
	High: CMF ≤0.7
[3] Implementation (Construction period)	Short: less than a year
	Medium: 1 to 2 years
	Long: Longer than 2 years

2.4 STEP 4—PRIORITIZE PROJECTS

The objective of this final step of the systemic safety project selection process is to identify/develop the list of high-priority safety improvement projects. This list of projects considers the prioritized at-risk locations identified in Step 2 and applies the most cost-effective countermeasures from the list selected in Step 3.

2.4.1 Task 1—Create Decision Process for Countermeasure Selection

This task involves the creation of a decision-making process that includes the set of criteria such as volume, environment, adjacent land use, or cross section that will be used to identify the appropriate countermeasure for high-priority locations. The decision-making process in the systemic approach does not just identify the most appropriate countermeasure for each individual location, as done when addressing hot spots, but considers multiple locations with similar risk characteristics, selecting a preferred countermeasure(s) appropriate and affordable for widespread implementation.

Example Application of Task 1 Using a Decision Tree

Figure 2-7 illustrates the decision process for selecting implementable countermeasures for SVROR crashes on two-lane rural highways. Although the installation of rumble strips is the most cost-effective countermeasure, there might be locations where this countermeasure is not an ideal choice. Application of a decision tree provides an alternative countermeasure to SVROR crashes at some locations.

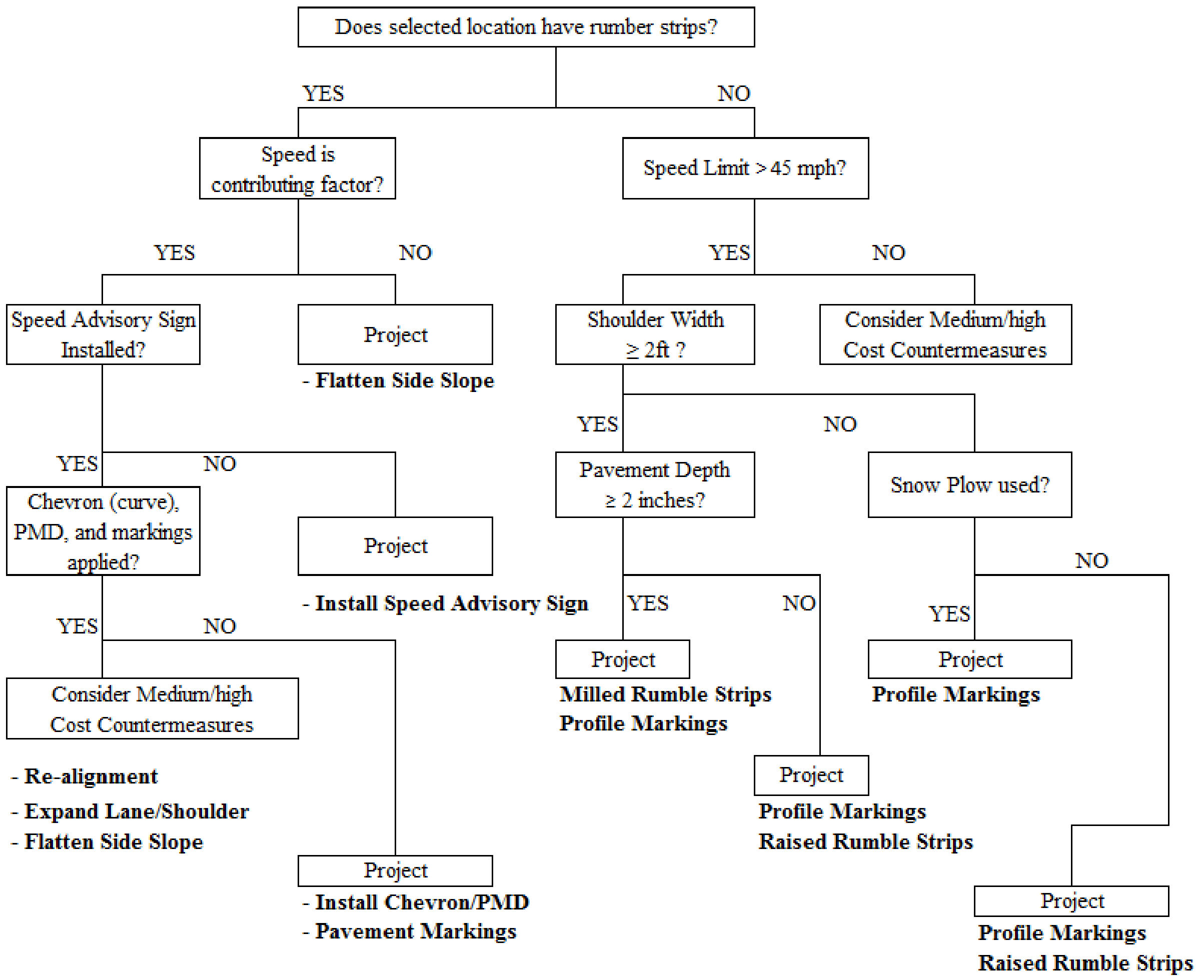


Figure 2-7 Decision Tree on Application of Rumble Strips on Two-Lane Rural Highways.

2.4.2 Task 2—Develop Safety Projects

This task involves applying the decision process to identify a specific countermeasure for each candidate site selected for safety investment. This includes providing a detailed description of the site (traffic volume, route number, mile point, intersecting roadway, segment length, curve radius, roadway grade, etc.), identifying the specific strategy selected, estimating implementation cost, and summarizing how the site scored with the risk factors. Finally, the anticipated reduction in the number and severity of the focus crash type will be provided.

2.4.3 Task 3—Prioritize Safety Project Implementation

The final task is to identify the order in which projects will be implemented, taking into consideration factors such as funding, other programmed projects, time to develop project plans, amount of public outreach needed, etc. The prioritized list of locations infers a particular order based on the number of risk factors present at a given location.

2.5 SUMMARY

Traditionally, the selection of safety projects for reducing crashes focuses on specific locations based on the number of crashes. Under this selection process, safety projects on rural highways with low traffic volumes are typically low priority because higher-volume roads tend to have more crashes. Although there is a higher proportion of fatal crashes in rural areas compared to urban areas, crashes on rural highways are hardly clustered because they are spread over thousands of miles. The systemic approach, which focuses on high-risk roadway features rather than specific high-crash locations, is more effective for addressing crashes on rural highways.

