VOLUME 6

NCHRP

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

REPORT 500

Guidance for Implementation of the AASHTO Strategic Highway Safety Plan

Volume 6: A Guide for Addressing Run-Off-Road Collisions



TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Guidance for Implementation of the AASHTO Strategic Highway Safety Plan

Volume 6: A Guide for Addressing Run-Off-Road Collisions

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SUBJECT AREAS
Safety and Human Performance

Research Sponsored by the American Association of State Highway and Transportation Officials
in Cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2003
www.TRB.org

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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NCHRP REPORT 500: Volume 6

Project G17-18(3) FY'00

ISSN 0077-5614

ISBN 0-309-08760-0

Library of Congress Control Number 2003104149

Price $21.00

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Each report is reviewed and accepted for publication by the technical committee according to procedures established and monitored by the Transportation Research Board Executive Committee and the Governing Board of the National Research Council.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

Transportation Research Board
Business Office
500 Fifth Street, NW
Washington, DC 20001

and can be ordered through the Internet at:

http://www.national-academies.org/trb/bookstore

Printed in the United States of America

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COOPERATIVE RESEARCH PROGRAMS STAFF FOR NCHRP REPORT 500

NCHRP PROJECT G17-18(3) PANEL
Field of Traffic—Area of Safety

FOREWORD

By Charles W. Niessner
Staff Officer
Transportation Research Board

The goal of the AASHTO Strategic Highway Safety Plan is to reduce annual highway fatalities by 5,000 to 7,000. This goal can be achieved through the widespread application of low-cost, proven countermeasures that reduce the number of crashes on the nation's highways. This sixth volume of *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan* provides strategies that can be employed to reduce the number run-off-road collisions. The report will be of particular interest to safety practitioners with responsibility for implementing programs to reduce injuries and fatalities on the highway system.

In 1998, AASHTO approved its Strategic Highway Safety Plan, which was developed by the AASHTO Standing Committee for Highway Traffic Safety with the assistance of the Federal Highway Administration, the National Highway Traffic Safety Administration, and the Transportation Research Board Committee on Transportation Safety Management. The plan includes strategies in 22 key emphasis areas that affect highway safety. The plan's goal is to reduce the annual number of highway deaths by 5,000 to 7,000. Each of the 22 emphasis areas includes strategies and an outline of what is needed to implement each strategy.

NCHRP Project 17-18(3) is developing a series of guides to assist state and local agencies in reducing injuries and fatalities in targeted areas. The guides correspond to the emphasis areas outlined in the AASHTO Strategic Highway Safety Plan. Each guide includes a brief introduction, a general description of the problem, the strategies/countermeasures to address the problem, and a model implementation process.

This is the sixth volume of *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan*, a series in which relevant information is assembled into single concise volumes, each pertaining to specific types of highway crashes (e.g., run-off-road, head-on) or contributing factors (e.g., aggressive driving). An expanded version of each volume, with additional reference material and links to other information sources, is available on the AASHTO Web site at http://transportation1.org/safetyplan. Future volumes of the report will be published and linked to the Web site as they are completed.

While each volume includes countermeasures for dealing with particular crash emphasis areas, *NCHRP Report 501: Integrated Management Process to Reduce Highway Injuries and Fatalities Statewide* provides an overall framework for coordinating a safety program. The integrated management process comprises the necessary steps for advancing from crash data to integrated action plans. The process includes methodologies to aid the practitioner in problem identification, resource optimization, and performance measurements. Together, the management process and the guides provide a comprehensive set of tools for managing a coordinated highway safety program.

Contents

Acknowledgments

This series of six implementation guides was developed under NCHRP Project 17-18(3). The project was managed by CH2M HILL. The co-principal investigators were Ron Pfefer of Maron Engineering and Kevin Slack of CH2M HILL. Timothy Neuman of CH2M HILL served as the overall project director for the CH2M HILL team. Kelly Kennedy Hardy, also of CH2M HILL, participated in development of the guides.

This phase of the project involved the development of guide books addressing six different emphasis areas of AASHTO's Strategic Highway Safety Plan. The project team was organized around the specialized technical content contained in each guide. The CH2M HILL team included nationally recognized experts from many organizations. The following team of experts, selected based on their knowledge and expertise in a particular emphasis area, served as lead authors for each of the guides.

- Forrest Council of BMI led the development of "A Guide for Addressing Run-Off-Road Collisions"
- Doug Harwood of Midwest Research Institute led the development of "A Guide for Addressing Unsignalized Intersection Collisions"
- Hugh McGee of BMI led the development of "A Guide for Addressing Head-On Collisions"
- Richard Raub of Northwestern University Center for Public Safety led the development of "A Guide for Addressing Aggressive-Driving Collisions"
- Patricia Waller led the development of "A Guide for Addressing Collisions Involving Unlicensed Drivers and Drivers with Suspended or Revoked Licenses"
- Charlie Zegeer and Kevin Lacy of University of North Carolina Highway Safety Research Center led the development of "A Guide for Addressing Collisions Involving Trees in Hazardous Locations"

Development of the guides utilized the resources and expertise of many professionals from around the country and overseas. Through research, workshops, and actual demonstration of the guides by agencies, the resulting document represents best practices in each emphasis area. The project team is grateful to the following list of people and their agencies for their input on the guides and their support of the project:

American Association of State Highway and Transportation Officials
Tony Kane

Arizona Governor's Office of Highway Safety
Alberto Gutier

Bastrop, Texas, Police Department
Bill Anderson

Ben Gurion University of the Negev
David Shinar

California Department of Motor Vehicles
Dave DeYoung

California Department of Transportation
Roy Peterson

City of Lubbock, Texas
Jeryl Hart

City of Winston-Salem, North Carolina
Stan Polanis

Consultant
Terry Witkowski

Craven County, North Carolina, Sheriff's Office
James Bradley
Richard Woods

CTTER
Stephen Blake

Dallas Trees and Parks Foundation
Mike Bradshaw

Delaware State Police
Mark Collender
Barbara Conley

Durham Police Department
James R. Cleary
Teen Ennis

Federal Highway Administration
Beth Alicandri
Craig K. Allred
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Joe Bared
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Michael Halladay
Carl Hayden
Hari Kalla
Martha Kapitanov
Nak Joo Kim
Kristine Leiphart
Liana Liu
Leonard Meczkowski
Richard Powers
Harry W. Taylor

Federal Highway Administration—Eastern Federal Lands
Ken Atkins

Federal Highway Administration—Midwest Resource Center
Patrick Hasson

Federal Highway Administration—Southern Resource Center
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Brian Blanchard
Patrick A. Brady
Billy Hattaway
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Georgia Institute of Technology
Karen Dixon

Insurance Institute for Highway Safety
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Iowa Department of Transportation
Dave Little
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Kansas Department of Transportation
Jim Brewer
Ron Seitz

Kentucky Department of Highways
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Lee County, Florida, Sheriff's Office
Dennis Brooks
Jerry Cantrell

Lockhart, Texas, Police Department
Charles L. Bethel

Maine Department of Transportation
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Robert LaRoche

Maryland Motor Vehicle Administration
Jane Valenzia

Maryland State Highway Administration
Ken Briggs
Curt Childress
Manu Shah

Michigan Department of Transportation
Kurt Kunde
Andy Zeigler

Michigan Governor's Office
Chad Canfield

Michigan State Police Department
Mike Nof

Mid-America Research
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Loren Hill

Mississippi Department of Transportation
John B. Pickering
John Reese
Jim Willis

Missouri Department of Transportation
Steve McDonald

National Association of County Engineers
Tony Giancolo

National Highway Traffic Safety Administration
Richard Compton

National Transportation Safety Board
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New Bern, North Carolina, Police Department
Todd Conway
James E. Owens

New Jersey Department of Transportation
John Spedding

New York State Department of Transportation
Jonathan Bray
Robert Limoges
David C. Woodin

Ohio Department of Transportation
Larry Sutherland

Oregon Department of Transportation
Jeff Greiner
Chris Monsere
Vivian Payne

Palm Beach County, Florida, Sheriff's Office
Capt. Steven Withrow

Parsons Brinckerhoff
Gregory Hoer

Pennsylvania Department of Transportation
Mike Baglio

Roadway Safety Foundation
Kathy Hoffman

Santa Barbara, California, Police Department/Traffic Safety
David Whitham

Scenic America
Meg Maguire

Smithville, Texas, Police Department
Lee Nusbaum

South Carolina Department of Transportation
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Terecia Wilson

Texas Department of Transportation
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Dean Iberson

Town of Chapel Hill, North Carolina
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Westat
Neil Lerner

West Virginia Department of Transportation
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Wisconsin Department of Transportation
Peter Amakobe

Worcester Polytechnic Institute
Malcolm Ray

A Guide for Addressing Run-Off-Road Collisions

The authors wish to express their thanks to Hugh McGee and Leanne Prothe of BMI for their many written and verbal contributions to the guide, particularly for their preparation of the section on skid-resistant pavement, and Kimberly Eccles of BMI for her assistance in the selection, identification, and acquisition of graphics for the final draft.

SECTION I

Summary

Introduction

The American Association of State Highway and Transportation Officials's (AASHTO's) Strategic Highway Safety Plan identified 22 goals to pursue in order to significantly reduce highway crash fatalities. One of the plan's hallmarks is to comprehensively approach safety problems. The range of strategies available in the guides will ultimately cover various aspects of the road user, the highway, the vehicle, the environment, and the management system. The guides strongly encourage the user to develop a program to tackle a particular emphasis area from each perspective in a coordinated manner. To facilitate this, the electronic form of the material uses hypertext links to enable seamless integration of various approaches to a given problem. As more guides are developed for other emphasis areas, the extent and usefulness of this integration will become ever more apparent.

AASHTO's overall goal is to move away from *independent* activities of engineers, law enforcement, educators, judges, and other highway safety specialists and to move toward *coordinated* efforts. The implementation process outlined in the series of guides promotes forming working groups and alliances that represent all of the elements of the safety system. In this formation, highway safety specialists can draw upon their combined expertise to reach the bottom-line goal of targeted reduction of crashes and fatalities associated with a particular emphasis area.

Goal 15 in the Strategic Highway Safety Plan is *Keeping Vehicles on the Roadway*, and Goal 16 is *Minimizing the Consequences of Leaving the Road*. Subsequently, three emphasis areas evolved from these two goals:

- Run-off-road (ROR) crashes,
- Head-on crashes, and
- Crashes with trees in hazardous locations.

The common solution to these emphasis areas is to keep the vehicle in the proper lane. While this solution will not eliminate crashes with other vehicles, pedestrians, bicyclists, and trains that may be in the path of the vehicle, it will eliminate many fatalities caused when a vehicle strays from the lane onto the roadside or into oncoming traffic. This section deals with ROR crashes.

ROR crashes involve vehicles that leave the travel lane and encroach onto the shoulder and beyond and hit one or more of any number of natural or artificial objects, such as bridge walls, poles, embankments, guardrails, parked vehicles, and trees. (Because trees are the most abundant objects along the road, they are treated as a separate emphasis area.) ROR crashes usually involve only a single vehicle, although an ROR vehicle hitting a parked vehicle could be considered a multivehicle crash. An ROR crash, which typically consists of a vehicle encroaching onto the right shoulder and roadside, can also occur on the median side where the highway is separated or on the opposite side when the vehicle crosses the opposing lanes of a nondivided highway.

Reducing the likelihood that a vehicle will leave the roadway through roadway design (e.g., flattening curves or installing shoulder rumble strips) prevents deaths and injuries resulting from ROR crashes. When an errant vehicle does encroach on the roadside, fatalities and injuries can be reduced if an agency either can minimize the likelihood of the vehicle crashing into an object (e.g., through object removal) or overturning (e.g., sideslope flattening) or can reduce the severity of the crash (e.g., by installing breakaway devices).

Objectives of the Emphasis Area

To reduce the number of ROR fatality crashes, the objectives should be to

- Keep vehicles from encroaching on the roadside,
- Minimize the likelihood of crashing or overturning if the vehicle travels off the shoulder, and
- Reduce the severity of the crash.

Explanation of Objectives

The ideal objective of good design is to keep the vehicle in the travel lane. For vehicles that do cross the outside edge of pavement, a related objective is to enable the driver to safely recover on the shoulder before encountering the roadside. Motorists do not purposely move onto the shoulder unless they need to pull over to slow or stop their vehicle. However, errant vehicles will cross over onto the shoulder, with many proceeding onto the roadside, resulting in an ROR crash. The reasons for such errant events are varied and include avoiding a vehicle, object, or animal in the travel lane; inattentive driving due to distraction, fatigue, sleep, or drugs; the effects of weather on pavement conditions; and traveling too fast through a curve or down a grade. There are also a number of roadway design factors that can increase the probability that a driver error will become an ROR crash (e.g., travel lanes that are too narrow, substandard curves, and unforgiving shoulders and roadsides). Strategies can be applied to deal with the ROR crashes caused by these factors.

If the motorist travels onto the roadside, the probability of a crash occurring depends upon the roadside features, such as the presence and location of fixed objects, shoulder edge dropoff, sideslopes, ditches, and trees. If the roadside is fairly flat without objects and the soil can support the vehicle tires, then the probability of a serious crash is minimal (indeed, in many cases the motorist may fully recover and no ROR crash is reported). Conversely, where the roadside is populated with a continuous line of different types of objects and features, the sideslope is too steep for the vehicle to recover or if the soil produces “vehicle tripping,” then the probability of a serious crash is high. Therefore, there are strategies directed at reducing the number and density of possibly hazardous roadside features that would contribute to the likelihood of an ROR crash given a roadside encroachment.

The final objective, reducing the severity of the crash, can be met by changes in the design of the roadside features (e.g., making roadside hardware more forgiving or modifying sideslopes to prevent rollovers) and by changes in the vehicle (e.g., better restraint systems or improved side protection) or by increased occupant use of available restraints. While increased use of restraints would probably provide the greatest benefit, the emphasis in this discussion is on roadway-related improvements.

Exhibit I-1 lists objectives and related strategies for reducing the consequences of ROR crashes. Details of these strategies are covered in the following narrative. It should be noted that this is not a comprehensive list of all possible strategies to reduce ROR crashes. For example, roadway design or rehabilitation strategies such as building wide lanes or adding lane width on entire systems or subsystems or using positive guidance principals in new roadway design can clearly affect ROR crashes. However, these strategies are most likely employed in the design phase for new facilities or rehabilitation of long sections of roadways and are often high-cost improvements. AASHTO chose to concentrate efforts in this guide

EXHIBIT I-1
Emphasis Area Objectives and Strategies

Objectives	Strategies
15.1 A—Keep vehicles from encroaching on the roadside	15.1 A1—Install shoulder rumble strips
	15.1 A2—Install edgeline “profile marking,” edgeline rumble strips or modified shoulder rumble strips on section with narrow or no paved shoulders
	15.1 A3—Install midlane rumble strips
	15.1 A4—Provide enhanced shoulder or in-lane delineation and marking for sharp curves
	15.1 A5—Provide improved highway geometry for horizontal curves
	15.1 A6—Provide enhanced pavement markings
	15.1 A7—Provide skid-resistant pavement surfaces
	15.1 A8—Apply shoulder treatments
	• Eliminate shoulder drop-offs (E)*
	• Widen and/or pave shoulders (P)*
15.1 B—Minimize the likelihood of crashing into an object or overturning if the vehicle travels off the shoulder	15.1 B1—Design safer slopes and ditches to prevent rollovers (see “Improving Roadsides,” page V-36)
	15.1 B2—Remove/relocate objects in hazardous locations (see “Improving Roadsides,” page V-36)
	15.1 B3—Delineate trees or utility poles with retroreflective tape
15.1.C—Reduce the severity of the crash	15.1 C1—Improve design of roadside hardware (e.g., light poles, signs, bridge rails) (see “Improving Roadsides,” page V-36)
	15.1 C2—Improve design and application of barrier and attenuation systems (see “Improving Roadsides,” page V-36)

* An explanation of (E) and (P) appears on page V-3.

on lower-cost strategies that can be implemented quickly; these strategies can also be applied to "spots" on the roadway (e.g., lane widening on hazardous curves). With few exceptions, it is these lower-cost, quickly implementable strategies that are covered below.

Target of the Objectives

The first objective addresses ways to communicate with the driver. However, there are other strategies for fulfilling this objective that target highway design features that could contribute to a crash (e.g., shoulder drop-offs and pavements with low skid resistance). The second objective employs strategies that focus on the highway, with more concentration devoted to nonfreeway facilities, especially to higher-speed rural roads. Higher-design facilities such as freeways have fairly wide shoulders and more forgiving, wider clear zones. Features within the clear zone are shielded from traffic by barriers and crash attenuation devices. On the other hand, there is an extensive system of mostly two-lane rural high-speed roadways that do not have these features. Crash data analyses show that this rural two-lane system is particularly vulnerable to ROR crashes and should be targeted for appropriate measures. Some of the same strategies appropriate for these two-lane, rural, high-speed roads can also be implemented on suburban and urban streets and on freeways. Vehicle design, restraint features and usage, and design of roadside features and roadside geometry are all valid targets for the third objective, reducing the severity of ROR crashes. Finally, another approach to comprehensively address ROR safety problems is to replace the *independent* activities of engineers, law enforcement personnel, educators, judges, and other highway safety specialists with *cooperative* efforts, an approach reiterated in this guide.