The systemic approach to project selection includes identifying risk factors associated with target crash types and facilities. The approach uses a B/C analysis for selecting low-cost, effective countermeasures to remove/alleviate risk factors. This systemic approach is beneficial for not only rural crashes but also crash types less likely clustered in urban areas, particularly crashes involving pedestrians, bicyclists, and motorcyclists. The proposed approach in this chapter is mainly based on the steps documented by FHWA, but the approach was adapted for the State of Texas based on the availability and characteristics of TxDOT data. In addition to the steps suggested by FHWA, the proposed approach includes the process of categorizing crashes as either preventable or non-preventable with the information related to the contributing factors provided in crash reports.

CHAPTER III
A SYSTEMIC APPROACH TO ROADWAY CHARACTERISTIC CLASSIFICATION

This chapter deals with developing roadway characteristic classification systemic improvements that focus on a particular countermeasure to have a positive impact on safety. The proposed approach in this chapter focuses on identifying and implementing low-cost countermeasures (i.e., initial cost of $10,000 or below per mile or installation) on rural highways.

3.1 STEP 1—IDENTIFY COUNTERMEASURE DESIRED TO CLASSIFY ROADWAY CHARACTERISTICS

Most countermeasures have their own features aimed at reducing specific traffic collision types by improving roadway/roadside characteristics, traffic control features, and pavement surface and markings. For example, rumble strips are an effective, low-cost countermeasure for roadway departure crashes because they prevent vehicles from encroaching onto the roadside.

This step involves the identification of low-cost countermeasures implementable on rural highways from among the comprehensive countermeasures provided in the TxDOT HSIP manual (TxDOT 2013). Table 3-1 lists low-cost countermeasures that are useful in addressing rural highway crashes. The CMF, service life, and costs provided here are based on the HSIP manual work codes. When the manual does not provide the required values, additional information is acquired from federal or other state reports that deal with countermeasures on rural highways.

Table 3-1 Low-Cost Countermeasures on Rural Highways.

Category	Countermeasure	Definition	CMF	Service Life (yr)	Cost ($)
Signing and Signals	Install Warning/Guide Signs	Provide advance signing for unusual or unexpected roadway features	0.80; 0.75[1]	6	Initial: $300[2]
	Overheight Warning System	Install electronic devices to detect overheight loads.	0.35	10	
	Install Delineators	Install post-mounted delineators to provide guidance.	0.70	2	
	Install Chevrons (Curve)	Install post-mounted chevron signs to provide guidance	0.70 0.89[3]	2	Initial: $3,000[4]
	Convert Two-Way Stop Signs to Four-Way Stop Signs	Provide four-way stop signs where two-way stop signs existed previously	0.85 0.50[1]	6	
	Install Advance Warning Signals and Signs (Intersection)	Provide flasher units and signs in advance of an intersection where none previously existed	0.85	10	
	Install Advance Warning Signals and Signs (Curve)	Provide flasher units and signs in advance of a curve where none previously existed	0.85	10	
	Install LED Flashing Chevrons (Curve)	Install LED flashing chevrons on curve to provide guidance	0.65	10	
	Install Flashing Yellow Arrow	Modernize existing intersection signals by adding a flashing yellow arrow indication	0.85	10	

Note: Based on TxDOT HSIP work codes.
[1] California (2013).
[2] Idaho (2012).
[3] ADOT (2009).
[4] Preston and Farrington (2011).
[5] Agent, Pigman, and Stamatiadis (2001).

Table 3-1 Low-Cost Countermeasures on Rural Highways (Continued).

Category	Countermeasure	Definition	CMF	Service Life (yr)	Cost ($)
Resurfac-ing and Roadway Lighting	Install Safety Lighting	Provide roadway lighting, either partial or continuous, where either none existed previously or major improvements are being made	0.60	15	Initial: $5,000[4] (per lighting pole) Maintenance: $100 per luminaire
	Install Safety Lighting at Intersection	Install lighting at an intersection where either none existed previously or major improvements are proposed	0.55 0.60[1]	15	Initial: $5,000[4] (per lighting pole) Maintenance: $100 per luminaire
Pavement Markings	Install Edge Marking	Place edge lines where none existed previously	0.75; 0.70[3]; 0.37[3] (Injury)	2	Initial: $650[4]
Roadway Work	Milled Edgeline Rumble Strips	Install continuous milled depressions (rumble stripes or rumble strips) along the edgeline	0.5	10	
	Profile Edgeline Markings	Install profile edgeline markings	0.4	5	
	Raised Edgeline Rumble Strips	Install non-reflective raised traffic buttons (yellow or white) along the edgeline	0.4	2	
	Milled Centerline Rumble Strips	Install milled centerline rumble strips along the centerline	0.65	10	
	Profile Centerline Markings	Install profile centerline markings and preformed thermoplastic strips along the centerline	0.65	5	
	Raised Centerline Rumble Strips	Install non-reflective raised traffic buttons (yellow or black) and preformed thermoplastic strips along the centerline	0.65	2	
	Transverse Rumble Strips	Install transverse or in-lane rumble strips in advance of a high incident and special geometric location	0.85	5	

Note: Based on TxDOT HSIP work codes.
[1] California (2013).
[2] Idaho (2012).
[3] ADOT (2009).

[4] Preston and Farrington (2011).
[5] Agent, Pigman, and Stamatiadis (2001).

3.2 STEP 2—IDENTIFY PREVENTABLE CRASH TYPE RELATED TO COUNTERMEASURES SELECTED

This step involves identifying preventable crash types and candidate locations for implementing countermeasures identified in Step 1. Table 3-2 presents preventable crash types and locations related to low-cost countermeasures provided in Table 3-1. For example, rumble strips are an effective countermeasure in reducing roadway departure crashes, such as SVROR. The rumble strips are usually installed on rural freeways and rural two-lane highways with travel speeds of 50 mph or greater and/or a history of SVRORs, where the remaining shoulder width beyond the rumble strip is 4 ft or greater (Golembiewski and Chandler 2011).

Table 3-2 Preventable Crash Types and Locations of Countermeasures.

Countermeasure	Preventable Crash Types	Candidate Locations
Install Warning/Guide Signs	- Rear-end - Sideswipe - Head-on	—
Install Delineators	Nighttime ROR	Entry and midpoint of curves
Convert Two-Way Stop Signs to Four-Way Stop Signs	Intersection related	Intersections experiencing high severity frontal impact collisions[1]
Install Advance Warning Signals and Signs (Intersection)	Intersection related	—
Install Advance Warning Signals and Signs (Curve)	- ROR - Angle - Rear-end - Sideswipe - Head-on	- Curves with a history of roadway departure crashes[2] - Advisory speed is 10 mph less than the posted speed[2]

[1] Simpson and Hummer (2010).
[2] Golembiewski and Chandler (2011).
[3] California (2013).
[4] FHWA (2008b).
[5] FHWA (2008b).
[6] McGee and Hanscom (2007).
[7] FHWA (2008a).

Table 3-2 Preventable Crash Types and Locations of Countermeasures (Continued).

Countermeasure	Preventable Crash Types	Candidate Locations
Install Chevrons (Curve)	—	- Curves with a history of roadway departure crashes[3] - Advisory speed is 15 mph less than the posted speed[3]
Install Safety Lighting	Nighttime	—
Install Safety Lighting at Intersection	Nighttime intersection related	Unsignalized intersection
Install Edge Marking	ROR	On paved rural arterials with a traveled way of 20 ft or more and ADT of 6,000 vehicles per day or greater[4]
Milled Centerline Rumble Strips, Profile Centerline Markings, Raised Centerline Markings	- ROR - Angle - Rear-end - Sideswipe - Head-on	- Roadway section with a history of head-on and opposite-direction sideswipe crashes[6] - Travel speeds of 50 mph or greater - Roadway section of at least 13-ft lane plus shoulder width[6]
Milled Edgeline Rumble Strips, Profile Edgeline Markings, Raised Edgeline Markings	- ROR - On slippery road	- Travel speeds of 50 mph or above[7] - Remaining shoulder width beyond rumble strip of 4 ft or greater[7]

[1] Simpson and Hummer (2010).
[2] Golembiewski and Chandler (2011).
[3] California (2013).
[4] FHWA (2008b).
[5] FHWA (2008b).
[6] McGee and Hanscom (2007).
[7] FHWA (2008a).

3.3 STEP 3—IDENTIFY LOCATIONS WITH PREVENTABLE CRASH TYPE

This step deals with identifying highway classification associated with the location of crash types. A crash tree diagram is an effective tool to identify locational characteristics. Figure 3-1 illustrates how to identify highway classification with an example specific to SVROR crash type. The TTI researchers analyzed statewide fatal/incapacitating crashes in Texas from 2009 to 2013. Many SVROR crashes occur on highways in rural areas. Two-thirds of SVROR crashes involve a collision with fixed objects on the roadside, and over 26 percent of those crashes involve collisions with trees/shrub.