SECTION II

Introduction

The American Association of State Highway and Transportation Officials's (AASHTO's) Strategic Highway Safety Plan identified 22 goals to pursue in order to significantly reduce highway crash fatalities. One of the plan's hallmarks is to comprehensively approach safety problems. Goal 15 in the Strategic Highway Safety Plan is *Keeping Vehicles on the Roadway*, and Goal 16 is *Minimizing the Consequences of Leaving the Road*. Subsequently, three emphasis areas evolved from these two goals:

- Run-off-road (ROR) crashes,
- Head-on crashes, and
- Crashes with trees in hazardous locations.

The common solution to these goal areas is to keep the vehicle in the proper lane. While this may not eliminate crashes with other vehicles, pedestrians, bicyclists, or trains, it would eliminate many fatalities that result when a vehicle strays from the lane onto the roadside or into oncoming traffic.

This emphasis area deals with ROR crashes associated with vehicles that leave the travel lane, encroach onto the shoulder and beyond, and hit one or more of any number of natural or artificial objects, such as bridge walls, poles, embankments, guardrails, parked vehicles, or trees. (Because trees are the most abundant objects along the road, they are treated as a separate emphasis area.)

ROR crashes usually involve only a single vehicle, although a ROR vehicle hitting a parked vehicle could be considered a multivehicle crash. A ROR crash, which consists of a vehicle encroaching onto the right shoulder and roadside, can also occur on the median side where the highway is separated or on the opposite side when the vehicle crosses the opposing lanes of a nondivided highway.

Reducing the likelihood that a vehicle will leave the roadway through roadway design (e.g., flattening curves or installing shoulder rumble strips) can prevent deaths and injuries resulting from ROR crashes. When an errant vehicle does encroach on the roadside, fatalities and injuries can be reduced if an agency can either (a) minimize the likelihood of the vehicle crashing into an object (e.g., through object removal or relocation) or overturning (e.g., through sideslope flattening or improved ditch design) or (b) reduce the severity of the crash (e.g., installing breakaway devices).

AASHTO's overall goal is to move away from *independent* activities of engineers, law enforcement, educators, judges, and other highway safety specialists and toward *coordinated* efforts. The implementation process outlined in the guides promotes forming working groups and alliances that represent all of the elements of the safety system. In this formation, highway safety specialists can draw upon their combined expertise to reach the bottom-line goal of targeted reduction of crashes and fatalities associated with a particular emphasis area.

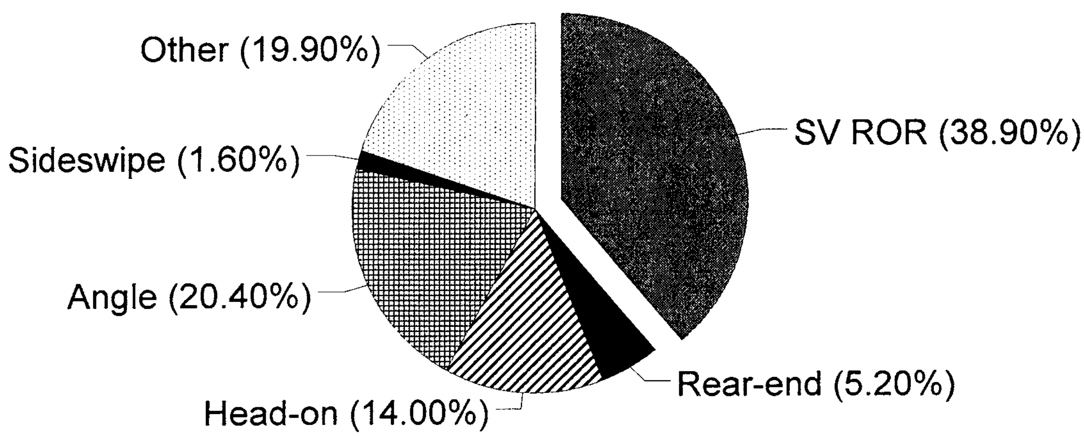
SECTION III

The Type of Problem Being Addressed

General Description of the Problem

The 1999 statistics from the Fatality Analysis Reporting System (FARS) show that nearly 39 percent of the 37,043 fatal crashes were single-vehicle ROR crashes on various road types (see Exhibit III-1).

EXHIBIT III-1
Single-Vehicle ROR Crashes as a Percentage of All Fatal Crashes



Source: FARS 1999

For two-lane, undivided, noninterchange, nonjunction roadways exclusively, there were 8,901 (24 percent) single-vehicle ROR crashes. Exhibit III-2 shows how single-vehicle ROR crashes on two-lane roads are distributed by roadway functional classification. There are more than twice as many ROR fatal crashes on rural roads than on urban roads, partly due to the higher speeds on rural roads and to the greater mileage.

Exhibits III-3 and III-4 show the distribution of ROR crashes by first harmful event and most harmful event for the same accident and roadway type, the latter being of higher severity (i.e., death) and the former being the first event or object hit, which may or may not result in injury or fatality. Attention should be focused on the first harmful event for strategies that deal with eliminating or protecting drivers from various roadside objects and to the most harmful event for strategies that minimize the severity of crashes when collisions with such objects occur. As noted, the objects that are hit most often are trees.

EXHIBIT III-2
Distribution of Single-Vehicle ROR Fatalities on Two-Lane, Undivided, Noninterchange, Nonjunction Roads by Highway Type (Source: 1999 FARS Data)

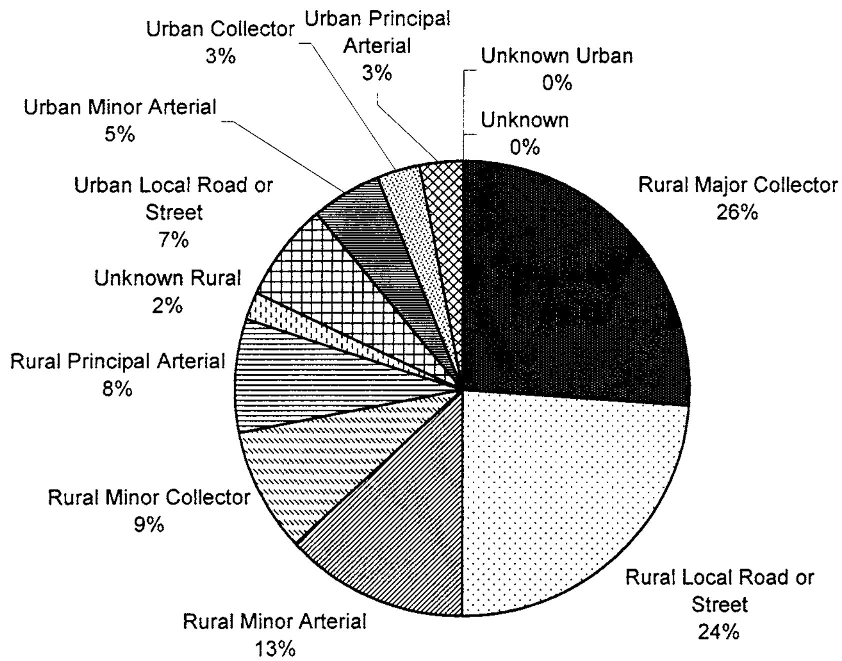
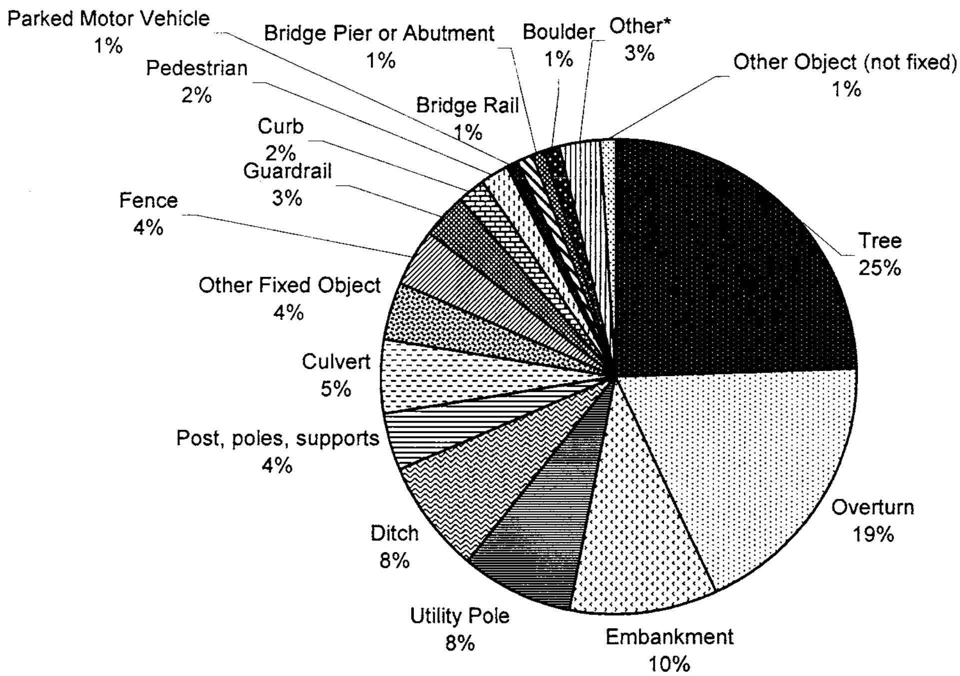
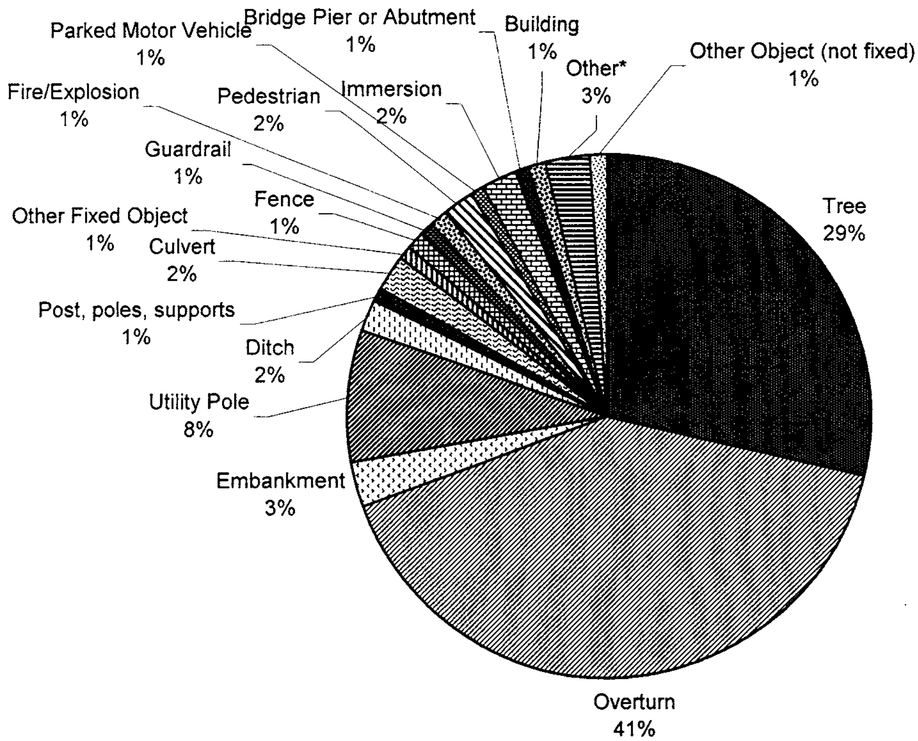


EXHIBIT III-3
Distribution of Single-Vehicle ROR Fatalities for Two-Lane, Undivided, Noninterchange, Nonjunction Roads by First Harmful Event (Source: 1999 FARS Data)



* Other includes events that each represent less than 0.5 percent of the total first harmful events: bridge parapet end, immersion, shrubbery, longitudinal barriers (concrete or other), pedal cycle, other noncollision, fire hydrant, snow bank, fell/jumped from vehicle, transport device used as equipment, animal, unknown, pavement surface irregularity, fire/explosion, other type of nonmotorist, vehicle occupant struck or run over by own vehicle, impact attenuator/crash cushion, railroad train, or gas inhalation.

EXHIBIT III-4
Distribution of Single-Vehicle ROR Fatalities for Two-Lane, Undivided, Noninterchange, Nonjunction Roads by Most Harmful Event (Source: 1999 FARS Data)

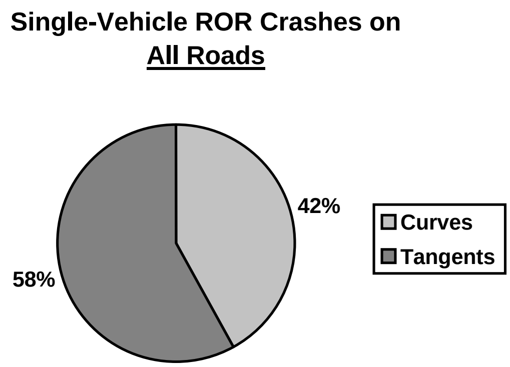


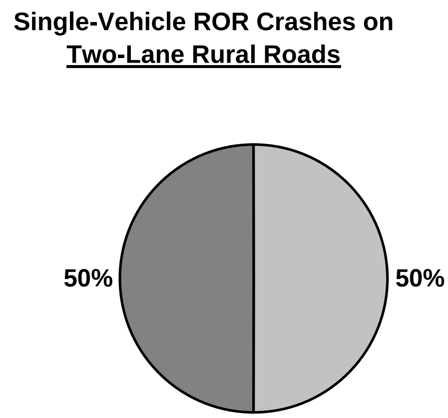
* Other includes events that each represent less than 0.5 percent of the total first harmful events: bridge parapet end, immersion, shrubbery, longitudinal barriers (concrete or other), pedal cycle, other noncollision, fire hydrant, snow bank, fell/jumped from vehicle, transport device used as equipment, animal, unknown, pavement surface irregularity, fire/explosion, other type of nonmotorist, vehicle occupant struck or run over by own vehicle, impact attenuator/crash cushion, railroad train, or gas inhalation.

Specific Attributes of the Problem

While vehicles are more likely to leave the roadway along curves, most ROR fatalities on all roads and on two-lane rural roads are on tangent sections, as shown in Exhibit III-5. For all roads, 42 percent of the 1999 ROR fatal crashes were on curves and 58 percent on tangents. For two-lane rural roads, the percentage of ROR fatal crashes on curves increased to 50 percent. The fact that more crashes occur on tangents for all roads most likely reflects the fact that most road sections are tangent. However, it is clear that both tangents and curves have significant problems and warrant treatment. As seen below, strategies are suggested for both curve and tangent sections.

EXHIBIT III-5
Distribution of Single-Vehicle ROR Crashes between Tangent and Curved Sections





As would be expected, roadside features cause the most damage in a ROR crash. FARS data for all roadway classes indicate that the most harmful event is most likely to be an overturn (42.1 percent of 1999 ROR single-vehicle fatalities), an impact with a tree (25.4 percent), an impact with a utility pole (7.2 percent), or an impact with a ditch or embankment (4.9 percent). Most other roadside objects (e.g., culverts, posts, or guardrails) are the most harmful event in 2 percent or less of the fatalities. For two-lane rural roads, the percentages for most harmful event are similar—an overturn (44.5 percent of 1999 ROR single-vehicle fatalities), an impact with a tree (28.7 percent), an impact with a utility pole (8.0 percent), or an impact with a ditch or embankment (5.0 percent). As all of these features are either necessary elements of the roadway, commonly found along the roadside, or both, strategies are needed to protect the vehicle and its occupants when it has failed to remain on the roadway.

SECTION IV

Index of Strategies by Implementation Timeframe and Relative Cost

Exhibit IV-1 provides a classification of strategies according to the expected timeframe and relative cost for this emphasis area. In several cases, the implementation time will be dependent upon such factors as the agency's procedures, the length of roadway involved, the need for additional right-of-way, and the need to follow environmental impact processes. The range of costs may also vary for some of these strategies because of many of the same factors. Placement in the table below is meant to reflect the most common expected application of the strategy.