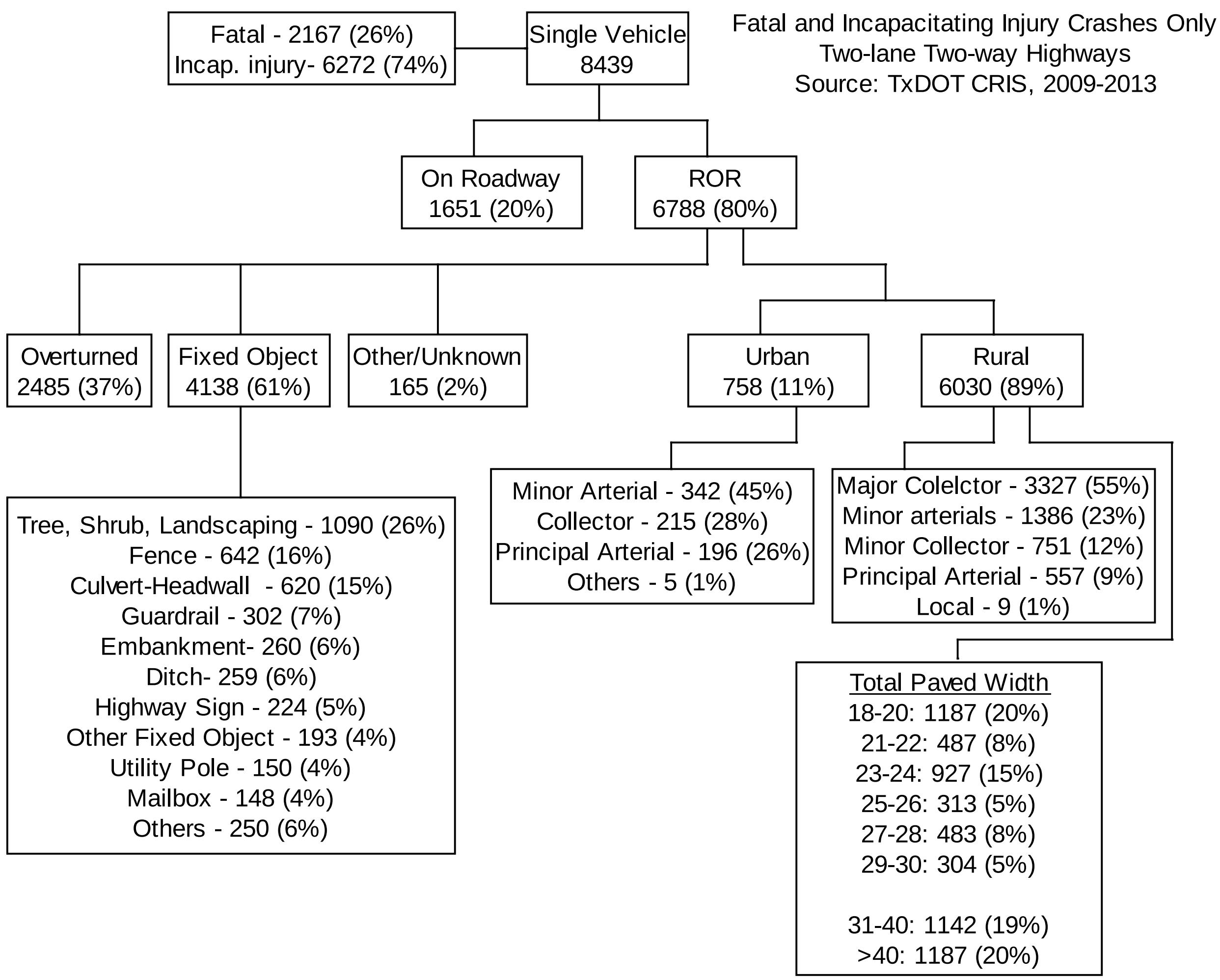


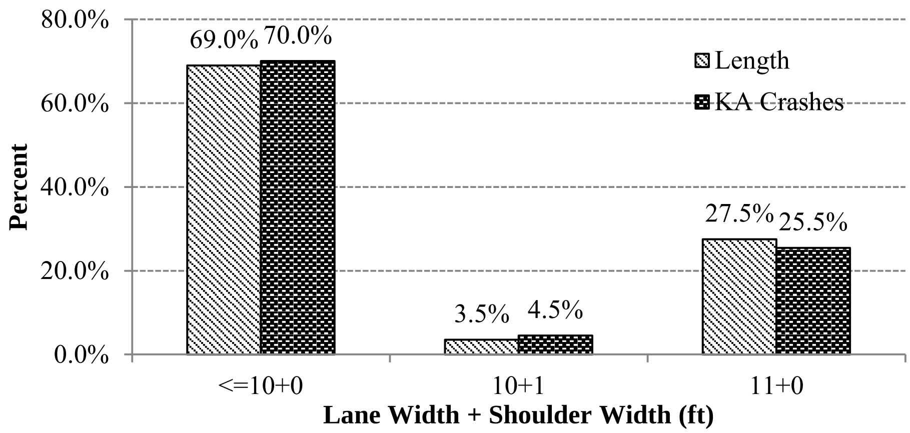
Figure 3-1 Crash Tree Diagram of SVROR KA Crashes.

3.4 STEP 4—IDENTIFY COMMON ROADWAY CHARACTERISTIC CLASSIFICATION

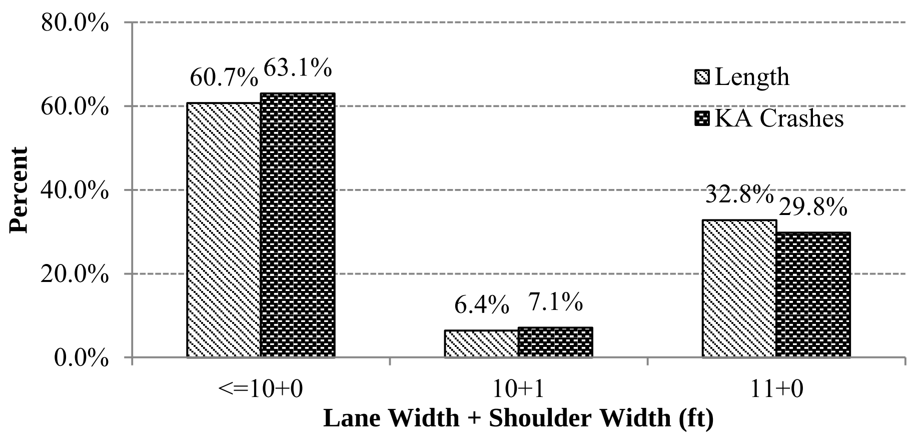
This step identifies roadway features related to the location of selected crash types. Based on Figure 3-1 in Step 3, the SVROR crash type is predominant on US and state highways and FM roads in rural areas. A categorical data analysis using roadway/roadside variables, such as ADT, alignment, lane and shoulder width, and roadside environment, will identify roadway risk characteristics related to a specific crash type. This analysis is similar to Task 4—identify and evaluate potential risk factors—of Step 1 of Chapter 1 related to the systemic approach to project selection.

The proportion of crashes for a specific range or value of a variable is compared with the proportion of existing highway mileage within the respective range or value. From this comparison, a specific range or value is identified as a risk factor when the proportion of crashes is greater than the proportion of accounted highway mileage. Figures 3-2 to 3-4 show the proportions of SVROR KA crashes and existing highway mileage by different variables (lane and shoulder pavement width, truck presence, and alignment) for traffic volume groups. For example, for moderate-volume group, the SVROR KA crashes on highways with a 10-ft lane width without paved shoulder are over-represented (see Figure 3-2). In addition to lane and shoulder width, a categorical data analysis should be done with other variables, such as alignment, and truck percentages, as was done in Task 4 of Step 2 in Chapter 2.

(a) Low volume (400≤ADT≤700)

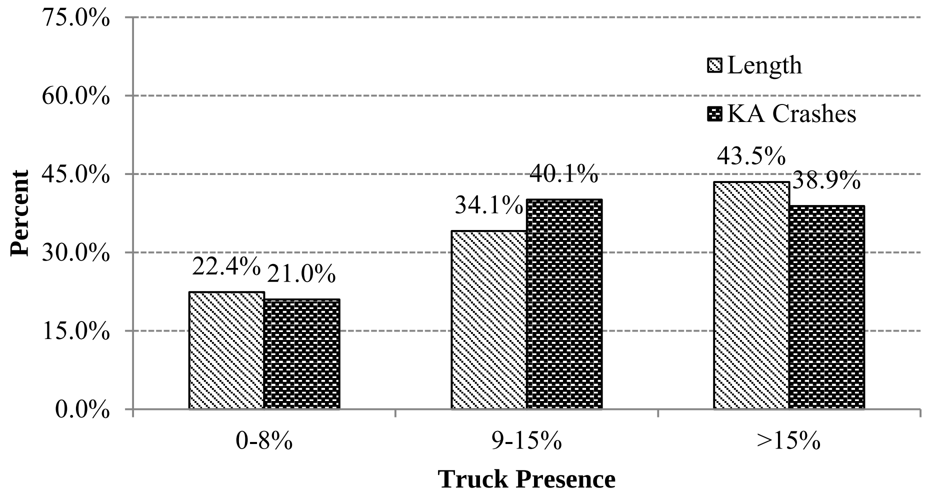


(b) Moderate volume (700<ADT≤1,500)