EXHIBIT IV-1
Classification of Strategies According to Expected Timeframe and Relative Cost

Timeframe for Implementation	Strategy	Relative Cost to Implement and Operate			
		Low	Moderate	Moderate to High	High
Short (<1 year)	15.1 A1—Install rumble strips	✓			
	15.1 A3—Install midlane rumble strips	✓			
	15.1 A4—Provide enhanced delineation of sharp curves	✓			
	15.1 A6—Provide enhanced pavement markings	✓			
	15.1 B3—Remove/relocate objects in hazardous locations[a]	✓			
Medium (1–2 (years)	15.1 A7—Provide skid-resistant pavements		✓		
	15.1 A8—Eliminate shoulder drop-off[b]	✓			
	15.1 B1—Provide shoulder treatments[c] or four-lane sections at key locations*		✓		
	15.1 B2—Design safer slopes and ditches			✓	
	15.1 C1—Improve roadside hardware			✓	
	15.1 C2—Improve barrier and attenuation systems			✓	

(*continued on next page*)

EXHIBIT IV-1 (Continued)
Classification of Strategies According to Expected Timeframe and Relative Cost

Timeframe for Implementation	Strategy	Relative Cost to Implement and Operate			
		Low	Moderate	Moderate to High	High
Long (>2 years)	15.1 A5—Improve horizontal curve geometry[d]				✓

[a] Removal/relocation of some objects (e.g., bridge abutments and drainage structures) can be costly, depending upon the object. It is assumed here, however, that most objects will be small appurtenances.
[b] The action could be done in a short timeframe. However, it is assumed to be done at little extra cost as part of a regular repaving program.
[c] The classification of shoulder treatments and safer slopes and ditches as moderate-cost or moderate-to-high-cost treatments assumes that no additional right-of-way is needed. If right-of-way is needed, the cost could be high and the time required would be long.
[d] Although the AASHTO Strategic Highway Safety Plan is focused upon relatively low-cost, short-term strategies, there are some higher-cost strategies such as curve flattening that have potential for such significant effectiveness that they have been included. Curve flattening would primarily be applicable in rehabilitation, resurfacing, and restoration (3R) and reconstruction projects that have been programmed outside the context of the AASHTO plan initiative.

SECTION V

Description of Strategies

Objectives

The objectives for reducing the number of ROR fatality crashes are to

- Keep vehicles from encroaching on the roadside,
- Minimize the likelihood of crashing or overturning if the vehicle travels off the shoulder, and
- Reduce the severity of crashes that occur.

The ideal objective of good roadway design is to keep the vehicle in the travel lane. A secondary but related objective for a vehicle that inadvertently crosses the edgeline is to allow it to recover safely before going beyond the shoulder (if present) or back onto the roadside. Motorists will not purposely move onto the shoulder unless they need to pull over to slow or stop their vehicle. However, errant vehicles will cross over onto the shoulder and then the roadside, ending in an ROR crash. The reasons for inadvertent roadside encroachments are varied and include avoiding a vehicle, object, or animal in the travel lane; inattentive driving due to distraction, fatigue, sleep, or drugs; the effects of weather on pavement conditions; and traveling too fast through a curve. Several roadway design factors can also increase the probability that a driver error will become an ROR crash: travel lanes that are too narrow, substandard curves, and unforgiving shoulders and roadsides. Specific strategies can be applied to deal with ROR crashes caused by these factors. If a motorist travels onto the roadside, the probability of a crash depends to some extent on the speed of the vehicle and the driver's experience and capabilities. However, for normal travel on higher-speed roads, the crash probability, and primarily its severity, depends more upon roadside features, such as the presence and location of fixed objects, shoulder drop-off, sideslopes, ditches, and trees. If the roadside is fairly flat without objects and the soil can support the vehicle tires, the probability of a serious crash is minimal (and in many cases the driver fully recovers and there is no reported ROR crash). Conversely, when there is a continuous line of different types of objects and features or when the soil produces "vehicle tripping," the probability of a serious crash is high. Therefore, there are strategies directed at reducing the number and density of possible hazardous roadside features or the proximity of these features to the traveled way.

The final objective, reducing the severity of the crash, can be met by changes in the design of roadside features (e.g., making roadside hardware more forgiving or modifying sideslopes to prevent rollovers) and by changes in the vehicle (e.g., better restraint systems or improved side protection) or by increased occupant use of available restraints. A combination of strategies appears appropriate, with increased use of restraints providing the greatest benefit. This discussion focuses on roadway-related improvements.

Exhibit V-1 lists the objectives and several related strategies to reduce the consequences of ROR crashes. Details of these strategies are covered below. This is not a comprehensive listing of all possible strategies to reduce ROR crashes. For example, roadway design or rehabilitation strategies (such as building wide lanes or adding lane width on entire systems or subsystems) or the use of positive guidance principles in new roadway design can clearly affect ROR crashes. However, these strategies are most likely used in the design phase for new facilities or rehabilitation of long sections of roadways and are often high-cost improvements. AASHTO has chosen to concentrate efforts in this guide on lower-cost strategies that can be implemented relatively quickly, including strategies that can be applied to "spots" on the roadway (e.g., lane widening on hazardous curves). With few exceptions, it is these lower-cost, quickly implementable strategies that are covered below.

EXHIBIT V-1
Emphasis Area Objectives and Strategies

Objectives	Strategies
15.1 A—Keep vehicles from encroaching on the roadside	15.1 A1—Install shoulder rumble strips (T) 15.1 A2—Install edgeline "profile marking," edgeline rumble strips or modified shoulder rumble strips on section with narrow or no paved shoulders (E) 15.1 A3—Install midlane rumble strips (E) 15.1 A4—Provide enhanced shoulder or in-lane delineation and marking for sharp curves (P/T/E) 15.1 A5—Provide improved highway geometry for horizontal curves (P) 15.1 A6—Provide enhanced pavement markings (T) 15.1 A7—Provide skid-resistant pavement surfaces 15.1 A8—Apply shoulder treatments • Eliminate shoulder drop-offs (E) • Widen and/or pave shoulders (P)
15.1 B—Minimize the likelihood of crashing into an object or overturning if the vehicle travels beyond the edge of the shoulder	15.1 B1—Design safer slopes and ditches to prevent rollovers (see "Improving Roadsides," page V-36) (P) 15.1 B2—Remove/relocate objects in hazardous locations (see "Improving Roadsides," page V-36) (P) 15.1 B3—Delineate trees or utility poles with retroreflective tape (E)
15.1 C—Reduce the severity of the crash	15.1 C1—Improve design of roadside hardware (e.g., bridge rails) (see "Improving Roadsides," page V-36) (T) 15.1 C2—Improve design and application of barrier and attenuation systems (see "Improving Roadsides," page V-36) (T)

Note: The following page explains (T), (E), and (P) demarcations.

Types of Strategies

The strategies in this ROR guide were identified from a number of sources, including the literature, contact with state and local agencies throughout the United States, and federal programs. Some of the strategies are widely used, while others are primarily an experimental idea of a single individual or agency. Some have been subjected to well-designed evaluations to prove their effectiveness. However, it was found that many strategies, including some that are widely used, have not been adequately evaluated.

The implication of the widely varying experience with these strategies, as well as of the range of knowledge about their effectiveness, is that the reader should be prepared to exercise caution in many cases before adopting a particular strategy for implementation. To help the reader, the strategies have been classified into three types, each identified by a letter:

- Tried (T)—Those strategies that have been implemented in a number of locations and that may even be accepted as standards or standard approaches, but for which there have not been found valid evaluations. These strategies—while in frequent, or even general, use—should be applied with caution, carefully considering the attributes cited in the guide and relating them to the specific conditions for which they are being considered. Implementation can proceed with some degree of assurance that there is not likely to be a negative impact on safety and very likely to be a positive one. It is intended that as the experiences of implementation of these strategies continue under the AASHTO Strategic Highway Safety Plan initiative, appropriate evaluations will be conducted so that effectiveness information can be accumulated to provide better estimating power for the user and the strategy can be upgraded to a "proven" (P) one.
- Experimental (E)—Those strategies that have been suggested and that at least one agency has considered sufficiently promising to try on a small scale in at least one location. These strategies should only be considered after the others have proven not to be appropriate or feasible. Even where they are considered, their implementation should initially occur using a very controlled and limited pilot study that includes a properly designed evaluation component. Only after careful testing and evaluations show the strategy to be effective should broader implementation be considered. It is intended that as the experiences of such pilot tests are accumulated from various state and local agencies, the aggregate experience can be used to further detail the attributes of this type of strategy so that it can be upgraded to a "proven" (P) one.
- Proven (P)—Those strategies that have been used in one or more locations and for which properly designed evaluations have been conducted that show it to be effective. These strategies may be employed with a good degree of confidence, but any application can lead to results that vary significantly from those found in previous evaluations. The attributes of the strategies that are provided will help the user judge which strategy is the most appropriate for the particular situation.

Targeting the Objectives

The first objective, keeping vehicles on the roadway, addresses various means of communicating with the driver. However, other strategies for fulfilling this objective target highway design features that could contribute to a crash (e.g., shoulder drop-offs and pavement with low skid resistance).

The second objective, minimizing the likelihood of an ROR crash given an encroachment, uses strategies that focus on the highway, with more concentration devoted to nonfreeway facilities and especially to higher-speed rural roads. Higher-design facilities such as freeways typically have fairly wide shoulders and more forgiving, wider clear zones.

Features within the clear zone are shielded from traffic by barriers and crash attenuation devices. However, there is an extensive system of mostly two-lane, rural, high-speed roadways that do not have these features. The crash data presented earlier show that this system is particularly vulnerable to ROR crashes and should be targeted for appropriate measures. Vehicle design, restraint features and usage, and design of roadside features are all valid targets associated with the third objective, reducing the severity of ROR crashes.

The largest part of the ROR crash problem is on two-lane, rural, high-speed roads. Therefore, most of the emphasis in the following discussion of strategies is oriented to this road class. This is not to imply that there is no ROR problem on suburban or urban streets. Many of the strategies included in this guide could be implemented on such roadways, since many suburban roadways have "near-rural" designs. However, the strategy may well be restricted on these streets and roads by restricted right-of-way and preexisting roadside conditions (e.g., curbs and sidewalks, utility poles adjacent to the travel lane, and bicycle paths) that will prevent implementation of strategies oriented to the "shoulder" or "roadside." The urban safety engineer will have to rely on strategies related to keeping the driver in the travel lane (e.g., enhanced pavement markings, roadside delineation, and skid-resistant pavement).

There are also many miles of rural two-lane roads that carry significant traffic at fairly high speeds that are also characterized by very limited rights-of-way. These conditions limit the range of strategy choices. Some *experimental* strategies (see definition above) have been included that are oriented to these types of roadways (e.g., profile marking, edgeline rumble strips, modified rumble strips for narrow shoulders, various pavement markings at horizontal curves, and the delineation of utility poles and trees). These same strategies might be considered for urban and suburban streets. As is emphasized below, these strategies are considered experimental, since no valid effectiveness evaluations have been found. The user should not substitute these strategies for the "proven" strategies when the latter can be implemented.

Related Strategies for Creating a Truly Comprehensive Approach

The strategies listed above and described in detail below are those considered unique to this emphasis area. However, to create a truly comprehensive approach to the highway safety problems associated with this emphasis area, five types of related strategies should be included as candidates in any program planning process:

- Public Information and Education (PI&E) Programs—Many highway safety programs can be effectively enhanced with a properly designed PI&E campaign. The traditional emphasis with PI&E campaigns in highway safety is to reach an audience across an entire jurisdiction or a significant part of it. However, there may be a reason to focus a PI&E campaign on a location-specific problem. While this is a relatively untried approach, as compared with areawide campaigns, use of roadside signs and other experimental methods may be tried on a pilot basis.

  Within this guide, where the application of PI&E campaigns is deemed appropriate, it is usually in support of some other strategy. In such a case, the description for that strategy will suggest this possibility (see the attribute area for each strategy entitled "Associated

Needs”). In some cases, specialized PI&E campaigns are deemed unique for the emphasis area and are detailed in the guide. In the future, additional guides may exclusively address the details regarding PI&E strategy design and implementation.

- Enforcement of Traffic Laws—Well-designed and -operated law enforcement programs can have a significant effect on highway safety. It is well established, for instance, that an effective way to reduce crashes (and their severity) is to have jurisdictionwide programs that enforce an effective law against driving under the influence (DUI) or driving without seat belts. When that law is vigorously enforced with well-trained officers, the frequency and severity of highway crashes can be significantly reduced. This should be an important element in any comprehensive highway safety program.

  Enforcement programs, by nature, are conducted at specific locations. The effect (e.g., lower speeds, greater use of seat belts, and reduced impaired driving) may occur at or near the specific location where the enforcement is applied. This effect can often be enhanced by coordinating the effort with an appropriate PI&E program. However, in many cases (e.g., speeding and seat belt usage), the impact is areawide or jurisdictionwide. The effect can be either positive (i.e., the desired reductions occur over a greater part of the system) or negative (i.e., the problem moves to another location as road users move to new routes where enforcement is not applied). Where it is not clear how the enforcement effort may impact behavior or where an innovative and untried method could be used, a pilot program is recommended. Within this guide, where the application of enforcement programs is deemed appropriate, it is often in support of some other strategy. Many of those strategies may be targeted at either a whole system or a specific location. In such cases, the description for that strategy will suggest this possibility (see the attribute area for each strategy entitled “Associated Needs for, or in Relation to, Support Services”). In some cases, where an enforcement program is deemed unique for the emphasis area, the strategy will be detailed. As additional guides are completed, they may detail the design and implementation of enforcement strategies.

- Strategies to Improve Emergency Medical and Trauma System Services—Treatment of injured parties at highway crashes can significantly impact the level of severity and length of time during which an individual spends treatment. This is especially true when it comes to timely and appropriate treatment of severely injured persons. Thus, a basic part of a highway safety infrastructure is a well-based and comprehensive emergency care program. While the types of strategies included here are often thought of as simply support services, they can be critical to the success of a comprehensive highway safety program. Therefore, an effort should be made to determine whether there are improvements that can be made to this aspect of the system, especially for programs focused upon location-specific (e.g., corridors) or area-specific (e.g., rural areas) issues. Additional guides may detail the design and implementation of emergency medical system strategies.

- Strategies Directed at Improving the Safety Management System—The management of the highway safety system is foundational to success. There should be a sound organizational structure, as well as infrastructure of laws, policies, etc., to monitor, control, direct, and administer a comprehensive approach to highway safety. A comprehensive program should not be limited to one jurisdiction, such as a state department of transportation (DOT). Local agencies often must deal with most of the road system and its related safety problems and are more familiar with its problems. Additional guides may detail the design and implementation of strategies for improving safety management systems.

- Strategies that Are Detailed in Other Emphasis Area Guides—Any program targeted at the safety problem covered in this emphasis area should be created having given due consideration to the inclusion of other applicable strategies covered in the following guides:
  - Trees in Hazardous Locations,
  - Head-On Crashes,
  - Utility Pole Crashes (work in progress), and
  - Crashes on Horizontal Curves (work in progress).

Objective 15.1 A—Keep Vehicles from Encroaching on the Roadside

Strategy 15.1 A1—Shoulder Rumble Strips

General Description

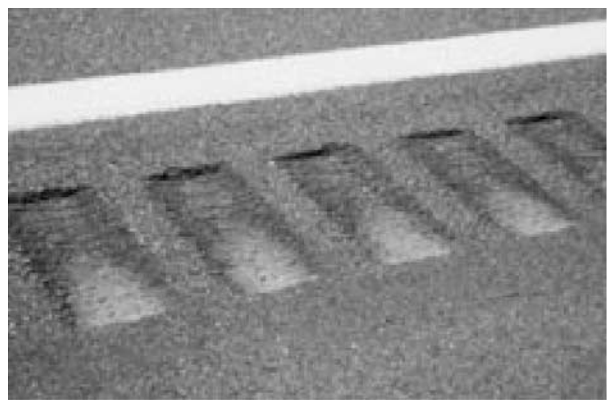


EXHIBIT V-2
Shoulder Rumble Strips

Shoulder rumble strips are crosswise grooves in the road shoulder (Exhibit V2). States have developed various design dimensions, but generally they are about 0.5 inches deep, spaced about 7 inches apart, and cut in groups of four or five. They can be rolled into hot asphalt or concrete as it is laid, or they can be milled in later. Vehicle tires passing over shoulder rumble strips produce a sudden rumbling sound and cause the vehicle to vibrate, thereby alerting inattentive, drowsy, or sleeping drivers of encroachment on the shoulder and possibly onto the roadside. Rumble strips have been used primarily on expressways and freeways, although some states install them on two-lane rural roads with a high number of single-vehicle crashes.

Many agencies have long used rumble strips on the roadway itself to alert drivers to unexpected or particularly important features ahead. Cross-lane rumble strips are commonly used in advance of stop signs on rural highways or in advance of construction zones. While the application of rumble strips on the shoulder is relatively new as an ROR safety strategy, there is considerable experience and information on design and construction, operational qualities, and the performance of shoulder rumble strips on freeways. Thus, this strategy is "proven"[1] for such freeways. Due to the current use in some states, but lack of effectiveness information, shoulder rumble strips are considered a "tried" strategy for two-lane roads.

Additional details concerning current practice with rumble strips can be found on the Federal Highway Administration's (FHWA's) "Rumble Strip Community of Practice" Web

[1] See explanation of ratings on page V-3.

page at the following address: http://safety.fhwa.dot.gov/programs/rumble.htm. This site provides definitions of types of rumble strips used, detailed construction drawings, effectiveness estimates, and interviews with users and other experts, among other information. Information and details describing, for example, the three major types of rumble strips (milled, rolled [or formed], and raised) are given on the FHWA Web page.

Shoulder rumble strips are compatible with other strategies designed to reduce the likelihood or severity of roadside encroachments and can sometimes be implemented in the same project effort with appropriate planning at little or no additional cost (e.g., inclusion of rumble strips in safety-based shoulder reconstruction or curve-flattening efforts).

EXHIBIT V-3
Strategy Attributes for Shoulder Rumble Strips

Technical Attributes	
Target	Drivers of errant vehicles, using sound and sensation to directly alert the individual of encroachment or pending encroachment.
Expected Effectiveness	On freeways, shoulder rumble strips have proven to be a very effective way to warn drivers that they are leaving or are about to leave the road. According to FHWA, several studies have estimated that rumble strips can reduce the rate of ROR crashes by 20 to 50 percent. Further statistics regarding effectiveness for specific programs are documented below. However, these crash reduction statistics apply to freeways. While this strategy is currently implemented on nonfreeways by a number of jurisdictions, there is little information on the safety effectiveness of shoulder rumble strips on these roads. Further evaluation is clearly needed. Care should be taken in extrapolating freeway application experience to the two-lane highway system. On one hand, the rumble strips could be less effective since freeway design provides the errant driver with a wider clear zone in which to recover after hitting the strip. On many two-lane roads, the clear zone—often just a shoulder—is much more limited. In such cases, the driver has little opportunity to recover even when given a warning. However, rumble strips could be more effective on two-lane roads for basically the same reason: since two-lane roads have much less clear zone and much more hazardous roadsides (less breakaway objects, more severe sideslopes, objects closer to roadway), a higher proportion of excursions from the travel lane may become crashes. Moreover, the quality of the roadway alignment is generally worse on two-lane versus freeway facilities, and hence the need for such warning to keep drivers on the road is greater. Similarly, most freeways commonly include full 12-foot lanes, while there are many high-speed two-lane rural highways with lane widths as narrow as 10 feet. Thus, if the shoulder rumble strips are effective, they could prevent more crashes per excursion. While it is not possible to determine which set of assumptions is correct, shoulder rumble strips should produce measurable benefits somewhat consistent with those demonstrated in studies for freeways. In the absence of such information, the following studies provide effectiveness estimates for shoulder rumble strips on freeways and expressways. The New York State Thruway Authority (NYSTA) installed continuous milled-in shoulder rumble strips on all four shoulders of 485 roadway miles of thruway between 1992 and 1993. In its before/after evaluation, NYSTA used accident data provided by the state police assigned specifically to the toll road system. One year of before data (1991) and 1 year of after data (1997) were used for the study (Exhibit V-4). Only single-vehicle ROR crashes with certain "causes" were selected for the study because "it was believed that these specific run-off-road crashes were indicative of those that could be mitigated by the use of continuous shoulder rumble strips and correcting the

(*continued on next page*)

EXHIBIT V-3 (Continued)
Strategy Attributes for Shoulder Rumble Strips

	driver's behavior" (Perrillo, 1998). These causes included use of alcohol or drugs, driver inattention or inexperience, fatigue, illness, passenger distraction, and glare. Exhibit V-4 shows the reduction of crashes observed from 1991 to 1997. In a companion study by the New York DOT of 300 miles of additional nonthruway mileage, the reduction of ROR crashes, resulting from driver inattention, fatigue, and drowsiness, is reported to be 65 percent with the installation of milled-in shoulder rumble strips (New York State DOT, 1998). The initial study also developed benefit-cost ratios for the rumble-strip installation program. The cost of installation was $3,995 per roadway mile for continuous rumble strips on all four paved shoulders. Hence, the total cost of installation for 485 roadway miles was more than $1.9 million. Using the cost of highway crashes as defined by the FHWA and assuming a yearly accident savings as summarized in Exhibit V-4, the total accident savings per year is $58.9 million. Assuming that the shoulder rumble strips have a maintenance-free lifespan of 6 years and that the yearly accident savings is as calculated by comparing 1991 data and 1997 data, the benefit-cost ratio equaled 186. Such a high benefit-cost ratio indicated shoulder rumble strips to be an extremely beneficial treatment. In a recent study, the FHWA used data extracted from the Highway Safety Information System (HSIS) to study continuous rolled-in shoulder rumble strips installed on 284 miles of rural and urban freeway in Illinois and 122 miles in California. Where possible, the author used two different before/after methodologies, one involving "yoked" or paired comparison sites and one involving a nonpaired comparison group. In contrast with the more restricted group of accident types in the New York Thruway study, all single-vehicle ROR crashes were studied here. The Illinois data indicated an 18.3-percent reduction in single-vehicle ROR crashes on all freeways combined and a 13-percent reduction in single-vehicle ROR injury crashes. Both reductions were statistically significant. Comparable reductions on Illinois rural freeways were 21.1 percent for single-vehicle ROR crashes and 7.3 percent for injury crashes. California data for the combined urban and rural freeways indicated a 7.3-percent reduction in single-vehicle ROR crashes, but the finding was not statistically significant. It is difficult to specify a crash reduction factor for shoulder rumble strips on rural two-lane roads. There have been no effectiveness studies on such roads, and the effect could be logically hypothesized to be either less than or greater than on freeways. There are also differences in the estimated effects on freeways, with crash decreases ranging from 7 percent of total single-vehicle crashes to 90 percent of single-vehicle crashes related to driver inattention or fatigue. Part of this wide range is the result of differing crash types being studied (i.e., the more selective the crash type, as in the New York studies, the greater the effect will be). Part may also stem from effectiveness differences between milled-in rumble strips (in the New York studies) and rolled-in strips (in the FHWA study). However, no study has been identified that specifically addresses this potential difference in effectiveness. A "best guess" at this time might be a 20- to 30-percent reduction in single-vehicle ROR crashes on rural freeways, with less effect on urban freeways. For the reasons cited above, it is difficult to define even a "best guess" for two-lane rural roads. With no specific study on these roads, one might assume a similar effect to that seen on rural freeways—a 20- to 30-percent reduction in single-vehicle ROR crashes.
Keys to Success	If the use of shoulder rumble strips on freeways continues to be as effective as studies indicate, states should readily adopt them on these roads. The key to increased installation on two-lane and other nonfreeway roads would appear to be further proof of effectiveness on these roads and resolution of incompatibility issues such as bicycle use, noise, etc. (See "Potential Difficulties" below.) The use of prototype studies is suggested to establish the validity of extending this strategy to nonfreeway facilities. It will also be important to identify appropriate road sections—sites where ROR crashes are a problem and continuous shoulder rumble strips can be installed.

EXHIBIT V-3 (Continued)
Strategy Attributes for Shoulder Rumble Strips

Potential Difficulties	Incompatibilities may exist between shoulder rumble strips and bicycle use. Since the transportation community encourages increased bicycle use, this may become a serious issue. In a recent Draft Technical Advisory on Roadway Shoulder Rumble Strips, FHWA has noted its full support of AASHTO's position, as stated in the 1999 AASHTO Guide for the Development of Bicycle Facilities, that Rumble strips or raised pavement markers . . . are not recommended where shoulders are used by bicyclists unless there is a minimum clear path of 0.3 m (1 foot) from the rumble strip to the traveled way, 1.2 m (4 feet) from the rumble strip to the outside edge of paved shoulder, or 1.5 m (5 feet) to adjacent guardrail, curb or other obstacle. (Draft Technical Advisory on Roadway Shoulder Rumble Strips) In that same advisory, the FHWA describes current state efforts to develop bicycle-friendly rumble strip programs and stresses the need for states to regularly sweep shoulders to remove debris where rumble strips and bicycles coincide in order to allow the bicyclists to use the outer rather than inner part of the paved shoulder. It is also noted that the Association of Pedestrian and Bicycle Professionals (APBP) has commented on these guidelines (see http://www.apbp.org/). Key suggestions for locations with bike traffic include only using rumble strips on two-lane roads where there is a significant, demonstrated crash problem (rather than a systemwide approach), minimizing the depth of the cut to 3/8 inch, preferably retaining 8 feet of clear paved shoulder outside the rumble strip, installing the strip at or under the edgeline rather than leaving the 1-foot "no man's land" between the edgeline and rumble strip, using 12-inch-wide strips with gaps, and no installation of rumble strips where there will be 4 feet or less of clear paved shoulder after installation without "overwhelming justification" and without warning signs to bicyclists. In its early use of rumble strips, Pennsylvania would only use raised (edgeline) rumble strips where there was at least 4 feet of paved shoulder in order to accommodate bicycle use. The state required a minimum of 4 feet of paved shoulder for shoulder rumble strips and preferred 6 to 8 feet. Because of these concerns, Pennsylvania has developed a design to make shoulder rumble strips "bicycle-tolerable." Working for the Pennsylvania DOT, the Pennsylvania Transportation Institute researched alternative designs to alert motorists without being disruptive to bicyclists. The resulting design, which is used on shoulders at least 6 feet wide, is a 3⁄8-inch-deep cut that is 5 inches wide with a 7-inch space between cuts. The rumble strips begin 6 inches off the edge of the pavement. The Transportation Institute also recommended a similar pattern, except with a 6-inch space between cuts for lower-speed roads. Research in Pennsylvania continues on an appropriate design for roadways with narrower shoulders (2 to 4 feet). (See Appendix 1 for detailed drawings.) Due to similar concerns, California DOT (Caltrans) tested the vibration, noise, and subjective comfort levels of 11 different rumble strip configurations using passenger cars, trucks, volunteer bicyclists and State Highway Patrol motorcyclists. Based upon a combination of results from the different tests, Caltrans adopted new standard rolled-in and milled-in rumble-strip designs for routes with bicycle usage. Where the shoulder is less than 5 feet wide, the policy allows for the use of raised/inverted profile thermoplastic traffic strips as the edgeline. See Exhibit V-5. Note that a similar raised edgeline design was modified in Great Britain due to bicycle and motorcycle concerns. The raised ribs in the final design are approximately 1/4 inch high. Details can be found at http://www.roads.dft.gov.uk/roadnetwork/ditm/tal/signs/02_95/index.htm. Of course, discouraging bicycle use on roadways prone to ROR crashes may be the appropriate thing to do (or providing safer, separated bicycle facilities within the same general corridor). To the extent that shoulder rumble strips

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EXHIBIT V-3 (Continued)
Strategy Attributes for Shoulder Rumble Strips

	would be used in a site-specific versus systemwide basis, this apparent conflict may be manageable. At least one state noted that motorcyclists may not be able to recover as well from riding along a rumble strip as from a normal paved shoulder. However, testing by Caltrans involving a very small sample of four state highway patrol motorcyclists indicated that the motorcyclists had no problems traversing any of the designs tested. Other potential pitfalls include complications with snow removal, shoulder maintenance requirements, and noise. With respect to adverse weather, ice and snow can collect in rumble strips. When the trapped water freezes, icy conditions may occur. However, the drainage designed for shoulders, as well as the speed, turbulence, and vibrations from passing vehicles, tends to knock the ice from the rumble strips. Continuous shoulder rumble strips also have proven to be an asset to truck drivers during inclement weather. The shoulder rumble strips aid in determining the edge of the roadway when low visibility makes it difficult to see painted roadway edges and markings. (Note, however, that North Carolina has found that the raised/inverted profile edgelines do not tolerate snowplowing.) With respect to maintenance, Pennsylvania has not noted any additional maintenance required for the rumble strips installed on interstates with shoulders in good condition. Neither Massachusetts nor New York has noted any degradation over the past 3 years. Indeed, in some user states, rumble strips have been shown to help snowplows find the edge of the travel lanes. While some states have expressed a concern that the installation of rumble strips might lead to pavement deterioration, the FHWA “Rumble Strip Community of Practice” Web page indicates that this does not occur with proper installation. Finally, with respect to degradation, Kansas is changing its rumble strip policy, which allowed rolled-in strips, to one requiring milled-in strips. This change is due to Kansas’s observation that rolled-in strips have a tendency to “heal over” and reduce effectiveness over time. There have been reports of noise complaints where shoulder rumble strips have been installed. New installations should acknowledge this concern and make provisions where necessary. Implementing a program of rumble strips systemwide should consider local sensitivities to maintain support for such a program. Finally, there is not a crash-proven rumble strip design for two-lane roads without paved shoulders or with very narrow paved shoulders (e.g., 2 feet wide). This is a significant problem for some state agencies and many county and local agencies where most or all two-lane roads do not have paved shoulders. It is possible that the effectiveness of shoulder rumble strips may well be lessened from freeway experience, by poor or narrow shoulders that exist on many two-lane highways, so that even an “alerted” motorist might not be able to safely recover. However, given the numbers of such miles in the United States, there is clearly a need to test some potential designs. (See sections below concerning possible experimental strategies.)
Appropriate Measures and Data	*Process measures* of program effectiveness would include the *number of miles of road* or *the number of hazardous locations* where rumble strips are installed. *Impact measures* include *the number of ROR crashes reduced* at these locations and *the changes in total crashes*. If possible, the impact measure should include potential “crash migration” (i.e., crashes occurring on downstream sections where rumble strips have not been applied, but where drowsy drivers may still be on the road) effects on adjacent roadways. The advent of low-cost vehicle-sensing and recording devices might allow for the use of a *surrogate measure* based upon the *number of encroachments onto the shoulder* over a specific section of road (e.g., a curve). In addition to process and crash data, the agency should also collect information on acceptance by the public and by bicyclists and on any adverse noise problems for adjacent properties.

EXHIBIT V-3 (Continued)
Strategy Attributes for Shoulder Rumble Strips

Associated Needs	There have been a few reports of people who mistook the sounds produced by the rumble strips as car trouble. A public information or education campaign, as well as standard installation, should eliminate such misinterpretations. However, current moves to standardized use on freeways may provide the most effective public training.

Organizational and Institutional Attributes

Organizational, Institutional, and Policy Issues	First, if the agency does not have a design policy for rumble strips that can be retrofitted to shoulders, one may need to be developed. Additionally, a policy regarding the types of two-lane road sections where placement is acceptable may be necessary. While many states have established specific design and placement policies for shoulder rumble strips on freeways and other access-controlled facilities, specific criteria for two-lane or other nonfreeway roads were much more limited. For example, Minnesota policy states that “Rumble strips can also be placed on the shoulders of two-lane roads at the discretion of the District.” Since 1991, the Kansas DOT has had a policy requiring shoulder rumble strips to be included on all reconstruction or new construction projects with a full width (8- to 10-foot) shoulder. Such strips were also required if full-width shoulders were being overlaid with a minimum of 1 inch of asphalt. This policy primarily pertains to freeways and expressways since few two-lane rural roads have full-width shoulders. However, Kansas is installing the rumble strips on its “Super-Two” sections—sections with 12-foot lanes and full-width shoulders. Finally, rolled-in strips on asphalt pavements tend to deform over time, thus reducing the size of the cuts and lessening their effectiveness. Due to these problems with “healing” rolled-in strips, Kansas is now considering a revision of this policy, which would mandate milled-in rumble strips. Review of freeway-related policies from Connecticut, New Hampshire, New Jersey, Massachusetts, Maine, and Minnesota indicate that factors to be considered in such policies include bicycle accommodation/routes, minimum shoulder width where allowable, offset from edgeline, placement on or near bridge decks, use at intersections, speed limits, and other factors. Second, while this strategy is implemented by the state DOT, there is a clear need for the inclusion of bicycle transportation offices or groups to be involved early in the planning process for treatment of nonfreeways.
Issues Affecting Implementation Time	Shoulder rumble strip programs can be implemented quickly, certainly within a year of an agency deciding to proceed. They can be implemented as components of both new construction and rehabilitation projects.
Costs Involved	Due to increased installation and technological advances, the cost of continuous shoulder rumble strips has decreased over the years. For instance, in 1990, the New York DOT reported paying $6.18 per linear meter compared with $0.49 per linear meter in 1998. Specific cost of installation on the New York Thruway was reported to be $3,995 per roadway mile for rumble strips on all four shoulders. The cost includes milling in the rumble strips, sweeping and discarding excess asphalt, and maintaining and protecting traffic. The Pennsylvania DOT reports an average cost of $0.25 per foot or $2,640 per mile for the installation of milled-in rumble strips on the shoulders on both sides of two-lane roads. Incremental costs would be even less for rumble strips being implemented concurrently with reconstruction or resurfacing of a highway.
Training and Other Personnel Needs	There appear to be no special personnel needs for implementing this strategy. Either agency personnel or contractors could do the installation. The need for training will depend on whether the agency has been using retrofitted rumble strips on freeways or other roadways. If not, either agency personnel or contractor personnel will need to be trained in proper installation techniques.