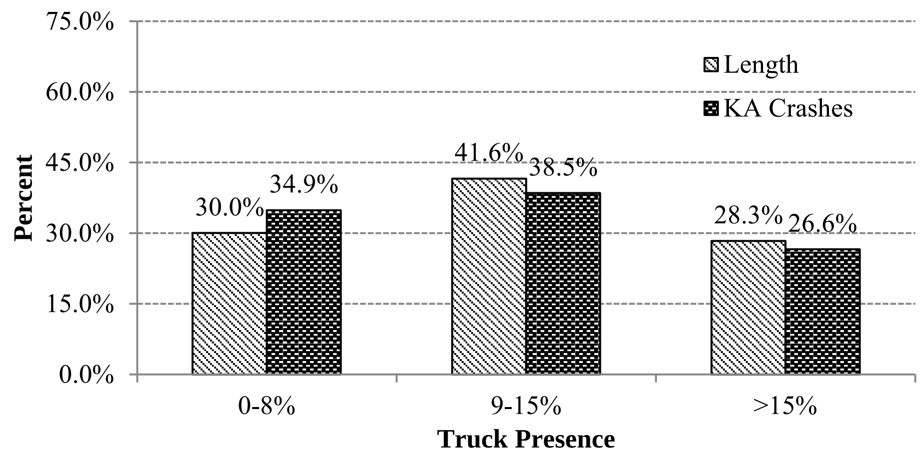


(c) High volume (ADT>1,500)

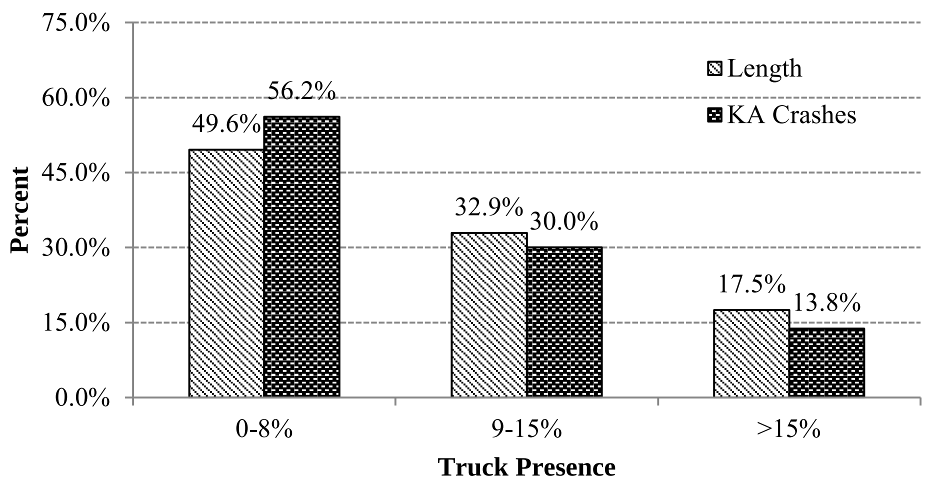
Figure 3-2 SVROR Crashes by Lane and Shoulder Widths on Two-Lane Rural Highways.



(a) Low volume (400≤ADT≤700)

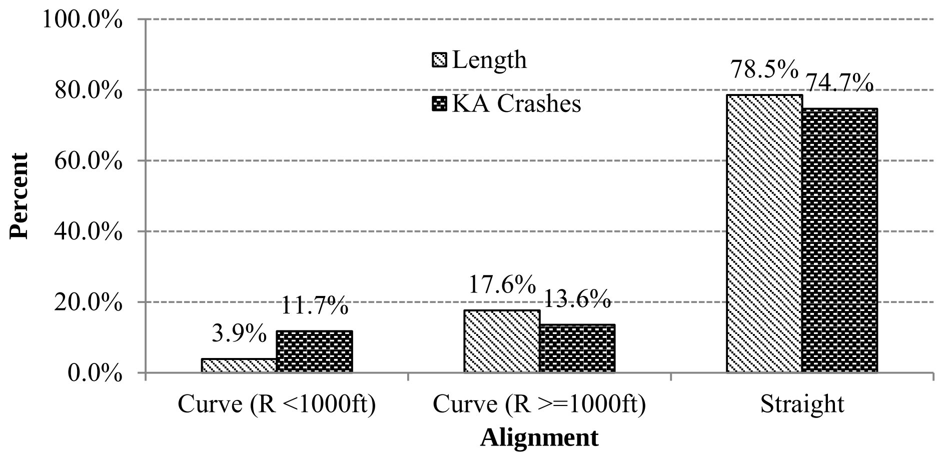


(b) Moderate volume (700<ADT≤1,500)

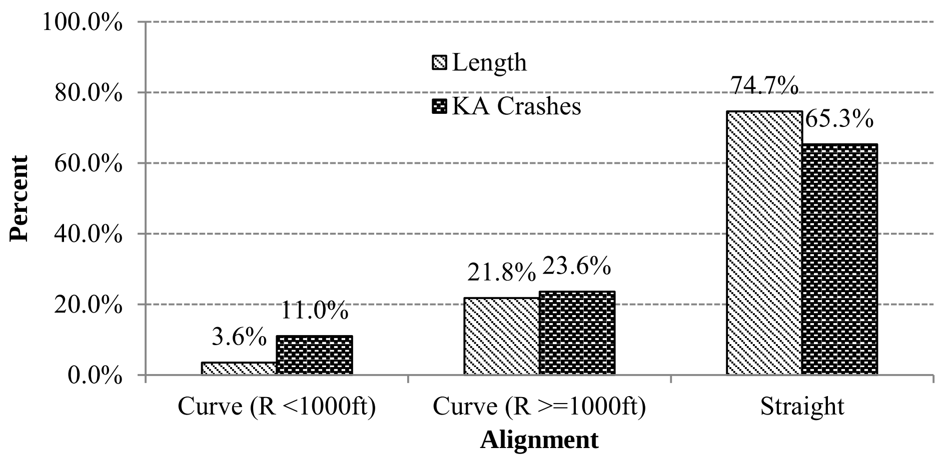


(c) High volume (ADT>1,500)