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EXHIBIT V-3 (Continued)
Strategy Attributes for Shoulder Rumble Strips

Legislative Needs	There do not appear to be any special legislative needs.
Other Key Attributes	
	One benefit of shoulder rumble strips is that, unlike other safety measures whose effectiveness may decrease over time as their "novelty" wears off, rumble strips primarily affect only drowsy or other inattentive drivers. Concern has been expressed that if fatigue-related crashes are prevented on one section of roadway, the problem may be transferred to another section. While the FHWA attempted to examine this issue, no data have been found to support or dispel the theory. Such a possibility may be reduced by public education urging fatigued drivers (particularly those who ride over the rumble strips and recover their vehicle from running off the road) to stop and rest before continuing.

EXHIBIT V-4
Before and After Data for Selected Single-Vehicle ROR Crashes on the New York Thruway (Source: New York State Police)

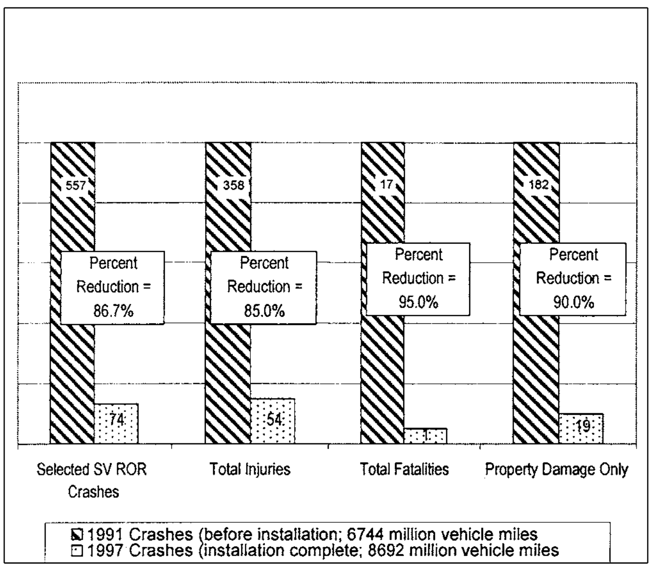
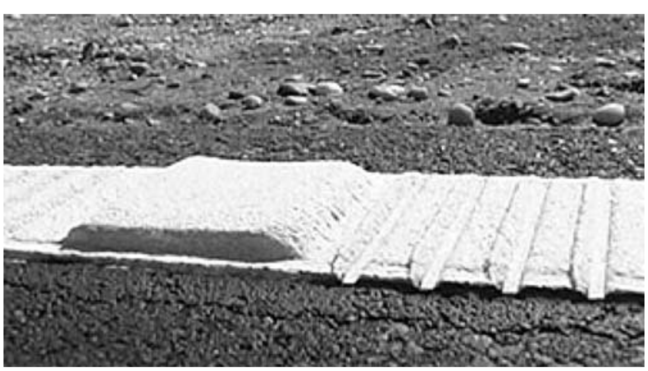


EXHIBIT V-5
California Raised/Inverted Profiled Thermoplastic Edgeline



Information on Agencies or Organizations Currently Implementing this Strategy

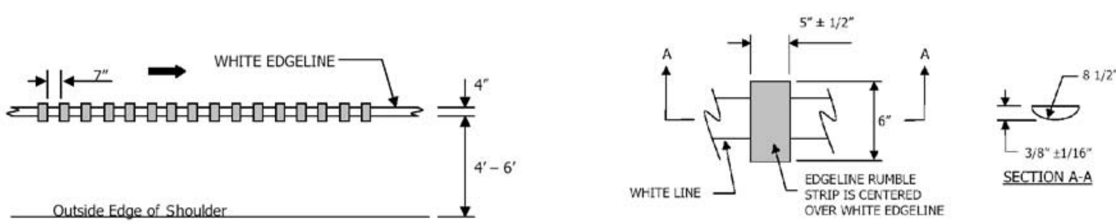
Almost all states have experience with shoulder rumble strips on interstates and other freeways. Some states are beginning to use them on two-lane roads. For example, as described in Appendix 2, Maryland has installed shoulder rumble strips on a limited number of miles of two-lane highways. Pennsylvania is currently installing "edgeline rumble strips" on the edgelines of two-lane roads with 4-foot shoulders (see Appendix 1). As noted above, Pennsylvania, California, and Colorado DOTs have developed a "bicycle-tolerable" rumble strip for use on such roads. As described in Appendix 3, Kansas is currently changing its rumble strip policy to move to milled-in strips only and has used shoulder rumble strips on limited sections of "Super Two" roadways (i.e., two-lane roads with wider lanes and full shoulders).

Strategy 15.1 A2—Rumble Strips for Roads with Narrow or Unpaved Shoulders (Experimental Treatment)

Most agencies require fairly wide paved shoulders before rumble strips will be installed (e.g., at least 4 feet in Pennsylvania, and 6 to 8 feet preferably in Pennsylvania and other states). However, state and local agencies are often faced with locations having high ROR crashes and either no paved shoulder or a very limited paved shoulder. In many cases, these roads are also characterized by lower average daily traffic (ADT) and limited right-of-way. Thus, widening and paving a shoulder for use with rumble strips may not be a viable option.

Three *experimental*[2] treatments that might be considered include a milled-in "edgeline" rumble strip design placed on the edgeline (see Exhibit V-6), the above-noted raised/inverted profile thermoplastic profile marker (edgeline) that was tested by California for use on shoulders of less than 5 feet in width, and a modified "standard" rumble strip design for use on narrow shoulders (e.g., 2-foot paved shoulders).

EXHIBIT V-6
Typical Drawing Detail for Milled Edgeline Rumble Strips for Noninterstate and Nonexpressway Use on Roadways (Source: Pennsylvania DOT)



North Carolina tested the raised/inverted profile marking on a limited sample of about 40 to 50 miles of two-lane rural U.S. routes, but has not completed any effectiveness evaluation (Appendix 4). Pennsylvania is pilot testing the milled-in edgeline rumble strip on sections with 4-foot paved shoulders and hopes to move to narrower shoulders in the future. Since this design is on the edgeline, it could be tested on roadways with no paved shoulders. As shown in Exhibit V-6 above, the Pennsylvania milled-in design is approximately 7 inches

[2] See explanation of ratings on page V-3.

apart, 5 inches wide, 0.25 inches deep, and the width of the edgeline (see Appendix 1 for contact information).

North Carolina has also initiated a test program on a 9-mile section of rural two-lane highway with narrow (i.e., 2-foot) paved shoulders. The rumble strip design being used is a modification of the "standard" milled-in design used in North Carolina. The 7-inch-wide milled cuts are ⅝ inches deep, are separated by 5 inches of unmilled pavement, and extend 12 inches out from the edgeline (Appendix 4).

A major potential problem with the raised/inverted profile edgeline is durability in areas where snowplowing is done. North Carolina has experienced this problem in its pilot test and is no longer using this design in areas where snowfall is expected. Local residents have also complained of noise problems. The potential problems with the milled-in design for shoulders would be the same—possible (but not proven) complications with snow removal, shoulder maintenance requirements, and noise. If bicyclists regularly use these roads with narrow shoulders, the same concerns would exist.

Finally, these treatments have either not been tested or are being pilot tested at this point. They should not be used in place of other nonexperimental treatments and should be pilot tested and evaluated before widespread use. The effectiveness of these designs is unknown and may be well be lessened from the estimates in the previous section, since these sections have poor or narrow shoulders where even an "alerted" motorist might not be able to safely recover. However, given the number of miles of such roads in the United States where ROR crashes do occur, pilot testing of these designs is clearly warranted.

Strategy 15.1 A3—Midlane Rumble Strips (Experimental Treatment)

Midlane rumble strips are an *experimental*[3] treatment that might be pilot tested on roadways with no shoulders or narrow paved shoulders. (This treatment is untested at this point, should not be used in place of other nonexperimental treatments, and should be pilot tested and evaluated before widespread use.) Midlane rumble strips appear similar to shoulder rumble strips—crosswise grooves in the pavement, perhaps 0.5 inch deep, spaced about 4 inches apart, and cut in groups of four or five, *but installed in the center of the travel lane* versus on the edge of the shoulder. They can be rolled into hot asphalt or concrete as it is laid, or they can be milled in later. Details of shoulder rumble strips that could be considered for use midlane can be found on the FHWA rumble strip Web site at http://safety.fhwa.dot.gov/programs/rumble.htm.

Midlane rumble strips have the same intent as shoulder rumble strips. When the driver tracks a path leading to an encroachment on the roadside, the rumble strip acts on the inside tire (as opposed to the outside tire for shoulder rumble strips) to alert the driver. Unlike shoulder rumble strips, midlane rumble strips would be compatible with bicycle use, but may be incompatible with motorcycle use. In addition, there is fear among some designers and safety engineers that the strip in the center of the lane may become an additional driver distraction. Since midlane rumble strips should also affect head-on crashes, they might be considered at locations with both an ROR and a head-on crash problem.

[3] See explanation of ratings on page V-3.

The major potential difficulty with this strategy would be public acceptance, particularly with motorcyclists. The California DOT had four police motorcyclists test steering and recovery capabilities on 11 different shoulder rumble strip configurations and found no problems. However, further testing by nonprofessional riders is needed. Midlane strips could have other adverse effects, including potential snow removal problems, additional lane maintenance costs, and noise. Snow removal and maintenance problems have not been found to be a major issue for shoulder rumbles strips (see discussion in "Potential Difficulties" for shoulder rumble strips in Exhibit V-3).

Clearly this is a new, experimental intervention that will give a different look and feel to the roadway. Thus, a public information/education program is necessary to explain the benefits of the treatment, and public and motorcycle groups should be included in early planning activities.

In summary, while there are potential problems with this experimental treatment, if successfully tested, evaluated, and documented, it could provide a new tool for preventing ROR crashes on roadways where shoulder rumble strips cannot be installed, and the treatment might provide additional benefits in terms of reduction of head-on crashes.

Strategy 15.1 A4—Enhanced Delineation of Sharp Curves

General Description

ROR crash risk on rural two-lane roads increases with degree of curvature. Given the knowledge that sharper curves result in more shoulder encroachments and crashes and given that the flattening of the curve may be too costly, the concept here is to provide drivers with a clear picture of the sharpness of the curve prior to curve entry, to "warn" drivers of the hazardous situation, or to cause drivers to decrease their speed prior to entering the curve (Exhibit V-7). The first and second could be done through improved shoulder delineation (e.g., chevrons or high-intensity chevrons, large arrow signs, or delineators on guardrails); by improved curve warning signs (e.g., warning signs with flashing beacons); or innovative on-pavement markings (e.g., warning arrows on the pavement prior to the curve). The speed-reduction treatment would also involve innovative pavement markings that create a sense of "danger" (e.g., transverse lines with decreasing spacing or edgelines that give the appearance of a narrowing lane width). As a last resort, one state installed transverse rumble strips on the traveled way prior to the hazardous curve.

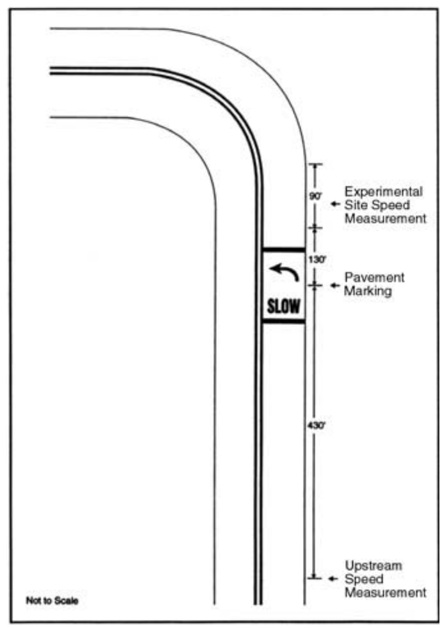


EXHIBIT V-7
Enhanced Delineation of Sharp Curves

The goal is to produce a delineation system "that will produce uniform speeds and placement throughout the curve. It will negate the need for excessive braking in the curve, and the absence of a change in speed within the curve is a prime indication that the driver has correctly perceived road curvature. Also, it will minimize encroachments on the centerline and edgeline and thereby leave most of the vehicles driving in the center of the lane" (Jennings and Demetsky, 1983).

Strategy Attributes

As noted, this strategy involves some type of delineation or pavement marking aimed at providing precurve information or warning to the driver. The proposed treatments are low-cost, currently available devices and markings. Since the speed of a vehicle entering a curve is related to the speed of the vehicle before the curve, it is important to reduce speed on tangent sections prior to the curve. All treatments suggested here are oriented to that goal. Speed reduction should result from better driver judgment, from driver recognition of and reaction to a well-designed and effective warning, or from driver reaction to a "heightened danger" situation (e.g., pavement markings that create the optical illusion of acceleration even at a constant speed).

As noted below, the shoulder delineation treatments are considered "proven"[4] strategies in terms of crash reduction, while the on-pavement treatments, aimed at warning the driver or increasing the visible level of hazard, have been "tried" by states, but are not considered "proven" in terms of crash reductions. This series of treatments is compatible with other ROR and head-on crash treatments and should not adversely affect other road users such as bicyclists or motorcyclists.

EXHIBIT V-8
Strategy Attributes for Delineation of Sharp Curves

Technical Attributes	
Target	Drivers of vehicles entering potentially hazardous curves.
Expected Effectiveness	At least limited evaluations of all three types of devices have been conducted. Based on these studies, well-placed shoulder delineators are a proven crash-reducing strategy, at least for roads with average or higher designs. The on-pavement treatments aimed at warning the driver or providing an increased sense of hazard have been evaluated in terms of speed reduction, but not crash reduction. The positive findings with respect to speed reductions would place these treatments in the "tried" category. In a very well-designed early study of post-mounted delineators on rural two-lane curves, Foody and Taylor (1966) found them to reduce ROR crashes by 15 percent. In a more recent nonaccident study, the "curve following behavior" of drivers was studied before and after rural, two-lane curves were treated with different combinations of chevron signs, post-mounted delineation, and raised pavement markings. Vehicle speed and the placement of the vehicle in the lane were measured at 46 sites in Georgia and 5 in New Mexico. The results for nighttime hours show that vehicles moved away from the centerline when chevrons were used (i.e., closer to the edgeline) and even farther away when raised pavement markers were used. When post-mounted delineators were used, vehicle placement on right curves shifted toward the centerline (Zador et al., 1987). Contrasting findings for raised reflector posts were found in a Swedish study by Kallberg (1993). (Note that this study was not restricted to posts on curves.) The author concluded that "reflector posts on narrow, curvy, and hilly roads can significantly increase driving speeds and accidents in darkness." Specifically, reflector posts increased accidents on roads with relatively low geometric standards and 50-mph posted speed limits. Although the specific effects of reflector posts on the lateral

[4] See explanation of ratings on page V-3.

EXHIBIT V-8 (Continued)
Strategy Attributes for Delineation of Sharp Curves

position remain unclear, it is clear that the shift in lateral position (if there is a significant shift) is toward the edge of the road. This before and after study with control sites was conducted on roadway segments in Finland. The counterintuitive findings are supported by the human factors concept of selective visual degradation. This theory explains that reflector posts do not improve the driver's ability to detect potential hazards but do improve the driver's ability for orientation tasks. This may reduce the frequency of ROR collisions, but it also may increase speeds and therefore increase the severity of those ROR crashes that do occur. With respect to warning messages placed on the pavement, the Insurance Institute for Highway Safety (IIHS) conducted a study for a single, very sharp curve (~90°) on a suburban two-lane secondary road in Northern Virginia with a posted speed limit of 35 mph (Retting and Farmer, 1998). The pavement marking consisted of the word "SLOW" in 8-foot-high white letters, a white 8-foot-high left curve arrow, and an 18-inch-wide white line perpendicular to the road at the beginning and end of the text/symbol. Results were based on before/after changes in mean speed, 90th-percentile speed, and percentage of vehicles exceeding 35 mph, 40 mph, and 45 mph, as compared with similar data from a nearby comparison curve that was not treated. The pavement marking was associated with a decrease in vehicle speed of 6 percent overall and 7 percent during daytime and late night periods.

The same pavement marking was used in a 1999 study at six sites in Pennsylvania (Retting, 1999). A before/after study of effects on vehicle speeds showed that these pavement markings had little effect on the average speed and the 85th-percentile speed. However, the 95th-percentile speed was reduced significantly. This year, the marking will be implemented at 200 sites statewide, and IIHS will again evaluate the effect.

Evaluations of markings on the pavement to slow drivers by heightening "apparent danger" have been conducted for a number of years both in the United States and internationally. In a 1979 study for the Ohio DOT, the effects of yellow-bar pavement markings installed perpendicular to the direction of travel were studied. There were "reported reductions in traffic speeds, most notably high speeds" resulting from the pavement markings installed prior to curves (Retting and Farmer, 1998). In a somewhat limited 1980 before/after study of one particularly hazardous curve on a rural two-lane road in Meade County, Kentucky, the treatment involved transverse lines of reflective tape in an ever-tightening pattern designed to slow a vehicle from 55 mph to 35 mph before entering the curve. The pattern consisted of 30 stripes with a total pattern length of 810 feet, designed to give the illusion of acceleration unless the driver slowed down. Daytime mean speeds decreased from 41.3 mph to 33.9 mph immediately after installation. The mean speed increased slightly to 34.9 mph 6 months after installation. Nighttime mean speeds decreased from 40.5 mph to 35.1 mph immediately after installation and increased to 39.1 mph 6 months later. Average crashes per year decreased from 7.7 in the preceding 6 years to three crashes the year after installation. An estimated benefit-cost ratio of 45.9 was calculated, and the authors concluded that the treatment was more effective than signs alone and should be used at other curves where excessive speed is an accident factor (Agent, 1980). In a more recent study of "optical speed bars" at approaches to workzones, Meyer (2001) examined the issue of whether the decrease in speed from transverse striping was due to the perceptual effects of "increasing speed" with a pattern of stripes with gradually decreasing spacing or simply from the "warning" given. The author examined changes in speed as a free-flowing vehicle passed through three adjacent patterns when entering the work zone. The first pattern of transverse stripes were

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EXHIBIT V-8 (Continued)
Strategy Attributes for Delineation of Sharp Curves

	equally spaced, the second had ever-decreasing spacing, and the third were much wider stripes further apart. The data indicated speed reductions of 2 to 3 mph in the mean and 85th-percentile speeds for each of the patterns. The authors concluded that there was both “perceptual” and “warning” effects present. They drew no conclusions concerning which pattern was more effective. No crash data were analyzed. (The effects could differ between curves and work zones due to the driver’s judgment of “hazard” related to each.) In the earlier noted 1999 study of hazardous curve sites in Pennsylvania, transverse striping giving the illusion of acceleration was studied at several sites (Retting, 1999). Unlike the pavement arrow described above, the before/after study showed that these pavement markings had little effect on the average, 85th-percentile, or 95th-percentile speeds. Other pavement markings designed to increase the “apparent danger” of the curvature have also been evaluated, but not for rural, two-lane curve situations. In a 1998 study of three urban exit ramps in Virginia and one ramp in New York, an experimental pavement-marking scheme was investigated. The treatment narrowed the apparent lane width of the entry to the ramp curve and the ramp curve itself by using a gradual inward taper of existing edgeline or exit gore pavement markings. Studies of vehicle speeds at three of the four ramps indicated that the proportion of passenger vehicles exceeding the posted speed limit by more than 10 mph decreased 20 to 30 percent while speeds at the control site and upstream site remained the same or increased. Similar or slightly larger decreases in the percentage of large trucks exceeding the posted advisory speed by more than 5 mph were also found at the three sites where the equipment differentiated trucks from other vehicles (Retting et al., 2000). Finally, in the Netherlands and other European countries, an experimental use of edgelines has been tried on curves on narrow, low-volume roads where no edgeline was used in the past (Steyvers and Waard, 1997). Both a solid edgeline and a dashed edgeline caused vehicles to move away from the roadway edge when compared with a completely unmarked curve and with a curve with only a centerline. Driving speeds were slightly higher with the edgelines than with no lines, but slightly lower than when a centerline only was present. No crash analysis was conducted. While experimentation with such markings deserves further testing for these low-volume roads, current *Manual of Uniform Traffic Control Devices* (MUTCD) guidelines should be taken into consideration. In summary, there are few studies of the accident-related effects of these innovative treatments. Based upon the only crash studies available, post-mounted delineators might be expected to reduce ROR accidents on curves by approximately 15 percent. There is some question concerning the cost-effectiveness of continuous use of such devices on narrow, hilly, curvy roads with lower design standards. While warning symbols on the pavement prior to the curve, pavement markings “narrowing” the lane, and some transverse markings have been shown to reduce either mean speed or 95th-percentile speeds, there are no sound accident-based studies available. Thus, there continues to be a need for well-designed before/after pilot evaluations of crash experience, particularly for the pavement arrow and transverse striping treatments. The ongoing work in Pennsylvania should provide data on the arrow treatment.
Keys to Success	The development of design standards, based upon sound evaluation studies of these innovative markings, will be important. The ability of interested states to have access to evaluations in other states will be important to achieve acceptance.
Potential Difficulties	If these treatments are targeted to curves with actual or expected safety problems, there appear to be few potential difficulties. The Pennsylvania study of the initial transverse-bar sites noted some motorists driving on the shoulder to avoid the lines.

EXHIBIT V-8 (Continued)
Strategy Attributes for Delineation of Sharp Curves

	This could be a problem with unpaved shoulders (but it is less likely to occur without paved shoulders) and if the vehicle makes a sudden avoidance maneuver without reducing speed (which, again, may not be likely to occur). Pennsylvania also noted that some drivers (presumably commuters) would drive across the centerline or onto the shoulders to avoid transverse rumble strips. Further observations of traffic behavior at treatment sites are needed to determine whether these are true problems. An attribute of these special treatments is their uniqueness and hence high level of notice by drivers. Overuse of these treatments could lead to them losing this uniqueness and ultimate effectiveness. A final possible difficulty could include maintaining the pavement markings over time, given that they are being crossed by all traffic.
Appropriate Measures and Data	In the evaluation of these delineation programs, process measures would include the *number of hazardous curves treated.* *Impact measures* involve c*omparison of crash frequencies or rates (with the study appropriately designed) for the period before and after modifications*. A useful *surrogate measure* is the *change in speed for vehicles entering selected curves.* The advent of low-cost vehicle-sensing and recording devices might also allow for the use of a surrogate measure based upon *the number of encroachments onto the shoulder over a specific section of road* (e.g., a curve). Sufficient data/information will be needed to target these treatments to the correct location. The expert system software noted in "Personnel and Other Training Needs" below will help in this effort.
Associated Needs Services	The transverse strips and the pavement arrow are new treatments, and a relatively modest public information effort may be helpful in garnering support for the effort. If evidence is found that a significant proportion of motorists do drive on the shoulder to avoid the transverse lines (see "Potential Difficulties" above) and if this is found to be a safety problem, then a more significant public education effort will be needed for this treatment.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	These strategies will be implemented by state and local roadway agencies, and it does not appear that extra coordination with other agencies or groups is needed. If these treatments prove effective and are accepted by states for implementation, both specific design policies and placement policies will be needed. There are two different approaches in selecting delineators for a curve—local practice/policy and the MUTCD. Some of the "newer" pavement markings may have to be approved for use by FHWA as an experimental marking and then eventually adopted as an acceptable device for the MUTCD. However, until a standard is adopted, engineers should consider the effects of implementation inconsistencies on violating driver expectancies. Jennings and Demetsky (1983) investigated the three post-mounted delineator systems used in Virginia (chevron, special striped delineator [on post], and reflector on a post) for their effectiveness in controlling ROR crashes and to recommend a standard policy regarding use of the system. The resulting simplified policy states that for moderate curves (less than 7 degrees) where delineation is necessary, standard delineation should be used as recommended in the MUTCD. If the curve is greater than 7 degrees, chevrons give better delineation information and the spacing should be 2 to 3 times MUTCD recommendation. Other policy-related advice on delineation selection and placement can be found in expert system software developed by Zwahlen and Schnell (1995). (See "Training and Other Personnel Needs" below.)

(*continued on next page*)

EXHIBIT V-8 (Continued)
Strategy Attributes for Delineation of Sharp Curves

Issues Affecting Implementation Time	Since these devices are relatively inexpensive and standard, they could be implemented very quickly.
Costs Involved	The cost of the arrow pavement marker is about $2,000 per site (both directions) according to Pennsylvania's experience. Cost figures are not available for the other treatments. However, many states already use chevrons and other delineators in certain locations and may have cost figures of their own.
Training and Other Personnel Needs	There appear to be no special personnel needs for implementing this strategy. Either agency personnel or contractors would do the installation. Since there are various low-cost devices available to the engineer, there is need for some guidance on treatment design and placement. Zwahlen and Schnell (1995) developed a PC-based expert system software package that helps the designer choose an appropriate treatment and place the devices for maximum effect. This expert system considers devices such as flexible post delineators, object markers, and various size chevrons.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Information on Agencies or Organizations Currently Implementing this Strategy. As noted in the Effectiveness section, various states (e.g., Ohio, Virginia, Pennsylvania, Kentucky, and New York) have implemented limited installations of delineation and warning systems on curves. As documented in Appendix 1, the most recent of these is Pennsylvania, which is implementing and testing an innovative "pavement arrow" treatment on curve approaches.

Strategy 15.1 A5—Improved Highway Geometry for Horizontal Curves

General Description

Both ROR and head-on crashes are 1.5 to 4 times more likely to occur on curves than on tangents (Glennon et al., 1985). Zegeer et al. (1992) found that ROR crashes accounted for approximately 57 percent of the total crashes on a sample of over 11,000 curves on two-lane rural roads. While many of the other strategies in this section (e.g., rumble strips, shoulder treatments, wider clear zones, and skid-resistant pavement) would have equal or greater effectiveness on curves, crash reductions on curves can also be realized through tailored programs. Specifically, flattening curves (i.e., increasing the curve radius on two-lane rural roadways) has been found by Zegeer et al. to result in total curve crash reductions of up to 80 percent (i.e., flattening a 30-degree curve to 5 degrees). Thus, this strategy has been "proven"[5] to reduce crashes. Given the size of these potential reductions, an agency should clearly consider this as a treatment alternative for locations with significant ROR problems if right-of-way and funding are available. Since some head-on crashes are the result of vehicles

[5] See explanation of ratings on page V-3.

leaving the lane onto the shoulder area and then "overcorrecting" such that they cross into the opposing lane of travel and strike an oncoming vehicle, this treatment will also affect head-on crashes.

Flattening of curves involves reconstructing a road section and changing the alignment. This strategy is among the higher-cost alternatives of those considered. Reconstruction may also entail the environmental process and will often include right-of-way acquisition, both of which require substantial time. Therefore, curve flattening will usually be outside the timeframe adopted for the AASHTO Strategic Highway Safety Plan. However, the strategy is included here since it can result in significant crash savings, which is based upon extensive research. Curve flattening is compatible with other ROR strategies such as shoulder or midlane rumble strips, enhanced delineation, wider shoulders, and roadside improvements. These complementary modifications, when implemented together, can result in lower costs than if they were instituted at separate times.

EXHIBIT V-9
Strategy Attributes for Improved Highway Geometry for Horizontal Curves

Technical Attributes	
Target	While the treatment will target hazardous or potentially hazardous curves, the ultimate target is a vehicle that runs off the roadway on these curves.
Expected Effectiveness	Research by Zegeer et al. concerning this proven strategy provides estimates of the effect of curve flattening for various degrees of curve on two-lane rural roads (assuming that the central angle remains constant, and therefore the less-sharp treated curve will be longer and will "replace" some tangent in the initial layout). While more detailed estimates based upon type of curve (isolated versus nonisolated) and central angle (10 to 50 degrees) can be found in the full report, Exhibit V-10 indicates ranges of estimated percent reduction in total crashes for such treatments. For example, flattening a 30-degree curve to 10 degrees is predicted to reduce total crashes on the section by 61 to 67 percent. As noted in a recent review of this study and others, in work related to development of accident modification factors (AMFs) for use with FHWA's Interactive Highway Safety Design Model (Harwood et al., 2000), the estimates provided by this cross-sectional modeling effort would be expected to be less accurate than results from well-conducted before/after studies of actual curve flattening efforts. However, in the absence of such before/after studies in the literature, these results were accepted by the AMF expert panel. As noted below, curve flattening along two-lane roads may be combined with other safety strategies, including lane and shoulder widening, to provide an additional safety benefit. Indeed, in the process of realigning a curve, the agency would simultaneously provide a new roadside, which itself could provide a positive contribution to safety. Exhibit V-10 summarizes the reductions possible. For instance, assume a 20-foot roadway (with two 10-foot lanes) is to be widened to 22 feet of paved surface with 8-foot gravel shoulders. Exhibit V-11 indicates that these improvements would reduce curve accidents by 5 percent (due to lane widening of 1 foot per side) and 24 percent (due to widening unpaved shoulders by 8 feet per side). Note that the 5-percent and 24-percent accident reduction values cannot merely be added numerically. In summary, improving the geometry of horizontal curves can lead to significant crash reductions. These reductions change with the amount of curve flattening or widening, as shown in Exhibits V-10 and V-11. It is noted that these reductions are related to

(*continued on next page*)

EXHIBIT V-9 (Continued)
Strategy Attributes for Improved Highway Geometry for Horizontal Curves

	percentages of total crashes, rather than just to ROR crashes. While these treatments clearly affect ROR crashes, specific percentages for this subset are not presented in the study. The authors have noted that since curve flattening and widening affects almost all crash types, percent reduction in total crashes were considered to be the most appropriate measure.
Keys to Success	Since this is a relatively expensive treatment, one of the keys to success would appear to be targeting higher-hazard curves. Since ROR crashes increase with degree of curve, the targeting could be based primarily on prior crash history, curve degree, ADT, and speed limit.
Potential Difficulties	As noted above, the estimated effects of this treatment may be inflated due to the fact that they are not based on before/after studies. If the implementing agency “expects” effects this large for a given site or project and after-treatment experience is lower, the agency might curtail similar future efforts. However, given the size of the predicted effects, even if the true effects are much lower (e.g., half as high), this will still remain one of the most effective treatments for ROR crashes on curves.
Appropriate Measures and Data	In estimates of program implementation effectiveness, appropriate *process measures* would include the *number or proportion of “hazardous” curves that are flattened (perhaps categorized by the change in curvature).* The *impact measure* would be the *number of total crashes reduced* in the roadway section replaced by the new design. Targeting will require data on crash frequencies, degree of curve, length of curve, speed limit, and ADT. The factor most likely missing from computerized state files is the degree of curve.
Associated Needs	None identified. This is a standard treatment requiring no additional public information (except as part of any required environmental study).

Organizational and Institutional Attributes

Organizational, Institutional, and Policy Issues	This strategy will be implemented by the state DOT or local roadway agency, and it does not appear that coordination with other agencies will be needed. (The exception would be coordination with environmental agencies if new right-of-way were required.) Since curve flattening is a standard treatment, it would appear that new policy efforts are not required. However, a slightly different “institutional safety philosophy” may be needed here in comparison with other strategies in this guide. Given the higher cost of this treatment (but coupled with the higher potential payoff), the agency must be prepared to implement more than just low-cost improvements.
Issues Affecting Implementation Time	Given that the treatment will require some form of design and reconstruction and will usually require purchase of additional right-of-way (and thus involve the environmental process), this treatment period will be relatively long.
Costs Involved	Costs will depend on the amount of reconstruction necessary and on whether additional right-of-way is required. In general, this is one of the higher-cost strategies recommended. It is also one of the most beneficial.
Training and Other Personnel Needs	There appear to be no special personnel or training needs for implementing this strategy, given that it involves “standard” reconstruction efforts.
Legislative Needs	None identified.

EXHIBIT V-9 (Continued)
Strategy Attributes for Improved Highway Geometry for Horizontal Curves

Other Key Attributes	
	Since curve flattening would require significant reconstruction, it would be very easy to combine this treatment with lane widening and shoulder improvement treatments noted elsewhere. In addition, it should provide some benefit for bicyclists using the shoulders since it reduces the number of vehicles that leave their lane.

EXHIBIT V-10
Percentage Reduction in Total Crashes on Two-Lane Rural Roads Due to Curve Flattening (Based on Zegeer et al., 1992)

Original Degree of Curve	New Degree of Curve	Percent Reduction in Total
30	25	15-17
	20	31-33
	15	46-50
	10	61-67
	5	78-83
25	20	17-20
	15	35-40
	10	53-60
	5	72-80
20	15	20-25
	10	41-50
	5	64-75
15	10	24-33
	5	50-66
	3	63-79
10	5	28-49
	3	42-69

EXHIBIT V-11
Percentage Reduction in Total Crashes on Two-Lane Rural Roads Due to Shoulder Widening (Based on Zegeer et al., 1992)

Total Amount of Lane or Shoulder Widening		Percent Accident Reductions		
Total (ft)	Per Side (ft)	Lane Widening	Paved Shoulder Widening	Unpaved Shoulder Widening
2	1	5	4	3
4	2	12	8	7
6	3	17	12	10
8	4	21	15	13
10	5		19	16
12	6		21	18
14	7		25	21
16	8		28	24
18	9		31	26
20	10		33	29

Strategy 15.1 A6—Enhanced Pavement Markings at Appropriate Locations

General Description

The focus of this strategy is the provision for better on-pavement "guidance" to drivers at locations where they might leave the roadway. This would be done through such alternative treatments as higher contrast or wider markings or raised pavement markers (RPMs) versus the standard pavement markings that would be used at other locations where the ROR risk is lower. (Note that this strategy relates to enhanced markings, often at spot locations, rather than to the installation of standard centerline and edgeline markings where no markings have existed in the past. The consensus of the literature on "standard" markings as reported in *NCHRP Report 440* (Fitzpatrick et al., 2000) is that they are recommended for roadways with any substantial traffic volumes. Warrants for and details of standard centerline and edgeline markings can be found in the MUTCD (FHWA, 1988), and supplemental guidelines on implementation can be found in the *Roadway Delineation Practices Handbook* (Migletz, 1994).