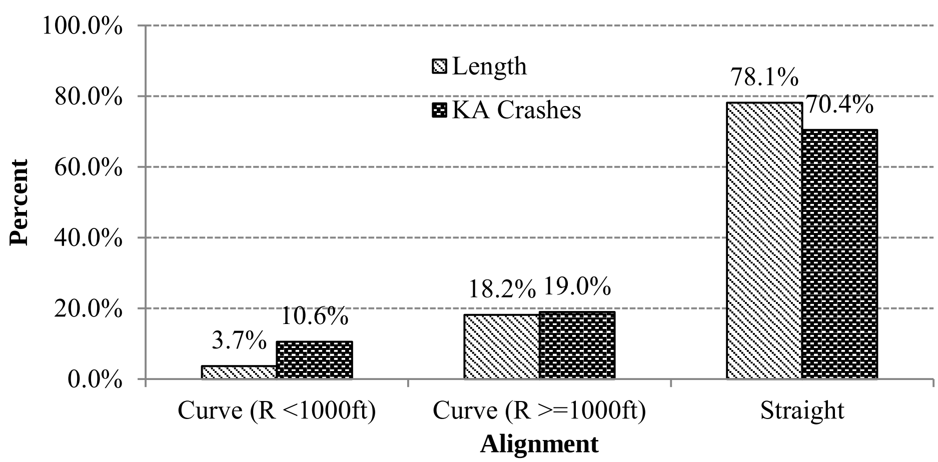
Figure 3-3 SVROR Crashes by Truck Presence on Two-Lane Rural Highways.



(a) Low volume (400≤ADT≤700)



(b) Moderate volume (700<ADT≤1,500)



(c) High volume (ADT>1,500)

Figure 3-4 SVROR Crashes by Alignment on Two-Lane Rural Highways.

3.5 STEP 5—DEFINE ROADWAY CHARACTERISTIC CLASSIFICATION BY POTENTIAL FOR PREVENTABLE CRASH TYPE

The proportions of SVROR crashes are over-represented on curves having a 10-ft lane width without paved shoulder, less than 8 percent truck percentages and/or 9 to 15 percent truck percentages. Table 3-3 summarizes the prioritization results of risk factors to SVROR KA crashes on highways in rural areas.

Table 3-3 Risk Factor Prioritization Results of SVROR KA Crashes on Rural Highways.

<table>
<tr><th colspan="2" rowspan="2">Risk Factor</th><th colspan="3">Weight (points)</th></tr>
<tr><th>Low Volume (400≤ADT≤700)</th><th>Moderate Volume (700<ADT≤1,500)</th><th>High Volume (ADT>1,500)</th></tr>
<tr><td rowspan="3">Lane & Shoulder Width</td><td>10+0</td><td>7</td><td>8</td><td>8</td></tr>
<tr><td>10+1</td><td>0</td><td>1</td><td>1</td></tr>
<tr><td>11+0</td><td>6</td><td>2</td><td>2</td></tr>
<tr><td rowspan="3">Truck Percentage</td><td>≤8%</td><td>2</td><td>7</td><td>11</td></tr>
<tr><td>9-15%</td><td>10</td><td>3</td><td>3</td></tr>
<tr><td>>15%</td><td>3</td><td>2</td><td>1</td></tr>
<tr><td rowspan="3">Alignment</td><td>Curve (R <1000ft)</td><td>8</td><td>8</td><td>7</td></tr>
<tr><td>Curve (R ≥1000ft)</td><td>1</td><td>3</td><td>2</td></tr>
<tr><td>Straight</td><td>7</td><td>6</td><td>7</td></tr>
</table>

3.6 SUMMARY

As discussed in this chapter, the TTI researchers developed the roadway characteristic classification systemic improvements detailed herein by focusing on particular countermeasures intended to have a positive impact on safety. Specifically, the researchers focused on identifying low-cost countermeasures for high-risk rural roadways. The information on CMFs, service life, and costs of countermeasures were collected from the TxDOT HSIP manual and federal/state reports. Then preventable crash types and candidate locations of the related countermeasures were identified. For risk factors associated with crash types, roadway features were analyzed using the categorical data method. Finally, the roadway features having greater proportions of crash total and/or over-representation were defined as risk factors to a particular crash type.

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APPENDIX A

TXDOT ROADWAY COUNTERMEASURES AND CRASH REDUCTION FACTORS[1]

[1] This is based on the TxDOT HSIP Work Codes Table (01/01/2015 Version)