Strategy Attributes

The goal of the strategy is to mark the roadway more clearly so that drivers will use the information to stay in their lanes and not merely to maintain or increase their speed. The specific markings to be used are low-cost, readily available materials.

As will be seen below, there remains conflicting evidence concerning the crash-related effectiveness of these devices. Thus, they are considered to be in the "tried"[6] category of strategies. If truly effective, these treatments appear to be compatible with other ROR and head-on treatments and should not adversely affect other road users such as bicyclists or motorcyclists.

[6] See explanation of ratings on page V-3.

EXHIBIT V-12
Strategy Attributes for Better Pavement Markings at Appropriate Locations

Technical Attributes

Target	Drivers of vehicles who might leave the roadway because of inability to see the edge of the pavement in the roadway section ahead.
Expected Effectiveness	Enhanced lane markings are an appropriate treatment if it is assumed that drivers leave the roadway because they cannot see the pavement edge in the downstream roadway sections. While some driver guidance is needed in such cases, the question is: How much should be added without changing the roadway geometry or the roadside design? Since some evaluations have raised questions about the overall effect of enhanced markings and RPMs, these features are considered a "tried" strategy at this time. For example, past research (Pendleton, 1996) and research being conducted by Bellomo-McGee, Inc., for NCHRP indicate a lack of significant effect or even a possible increase in crashes on some locations. This could be because drivers tend to drive faster when presented with a clearer delineation of the lane edge. Note, however, that evaluations of such treatments reflect studies of projects involving delineation that was implemented in conjunction with resurfacing. What is not clear is whether speeds increase because of simultaneous resurfacing and remarking or because improved markings were added without alignment or shoulder treatments. A review of earlier studies on wider edgelines in *NCHRP Report 440* noted that, in general, the effectiveness of 8-inch edgelines to reduce ROR crashes is "questionable." The study recommends that they be used only on roads with 12-foot lanes, unpaved shoulders and ADT between 2,000 and 5,000 vehicles per day. In contrast, a 1988 study by the New York DOT indicated that sections of curving two-lane rural roads with new 8-inch edgelines resulted in higher crash reductions than similar sections with new 4-inch edgelines. The study indicated greater safety effects for total crashes (a 10-percent decrease for the wider edgelines versus a 5-percent increase for standard edgelines); for injury crashes (15-percent decrease versus 10-percent decrease, respectively); and for fixed-object crashes (33-percent decrease versus 17-percent decrease, respectively). The study appears to have controlled for the regression to the mean bias by choosing both sets of experimental and control sites from a listing of high-crash locations. It is not clear whether the choice was made randomly. Effectiveness studies of RPMs have been conducted by states in before/after analyses of treatments at high-hazard locations. (It should be noted that accurately evaluating a treatment at a high-crash location is difficult because of the "regression to the mean" phenomenon. Whether the following studies controlled for such potential biases is unknown.) In southern New Jersey, RPMs have been used on two separate routes, both two-lane rural highways totaling 53.5 miles. The total project cost was $122,730 (1985 dollars). Using data from 2 years before and 1 year after, there was a statistically significant reduction in various types of nighttime accidents including total, injury, head-on, fixed object, overturn, and between intersection accidents. The calculated benefit-cost ratio was 19.89 (State of New Jersey, 1986). In northern New Jersey, RPMs were installed on six routes (over 126 miles), generally rural two-lane roads. The total project cost was $314,242 (1985 dollars). Again, using data from 2 years before and 1 year after, there was a statistically significant reduction in various nighttime crashes including total, injury, property damage, overturn, head-on, fixed object, and between intersection crashes. The calculated benefit-cost ratio was 15.45 (State of New Jersey, 1986).

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EXHIBIT V-12 (Continued)
Strategy Attributes for Better Pavement Markings at Appropriate Locations

	For projects with fewer than 800 markers, state forces (not independent contractors, as above) do the installation. For six different route sections totaling 47.8 miles, the construction cost was $151,493. Analysis results show a statistically significant reduction in accidents in every nighttime accident category (total, fatal, injury, property damage, head-on, fixed object, wet surface, and between intersections). The benefit-cost ratio was 25.51. In Ohio, marker studies were conducted at 184 locations that had high accident rates prior to 1977, including horizontal curves, narrow bridges, stop approaches, and interchanges. Over 3,200 accidents at marker locations were analyzed 1 year before and 1 year after. The results show a 9.2-percent reduction in accidents and a 14.9-percent decrease in injuries. Markers were determined to be effective in all types of driving conditions, including nighttime (5.3-percent reduction) and adverse weather conditions (5.5-percent reduction in crashes at the same time precipitation increased by 10.6 percent). The study concluded that “a dollar spent on raised reflective highway markers in Ohio has returned $6.50 in savings due to accident reduction.” As of 1981, nearly 700,000 RPMs were installed in Ohio (*The Ohio Underwriter,* 1981). In a 1997 report, the New York State DOT concluded from prior evaluations that raised snowplowable pavement markers (RSPMs) can reduce “guidance-related accidents” (fixed-object collisions, ROR, and encroachment) by approximately 19 percent if selectively applied at locations having high percentages of such crashes. (It is not clear from the report whether the regression-to-the-mean bias has been accounted for.) Based upon an evaluation of 1992 data and a review of studies from other states, the DOT further concluded that RSPMs should not be applied systemwide, since they are somewhat costly and would have no effect or a possible negative effect on crashes at such nonspecific locations. In summary, the effectiveness of RPMs as a general “systemwide” treatment appears questionable. The effectiveness of RPMs at high-hazard sites may also be less clear than first thought. This is not to say they should not be tried. Their relatively low cost argues for experimentation. However, at this point, it is not possible to specify a crash reduction factor for these devices. Clearly, well-designed before/after studies of effectiveness at such sites are needed—studies that account for the “regression-to-the-mean” bias. Thus, although this treatment may be effective in reducing crashes, careful targeting, monitoring, and evaluation are needed. Similarly, the effectiveness of wider edgelines is also difficult to specify based upon past studies. While the *NCHRP Report 440* review found wider edgelines “questionable” in general, the New York State DOT study indicated that implementation on high-crash sites on two-lane roads might result in a 10- to 15-percent decrease in ROR crashes.
Key to Success	Based upon the effectiveness studies, the key to success is the targeted application of this treatment to sites where more guidance is needed for the driver, but where vehicle speeds will not be increased to unsafe levels.
Potential Difficulties	A potential difficulty with RPMs is the damage to the reflector or possible dislodging of the reflector during snow plowing. However, these concerns have lessened due to the creation of plowable RPMs. Another potential pitfall is nontargeted or erroneously targeted application of the devices on high-speed two-lane roads. This could result in adverse safety effects, which might negatively affect opinions about the treatment and therefore keep it from being implemented where needed.
Appropriate Measures and Data	In agency evaluations of implementation effectiveness, *process measures* would include *the number of hazardous curves treated* and *the type of treatment applied.*

EXHIBIT V-12 (Continued)
Strategy Attributes for Better Pavement Markings at Appropriate Locations

	Impact measures would involve before/after *changes in crash frequencies or rates* (with the study appropriately designed) and *changes in speed from before to after treatment.* It would also appear that data are needed to better target the treatment, targeting to sites where additional visual guidance is needed, but where speeds are less likely to be increased. This is a difficult task. It may be aided by use of video logs and conduct of safety audit types of studies.
Associated Needs	No new public information efforts appear to be needed since this is a publicly accepted treatment on other roads. (Efforts to train the public to use them correctly—i.e., not to increase speed—are not expected to be effective).
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	This strategy could be implemented by the state DOT or a local roads agency, and it does not appear that additional cooperative efforts with other agencies are needed. The only exception might be if the enhanced delineation led to increased speeds. In this case, targeted speed enforcement could be needed. After effectiveness is established and targeting methods are developed, a design and placement policy is needed to facilitate implementation, along with AASHTO support and guidance.
Issues Affecting Implementation Time	Since these devices are relatively inexpensive and are standard devices, they could be implemented in a very short timeframe.
Costs Involved	An old cost figure states that Ohio's average cost is $14.71 per unit for 35,000 units. A 1997 New York DOT report indicates that an RSPM (which is more expensive than a standard RPM) costs approximately $25–30 to install and $6–8 each 3 years for reflector replacement. Installation was found to increase the cost of delineation from approximately $2,000 to $5,300 per mile. However, states have most likely developed their own cost estimates, since these treatments are being widely used.
Training and Other Personnel Needs	There appear to be no special personnel or training needs for implementing this strategy. The installation would be done by either agency personnel or contractors and indeed is already being done in most state agencies.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy 15.1 A7—Skid-Resistant Pavements

General Description

The 1999 statistics from FARS show that for two-lane, undivided, noninterchange, nonjunction roadways, 11 percent of single-vehicle ROR fatal crashes occur on wet roadways, with 3 percent more occurring on roadways with snow, slush, or ice (Exhibit V-13). Accidents on wet pavements are often related to the skid resistance of the pavement. It can also happen that the pavement friction available under dry roadway conditions will be significantly less than specified for the roadway and assumed in establishing design criteria (e.g., superelevation on curves). This can also lead to crashes. However, the major problem appears to be with wet pavement crashes.

A vehicle will skid during braking and maneuvering when frictional demand exceeds the friction force that can be developed at the tire-road interface. While this can happen on dry pavements at high speeds, friction force is greatly reduced by a wet pavement surface. In fact, a water film thickness of 0.002 inches reduces the tire pavement friction by 20 to 30 percent of the dry surface friction. Therefore, countermeasures should seek to increase the friction force at the tire-road interface and reduce water on the pavement surface. The coefficient of friction is most influenced by speed. However, many additional factors affect skid resistance, including the age of the pavement, pavement structural condition, traffic volume, road surface type and texture, aggregates used, pavement mix characteristics, tire conditions, and presence of surface water.

There has been a large amount of research funded by the FHWA, AASHTO, and pavement associations concerning designing better pavements—pavements which are more durable and more cost-effective (e.g., the FHWA/AASHTO Strategy Highway Research Program). The FHWA has issued a series of pavement-related technical advisories on such issues as needed changes in surface finishing of Portland cement concrete pavements for increased safety (FHWA, 1996). An important parameter in all this work is pavement skid resistance, perhaps the major safety-related factor along with pavement drainage design. However, most of this research and implementation effort is oriented toward policy or systemwide changes in new pavements or repaving efforts. While the best safety-related pavement design possible should be used in all paving efforts, the details of pavement design are beyond the scope of this guide.

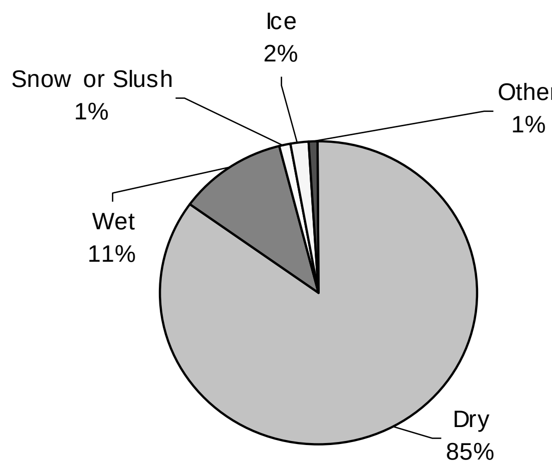

EXHIBIT V-13
Distribution of Single-Vehicle ROR Fatalities for Two-Lane, Undivided, Noninterchange, Nonjunction Roads by Roadway Condition (Source: 1999 FARS)

Instead, this section will concentrate on improvements that can be made to sites that have, or are expected to experience, skidding-related ROR crashes. These usually involve improvements to increase skid resistance (higher friction factor). Such improvements should have high initial skid resistance, durability to retain skid resistance with time and traffic, and minimum decrease in skid resistance with increasing speed. Countermeasures to improve skid resistance include asphalt mixture (type and gradation of aggregate as well as asphalt content), pavement overlays on both concrete or asphalt pavements, and pavement grooving. Water can also build up on pavement surfaces due to tire rutting, an inadequate crown, and poor shoulder maintenance. These problems can also cause skidding crashes and should be treated when present. While there is only limited research on such site-specific programs (see below), the results of this research coupled with the results of research on the general effectiveness of decreasing skidding would place this in the "proven"[7] category.

[7] See explanation of ratings on page V-3.

EXHIBIT V-14
Strategy Attributes for Skid-Resistant Pavement Surfaces

Technical Attributes	
Target	Treatment will target locations where skidding is determined to be a problem, in wet or dry conditions. The ultimate target, however, is a vehicle involved in a crash due to skidding, usually on wet pavement. With respect to ROR or head-on crashes, the target vehicle is one that runs (skids) off the road due to insufficient skid resistance or becomes involved in a head-on crash either by skidding into the opposing lane or by crossing into the opposing lane after an over-correction from an initial ROR maneuver caused by insufficient skid resistance.
Expected Effectiveness	There are many different specific countermeasures that may be implemented to improve skid resistance. This may include changes to the pavement aggregates, adding overlays, or adding texture to the pavement surface. The effectiveness of the countermeasure not only depends on that measure selected, but also will vary with respect to location, traffic volume, rainfall propensity, road geometry, temperature, pavement structure, etc. The New York State DOT has implemented a program that identifies sites statewide that have a low skid resistance and treats them with overlays or microsurfacing as part of the maintenance program. A site is eligible for treatment if its 2-year wet accident proportion is 50 percent higher than the average wet accident proportion for roads in the same county. Between 1995 and 1997, 36 sites were treated on Long Island, resulting in a reduction of more than 800 annually recurring wet road accidents. These results and others within the state support earlier findings that treatment of wet road accident locations result in reductions of 50 percent for wet road accidents and 20 percent for total accidents. While the reductions in ROR or head-on crashes cannot be extracted from the data at this time, it appears that reductions in these types would be at least the same as for total crashes. While these results could be subject to some regression-to-the-mean bias, the New York staff has found that untreated sites continue to stay on the listing until treated in many cases—an indication that these reductions are clearly not totally due to regression. The New York State DOT is planning a more refined data analysis to account for possible biases in these effectiveness estimates. Based on the current knowledge, this identification/treatment strategy would be classified as “proven.”
Keys to Success	Monitoring the skid resistance of pavement requires incremental checks of pavement conditions. Evaluation must identify ruts and the occurrence of polishing. Recent research (Galal et al., 1999) has suggested that the surface should be restored between 5 and 10 years in order to retain surface friction, but the life span is affected by site characteristics such as traffic volume. In addition, spot- or section-related skid accident reduction programs will be clearly most successful if targeted well. The New York State DOT program noted above provides a methodology for such targeting. In addition, in a 1980 Technical Advisory, the FHWA provided a detailed description of a “Skid Accident Reduction Program,” including not only details of various treatments, but also the use of crashes and rainfall data in targeting the treatments.
Potential Difficulties	Skid resistance changes over time. This requires a dynamic program and strong commitment. As noted in the preceding section, it also requires good “targeting.” When selecting sites for skid resistance programs, it is important to somehow control for the amount of wet-pavement exposure. This will help decrease the identification of sites that have a high wet-accident proportion or that rate simply because of high wet-weather

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EXHIBIT V-14 (Continued)
Strategy Attributes for Skid-Resistant Pavement Surfaces

	exposure with no real pavement-friction problems. Unfortunately, it is difficult or impossible for an agency to develop good wet-pavement crash rates per vehicle mile for all roadway sections due to the lack of good wet-weather exposure data for all sites. Such data would require both good rainfall data for all potential sites and good measures of traffic volume during wet and dry weather. In its Skid Accident Reduction Program (SKARP), the New York State DOT uses a surrogate for such detailed data. The DOT compares the proportion of wet-weather crashes at each site with the proportion for similar roads in the same county. The assumption here is that rainfall (and thus wet-pavement exposure) would be similar across a county, a reasonable assumption.
Appropriate Measures and Data	Data are needed on traffic crashes by roadway condition. In addition, measures of traffic exposure that identify and reflect both dry and wet periods are needed. Finally, measurements of road friction and pavement water retention should be documented both before and after implementation of a strategy.
Associated Needs	None required. Relatively unnoticed by the public.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Implement by state DOT; no coordination required. Policy may be needed in order to determine the most appropriate pavement aggregate statewide and at special locations. Additionally, guidelines may be needed to highlight when pavement groove cuts should be considered. These countermeasures may also require cooperation within an agency, especially if these types of safety treatments are to be tied to routine maintenance.
Issues Affecting Implementation Time	Depends upon the treatment. Grooving can be done quickly, but overlays require more time. Nevertheless, all strategies being suggested should have short implementation periods.
Costs Involved	Highly variable depending upon the specific treatment. The New York State DOT estimates that its resurfacing/microsurfacing projects are approximately 0.5 miles long, with an average treatment cost of approximately $20,000 per lane mile (1995 dollars).
Training and Other Personnel Needs	No special personnel needs for implementing this strategy. Either agency personnel or contractors could do installation.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Information on Current Knowledge Regarding Agencies or Organizations that Are Implementing This Strategy

Many states have an ongoing program aimed at the systematic monitoring of pavements, including measurement of skid numbers. As described in Appendix 5, New York State DOT has established SKARP to incorporate safety into pavement maintenance. The program was established to address problems with inadequate pavement friction. Using a systematic approach, over 100 statewide sites are identified annually and further tested and possibly treated. The treatments include resurfacing and microsurfacing.