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Install Warning/Guide Signs	Provide advance signing for unusual or unexpected roadway features where no signing existed previously.	0.80	6	N/A
Install STOP Signs	Provide STOP signs where none existed previously.	0.80	6	N/A
Improve Advance Warning Signals	Bring existing flasher units into conformance with current design standards. Refer to W.C. 106 for modernization of intersection flashing	To be defined.	10	N/A
Install Intersection Flashing Beacon	Provide a flashing beacon at an intersection where a beacon did not exist previously.	0.65	10	$2,100 (overhead) $1,300 (roadside mounted)
Modernize Intersection Flashing Beacon	Improve an existing overhead flashing beacon, located at an intersection, to current design standards. Refer to W.C. 104 for non-intersection flashing beacon.	0.90	10	N/A
Install Traffic Signal	Provide a traffic signal where none existed previously.	0.65	10	$3,400 (Isolated) $3,900 (Interconnected) $5,400 (Diamond Interchange)
Improve Traffic Signals	Modernize existing intersection signals to current design standards. Refer to W.C. 106 for modernization of intersection flashing beacons.	0.50	10	N/A
Install Pedestrian Signal	Provide a pedestrian signal at an existing signalized location where no pedestrian phase exists, but pedestrian crosswalks are existing. Refer to W.C. 403 for installation of pedestrian crosswalks.	0.85	10	N/A
Interconnect Signals	Provide a communication link between two or more adjacent signals in a corridor. Specify all signalized intersections to be	0.90	10	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
	included in the interconnection.			
Overheight Warning System	Install electronic devices to detect overheight loads.	0.35	10	N/A
Install Delineators	Install post-mounted delineators to provide guidance.	0.70	2	N/A
Install School Zones	Place school zones to include flashers, signing and/or pavement markings where none existed previously. Refer to W.C. 403 for pedestrian crosswalk markings.	0.80	5	N/A
Replace Flashing Beacon with a Traffic Signal	Replace an existing flashing beacon at an intersection with a traffic signal.	0.75	10	$1,300
Install Overhead Guide Signs	Install overhead advance signing for unusual or unexpected roadway features where no signing existed previously.	0.80	6	N/A
Convert 2-way STOP Signs to 4-way STOP Signs	Provide 4-way STOP signs where 2-way STOP signs existed previously	0.85	6	N/A
Install Advance Warning Signals (Intersection — Existing Warning Signs)	Provide flasher units in advance of an intersection where none previously existed. Advance warning signs already exist.	0.90	10	$1,300 per approach
Install Advance Warning Signals (Curve – Existing Warning Signs)	Provide flasher units in advance of a curve where none previously existed. Advance warning signs already exist.	0.90	10	$1,300 per approach
Install Advance Warning Signals and Signs (Intersection)	Provide flasher units and signs in advance of an intersection where none previously existed.	0.85	10	$1,300 per approach
Install Advance Warning Signals and Signs (Curve)	Provide flasher units and signs in advance of a curve where none previously existed.	0.85	10	$1,300 per approach
Install Advance Warning Signs (Intersection)	Provide signs in advance of an intersection where none previously existed.	0.95	6	N/A
Install Advance Warning Signs (Curve)	Provide signs in advance of a curve where none previously existed.	0.95	6	N/A
Improve Pedestrian Signals	Bring existing pedestrian signal units into conformance with current standards.	0.90	10	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Install Advance Warning Signals and Signs	Provide flasher units and signs in advance of hazard where none previously existed.	0.90	10	$1,300 per approach
Improve School Zone	Improve an existing school zone by upgrading signing, pavement markings or signals.	0.95	5	N/A
Install LED Flashing Chevrons (Curve)	Install LED flashing chevrons on curve to provide guidance.	0.65	10	N/A
Install Chevrons (Curve)	Install chevrons on curve to provide guidance.	0.75	10	N/A
Install Flashing Yellow Arrow	Modernize existing intersection signals by adding a flashing yellow arrow indication. Refer to W.C. 108 for improvement of traffic signal.	0.85	10	N/A
Install Surface Mounted Delineators on Centerline	Install surface mounted delineators on centerline.	0.65	2	N/A
Wrong Way Driver Warning Signs and Markings	Provide warning signs and markings to warn wrong way drivers at freeway entrances.	TBD	TBD	TBD
Install Median Barrier	Construct a metal, concrete, or cable safety system median barrier where none existed previously.	0.45	20	N/A
Convert Median Barrier	Remove an existing metal median barrier system and install a concrete or cable safety system median barrier.	0.60	15	N/A
Install Raised Median	Install a roadway divider using barrier curb	0.75	20	N/A
Flatten Side Slope	Provide an embankment side slope of 6:1 or flatter.	0.54	20	N/A
Modernize Bridge Rail and Approach Guardrail	Improve existing substandard bridge rail and approach guardrail to current design standards.	0.85	10	N/A
Improve Guardrail to Design Standards	Bring existing substandard guardrail into conformance with current design standards.	0.65	10	N/A
Install Protection	Install guardrail or concrete traffic barrier where none existed previously. Refer to W.C. 209 if using guardrail to safety treat a fixed object or drainage structures.	0.70	10	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Safety Treat Fixed Objects	Remove, relocate or safety treat all fixed objects including the installation of guardrail for safety treatment of a fixed object or drainage structures within the project limits, to include both point and continuous objects.	0.50	20	N/A
Install Impact Attenuation System	Provide any of a variety of impact attenuators where none existed previously.	0.40	10	N/A
Widen Bridge	Provide additional width across an existing structure, either by rehabilitation or replacement. Specify existing bridge width, existing approach roadway width and roadway type (2 lane, 4 lane undivided, etc.)	0.45	20	N/A
Install Curb – Control of Access	Install curb for an urban low-speed design highway where no previous curb existed and the crash history indicates a control of access problem.	0.90	10	N/A
Relocate Luminaire Supports From Median	Relocate luminaire supports from median (usually narrow) and place between outside curb and R.O.W.	To be defined.	10	N/A
Improve Impact Attenuation System	Improve existing impact attenuators.	0.90	10	N/A
Improve Median Barrier	Replace an existing median barrier with an improved barrier. Refer to W.C. 201 for installing a new median barrier where none previously existed.	0.85	20	N/A
Install Dragnet	Install dragnet at overpass to prevent vehicles from running off embankment between bridges.	0.45	20	N/A
Resurfacing	Provide a new roadway surface to increase pavement skid numbers on all the lanes.	0.70	10	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Safety Lighting	Provide roadway lighting, either partial or continuous, where either none existed previously or major improvements are being made. Refer to W.C. 305 for intersection lighting.	0.60	15	$100 per Luminaire
Safety Lighting at Intersection	Install lighting at an intersection where either none existed previously or major improvements are proposed. Refer to W.C. 304 for general lighting.	0.55	15	$100 per Luminaire
High Friction Surface Treatment (Curve)	Provide a high friction surface treatment on a curve.	0.55	5	N/A
High Friction Surface Treatment (Intersection)	Provide a high friction surface treatment at an intersection approach.	0.80	5	N/A
Install Pavement Markings	Place complete pavement markings, excluding crosswalks, in accordance with the TMUTCD where either no markings or nonstandard markings exist. Refer to W.C. 402 for edge marking, W.C. 403 for pedestrian crosswalks, W.C. 404 for centerline striping.	0.80	2	N/A
Install Edge Marking	Place edge lines where none existed previously.	0.75	2	N/A
Install Pedestrian Crosswalk	Place pedestrian crosswalk markings where none existed previously. Refer to W.C. 114 for school zones, and W.C. 110 for pedestrian signal.	0.90	2	N/A
Install Centerline Striping	Provide centerline striping where either no markings or nonstandard markings existed previously. Refer to W.C. 401 for complete pavement markings.	0.35	2	N/A
Install Sidewalks	Install sidewalks where none existed previously.	0.80	10	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Modernize Facility to Design Standards	Provide modernization to all features within the Right-of-Way to achieve current desirable standards. This includes work such as widening the travelway, widening the shoulders, constructing shoulders, flattening the side slopes, and treating roadside obstacles.	0.85	20	N/A
Widen Lane(s)	Provide additional width to the lane(s). Refer to W.C. 517 if adding a through lane.	0.70	20	N/A
Widen Paved Shoulder (to 5 ft. or less)	Extend the existing paved shoulder to achieve desirable shoulder width. Refer to W.C. 504 or 537 for constructing a paved shoulder.	0.75	20	N/A
Construct Paved Shoulders (1 – 4 ft.)	Provide paved shoulders of 1- to 4-foot width where no shoulders existed previously. Refer to W.C. 503 or 536 for widening paved shoulders.	0.75	20	N/A
Improve Vertical Alignment	Reconstruct the roadway to improve sight distance.	0.50	10	N/A
Improve Horizontal Alignment	Flatten existing curves. Refer to W.C. 507 for providing superelevation, and W.C. 508 for intersection realignment.	0.45	10	N/A
Increase Superelevation	Provide increased superelevation on an existing curve.	0.35	10	N/A
Realign Intersection	Improve an existing intersection by partial or complete relocation of the roadway(s). Refer to W.C. 509 for channelization, and W.C. 506 for improving horizontal alignments.	To be defined.	10	N/A
Channelization	Install islands and/or pavement markings to control or prohibit vehicular movements. A sketch of the proposed channelization should be provided. Refer to W.C. 508 for intersection realignment.	To be defined.	10	N/A
Construct Turn Arounds	Provide turnarounds at an intersection where none existed previously.	0.60	10	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Grade Separation	Construct vertical separation of intersecting roadways.	0.20	30	N/A
Construct Interchange	Construct vertical separation of intersecting roadways to include interconnecting ramps.	0.35	30	N/A
Close Crossover	Permanently close an existing crossover.	0.05	20	N/A
Add Through Lane	Provide an additional travel lane.	0.72	20	N/A
Install Continuous Turn Lane	Provide a continuous two-way left turn lane where none existed previously.	0.50	10	N/A
Add Left Turn Lane	Provide an exclusive left turn lane where none existed previously. The affected intersection approaches must be specified.	0.75	10	N/A
Lengthen Left Turn Lane	Provide additional length to an existing exclusive left turn lane. Affected intersection approaches must be specified.	0.60	10	N/A
Add Right Turn Lane	Provide an exclusive right turn lane where none existed previously. Affected intersection approaches must be specified.	0.75	10	N/A
Lengthen Right Turn Lane	Provide additional length to an existing exclusive right turn lane. Affected intersection approaches must be specified.	0.60	10	N/A
Construct Pedestrian Over / Under Pass	Construct a pedestrian crossover where none existed previously.	0.05	20	N/A
Increase Turning Radius	Provide an increased turning radius at an existing intersection.	0.90	10	N/A
Convert to One-Way Frontage Roads	Convert two-way frontage roads to one-way operation.	0.75	10	N/A
Increase Vertical Clearance (Lower Grade)	Increase vertical clearance of a roadway underneath an overhead obstacle by lowering the roadway grade.	0.50	10	N/A
Increase Vertical Clearance (Remove Structure)	Remove an overhead structure in order to increase vertical clearance.	0.05	10	N/A
Construct Median Crossover	Provide crossovers in the median where none previously existed.	0.80	10	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Remove Raised Median/Concrete Island	Permanently remove raised median/concrete island.	0.65	10	N/A
Milled Edgeline Rumble Strips	Install continuous milled depressions (rumble stripes or rumble strips) along the edgeline.	0.50	10	N/A
Profile Edgeline Markings	Install profile edgeline markings.	0.40	5	N/A
Raised Edgeline Rumble Strips	Install non-reflective raised traffic buttons (yellow or white) along the edgeline.	0.40	2	N/A
Widen Median Opening for Storage	Widen an existing opening in the median to accommodate vehicles for storage.	0.80	10	N/A
Widen Paved Shoulders (to > 5 ft.)	Extend the existing paved shoulder to greater than 5 ft. Refer to W.C. 504 or 537 for constructing a paved shoulder.	0.60	20	N/A
Construct Paved Shoulders (≥ 5 ft.)	Provide paved shoulders 5 feet or greater where no shoulders existed previously. Refer to W.C. 503 or 536 for widening paved shoulders.	0.60	20	N/A
Convert 2-Lane Facility to 4-Lane Divided	Convert an existing 2-lane facility to a 4-lane divided facility.	0.55	20	N/A
Install Median on Undivided Facility	Install a grass or flush median on an undivided facility.	0.60	20	N/A
Install Passing Lanes on 2-Lane Roadway	Install passing lanes on a 2-lane roadway where none currently exist.	0.75	15	N/A
Provide Additional Paved Surface Width	Provide additional paved surface width with appropriate subsurface to each side of two lane, two-way roadways with existing paved surface width less than 24' to a maximum width of 28'.	0.70	20	N/A
Milled Centerline Rumble Strips	Install milled centerline rumble strips along the centerline.	0.65	10	N/A
Profile Centerline Markings	Install profile centerline markings and preformed thermoplastic strips along the centerline.	0.65	5	N/A

Treatment	Definition	CMF	Service Life (yr)	Maintenance Cost ($)
Raised Centerline Rumble Strips	Install non-reflective raised traffic buttons (yellow or black) and preformed thermoplastic strips along the centerline.	0.65	2	N/A
Transverse Rumble Strips	Install transverse or in-lane rumble strips in advance of a high incident and special geometric location.	0.85	5	N/A
Convert 4 Lane Undivided to Super 2 with Paved Shoulders	Convert an existing 4 lane undivided highway with no shoulders into a Super 2 highway with shoulders.	0.75	20	N/A
Construct a Roundabout	Convert an existing intersection to a roundabout design	0.60	10	N/A