Strategy 15.1 A8—Shoulder Treatments

General Description

If a vehicle that has intentionally or unintentionally left its lane and entered the shoulder area is allowed to safely recover, ROR crashes can be reduced. The probability of such a safe recovery is increased if the errant vehicle is provided with a wider and smoother area in which to initiate such a recovery and if the recovery is not impeded by a pavement irregularity that causes the driver to either fail to re-enter the lane or to enter it at such an angle that the vehicle crosses into the opposing lane. Shoulder treatments that promote safe recovery include shoulder widening, shoulder paving, and the reduction of pavement edgedrops (i.e., differences in lane pavement and shoulder surface heights, whether paved or not). While each strategy could be covered separately, the effectiveness is related, and the actual treatment can often be completed as a "package" during roadway resurfacing. Note that these same shoulder treatments, particularly shoulder paving and correcting edgedrops, can reduce head-on crashes. These treatments enable the vehicle's recovery to be made in a more controlled fashion and at a less sharp angle, thereby reducing the chances that the recovering vehicle will over-correct into the opposing lane.

Strategy Attributes

While the nature of the widening and paving treatments is self-evident, there are alternatives to the treatment of edgedrops (Exhibit V-15). Edgedrops can result from repaving, where material is added to the lane but not to the adjacent shoulder, or from weather or vehicle-caused "erosion" of unpaved shoulders. In their discussion of possible treatments, Humphreys and Parham (1994) noted that the best treatment is to always retain the lane and shoulder heights at the same level. This is often difficult due to repaving practices and unpaved shoulders that deteriorate. They then noted that an excellent alternative for both paved and unpaved shoulders is adding a 45-degree fillet at the lane/pavement edge: a wedge of pavement that would allow the vehicle to safely return to the roadway. This wedge (or a 45-degree beveled edge) can be added during repaving by attaching a device known as a "moulding shoe" to modern paving equipment.

EXHIBIT V-15
Example of an Edgedrop

Based upon current research concerning crash-related effectiveness, shoulder paving and widening are considered "proven" strategies, while edgedrop treatments are considered "experimental."[8] These shoulder treatments are compatible with other ROR treatments. Paving shoulders can be accompanied by shoulder rumble strips, and paving and widening shoulders should make the shoulders more compatible with bicycle use.

[8] See explanation of ratings on page V-3.

EXHIBIT V-16
Strategy Attributes for Shoulder Treatments

Technical Attributes	
Target	The targets of this package of strategies are vehicles that stray from their lanes onto the shoulder area. The ultimate targets are the drivers of these vehicles, who are being provided with an opportunity for a safe recovery.
Expected Effectiveness	Even though there have been numerous studies of both shoulder widening and paving and limited studies of pavement edgedrop elimination, there is still some uncertainty about the true effect of such treatments. A recent unpublished literature review by Hauer (2000) demonstrated this uncertainty, noting some studies of shoulder widening/paving that indicated effects as large as 30- to 40-percent reductions and other studies that indicated no effect or even a possible increase in crashes for certain ADT levels. (If true, such an increase could be attributed to increased speeds resulting from shoulder improvements without changes in curvature or other factors.) The major shortcoming in the large body of research is that most findings are not based on well-conducted before/after studies where shoulders have actually been improved in the field. Instead, most are “cross-sectional” studies, in which different segments of roads with different shoulder characteristics are used in statistical models that estimate the effect of a change in width by changes in model output. However, based on the best available research, shoulder widening and paving would be considered “proven” strategies. Even though their safety benefits would appear to be “obvious,” strategies related to edgedrop elimination would have to be considered “experimental,” since no research into effectiveness is available. With respect to shoulder widening and paving, in a recent FHWA effort related to determining AMFs for use with the Interactive Highway Safety Design Model (Harwood et al., 2000), a panel of experts attempted to develop a best estimate of shoulder treatment effectiveness based on a review of a number of research studies. Their estimate of effectiveness of shoulder widening on two-lane rural roads is shown in Exhibit V-17. Here, the base shoulder is a 6-foot-wide paved shoulder, and the AMFs shown for different ADTs are relative to this base shoulder. For example, a roadway with 500 vehicles per day and a 2-foot shoulder would be expected to have 30 percent more “related crashes” than the same road with a 6-foot shoulder (i.e., an AMF of 1.3). In like fashion, a two-lane rural road with 2,000 vehicles per day and an 8-foot shoulder would be expected to have 13 percent fewer related crashes than the same road with a 6-foot shoulder (i.e., an AMF of 0.87). Note that these reductions are not for total crashes, but for “related crashes,” which include single-vehicle ROR, multivehicle opposite-direction (i.e., head-ons and opposing sideswipes), and multivehicle same-direction sideswipe crashes. To obtain the percentage reductions in total crashes, these AMFs would be multiplied by the percentage of total crashes they represent (typically, 35 percent for two-lane rural highways). In the same study, the panel also defined AMFs for turf, composite, and stabilized gravel shoulders relative to the paved shoulder of the same width. As shown in Exhibit V-18, these effects change with shoulder type and shoulder width. For example, for an 8-foot width, turf shoulders are expected to experience 11 percent more “related crashes.” Much less is known about the effectiveness of edgedrop treatments, since it is difficult to specifically define the percentage of ROR or head-on crashes, which is the result of “overcorrection” by vehicles that run off the road first. Whatever that percentage, Humphreys and Parham (1994) concluded that a 45-degree-angle asphalt fillet at the lane edge would virtually eliminate this type of crash, even in cases where the shoulder is unpaved and suffers subsequent erosion damage.

EXHIBIT V-16 (Continued)
Strategy Attributes for Shoulder Treatments

Keys to Success	As with other ROR treatments, keys to success will include treatment targeting, such that funds are used as efficiently as possible. Targeting them to higher-speed roads with high ROR crash frequencies and rates could enhance all three strategies. Implementation of the edgedrop treatments will be enhanced by the identification of “champion” states that have implemented edgedrop treatments as a standard part of their repaving efforts and have found the treatments to be both low cost and effective. If an edge-fillet program is to be implemented, an additional key to success will be the development of an inclusive pavement specification and the necessary equipment modifications.
Potential Difficulties	While not evaluated extensively, it appears that the edge fillet or other edgedrop treatments would not have significant potential difficulties unless the use of this treatment resulted in less maintenance of unpaved shoulders. However, if wider paved shoulders are added to high-speed roads with poor alignment and hazardous roadsides, they possibly could lead to an increase in vehicle speeds and total crash frequency and severity. Thus, careful targeting and monitoring is needed.
Appropriate Measures and Data	In the evaluation of strategy implementation effectiveness, process measures would include the number of road miles or number of hazardous locations where these shoulder treatments are installed, as well as the type of installation. Impact measures will include the number and rate of ROR (and head-on) crashes reduced at these locations. However, due to possible adverse effects, changes in total crashes also should be studied. Data on ROR crashes would be needed to target the shoulder widening/paving treatment. If the state decided to use only the pavement edge treatment at selected locations (rather than as a standard add-on to resurfacing activities), criteria would need to be developed to define those critical locations, and data (e.g., crash or edgedrop inventory) would be needed to identify the locations. In addition, as noted above, since the edge-fillet treatment has not been evaluated, if a state were to implement the wedge, it is critical that the necessary treatment location, crash, and roadway inventory data on possible confounding factors be collected.
Associated Needs	Since these are somewhat “standard” treatments, there does not appear to be a critical need for public information or education efforts.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	This strategy can be implemented by the state DOT or local roadway agency, and it would appear that there is no need for cooperative efforts with other agencies. Since these are “standard” treatments in general, no significant policy action appears needed other than a possible design policy for the pavement edge fillet.
Issues Affecting Implementation Time	Unless shoulder widening requires additional right-of-way, these treatments can be implemented in a relatively short timeframe. While all three would involve retrofits to existing pavements, it seems that the most opportune time to implement them would be in conjunction with repaving efforts.
Costs Involved	Shoulder widening costs would depend on whether new right-of-way is required and whether extensive roadside moderation is needed. Shoulder pavement costs should be similar to lane pavement costs and depend on how much shoulder stabilization is required.

(*continued on next page*)

EXHIBIT V-16 (Continued)
Strategy Attributes for Shoulder Treatments

	Humphreys and Parham (1994) note that the cost of adding a pavement edge fillet when resurfacing a roadway is very low—perhaps 1 to 2 percent of the typical resurfacing cost.
Training and Other Personnel Needs	There would appear to be no special personnel needs for implementing these strategies, since they are similar to other paving/construction activities. The only new training needed would be for paving forces (whether state or contract) that would place the pavement edge fillet.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

EXHIBIT V-17
Accident Modification Factor for Paved Shoulder Width (Relative to 6-Foot Paved Shoulder) on Two-Lane Rural Highways (Source: Harwood et al., 2000)

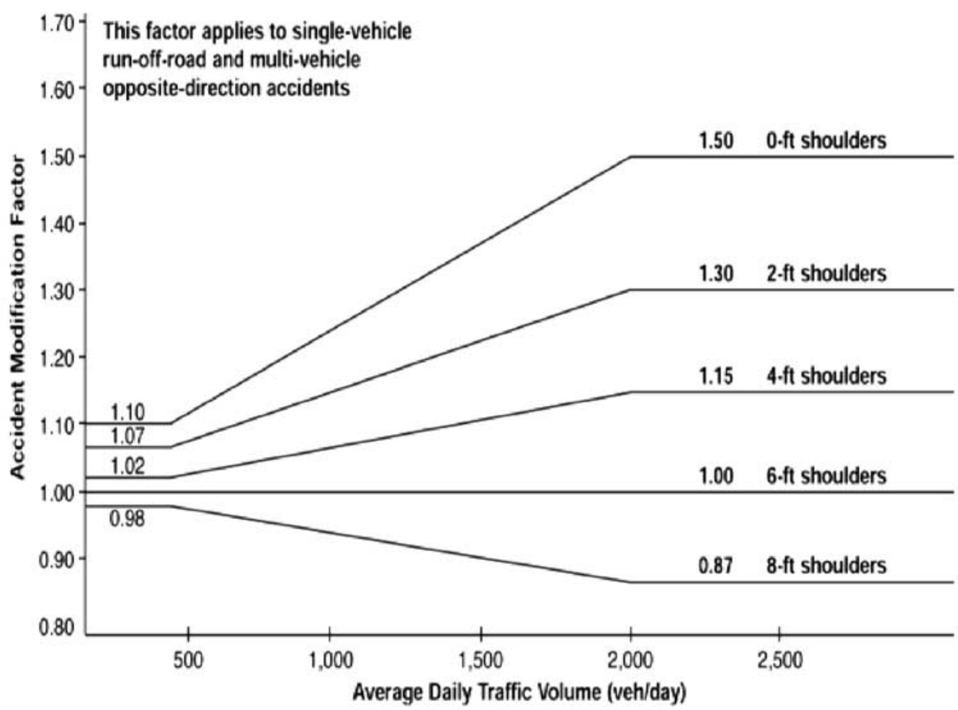


EXHIBIT V-18
Accident Modification Factor for Shoulder Type on Two-Lane Rural Highways (Source: Harwood et al., 2000)

	Shoulder Type			
Shoulder Width (ft)	Paved	Gravel	Composite	Turf
0	1.00	1.00	1.00	1.00
1	1.00	1.00	1.01	1.01
2	1.00	1.01	1.02	1.03
3	1.00	1.01	1.02	1.04
4	1.00	1.01	1.03	1.05
6	1.00	1.02	1.04	1.08
8	1.00	1.02	1.06	1.11
10	1.00	1.03	1.07	1.14

Information on Agencies or Organizations Currently Implementing this Strategy

Almost all states have some experience with widening and paving shoulders. The only state identified with a current policy regarding a pavement edge "wedge" is Kansas. The Kansas DOT has had a policy for more than a decade requiring that a pavement edge "wedge" be installed at the edge of pavement during 1-R (repaving) projects. Somewhat different from the 45-degree fillet of paving material described above, Kansas requires a wedge with a slope equaling the shoulder slope constructed of either rock, earth, or recycled asphalt. Rock is the most often used material. In all cases, the wedge material is compacted according to specifications.

Objective 15.1 B—Minimize the Likelihood of Crashing into an Object or Overturning if the Vehicle Travels Off the Shoulder

Strategy 15.1 B1—Design Safer Slopes and Ditches to Prevent Rollovers

This strategy has been covered below with closely related strategies under the section entitled Combined Strategy: Improving Roadsides.

Strategy 15.1 B2—Remove/Relocate Objects in Hazardous Locations

This strategy has been covered below with closely related strategies under the section entitled Combined Strategy: Improving Roadsides.

Strategy 15.1 B3—Delineation of Roadside Objects (Experimental Treatment)

This strategy has been covered below with closely related strategies under the section entitled Combined Strategy: Improving Roadsides.

Objective 15.1 C—Reduce the Severity of the Crash

Strategy 15.1 C1—Improve Design of Roadside Hardware (e.g., Bridge Rails)

This strategy has been covered below with closely related strategies under the section entitled Combined Strategy: Improving Roadsides.

Strategy 15.1 C2—Improve Design and Application of Barrier and Attenuation Systems

This strategy has been covered below with closely related strategies under the section entitled Combined Strategy: Improving Roadsides.

Combined Strategy: Improving Roadsides

The section includes strategies aimed at both minimizing the likelihood of a crash or overturning, if a vehicle travels off the shoulder and onto the roadside, and minimizing the severity of the crashes that do occur on the roadside. Because this strategy has multiple possible components that are covered in detail in other documents, the following narrative will be more general than the preceding sections. The reader should also refer to the AASHTO *Roadside Design Guide* for a detailed discussion of this strategy area.

General Description

The series of strategies covered first in this guide are related to keeping the vehicle from encroaching onto the shoulder—keeping the vehicle in its lane (e.g., shoulder rumble strips). The second set of strategies describing shoulder treatments is related to minimizing ROR crash likelihood by allowing the errant vehicle to safely recover to the travel lane. The set of strategies covered in this final section are related to the roadside—the area outside the shoulder. Each strategy is aimed at meeting one or both of the following goals:

- Minimize the likelihood of crashing into an object or overturning if the vehicle travels beyond the edge of the paved (or unpaved) shoulder.
- Reduce the severity of the crash if an impact occurs.

Improvements to the roadside can meet both goals by providing a traversable "clear zone," which (a) is free of highway hardware and unsafe natural objects (e.g., trees); (b) protects the objects that cannot be removed (e.g., crash attenuators in front of hazardous utility poles, guardrails protecting steep sideslopes); or (c) makes objects that cannot be removed less severe to the striking vehicle (e.g., breakaway signs and utility poles). In addition, the well-designed clear zone will

- Be of sufficient width that most vehicles that leave the road do not exceed its limits,
- Have up and down slopes that do not cause vehicle rollovers, and
- Possess soil characteristics that do not lead to vehicle tripping and thus rollovers.

Strategy Attributes

Strategies that are directed at roadside design range from very costly to relatively inexpensive. The former include purchasing new right-of-way, building wider and safer clear zones where limited zones now exist, and clearing and grading clear zones on right-of-way already owned. Less costly (but not inexpensive) strategies may include replacing nonbreakaway or outdated roadside hardware (e.g., guardrail ends, culverts) with newer technology at selected locations, burying utility lines, or relocating utility poles. The question for the agency then becomes one of how to spend limited roadside safety dollars in the most cost-efficient manner. That is, what should be targeted, and how?

FARS data for all roadway classes shown in Exhibit V-19 indicate that the most harmful event in a nonintersection ROR crash is most likely to be an overturn (42 percent of 1999 ROR single-vehicle fatalities), an impact with a tree (26 percent), an impact with a utility pole (7 percent), or an impact with a ditch or embankment (5 percent). Most other roadside objects (e.g., culverts, posts, and guardrails) are found to be the most harmful event in 2 percent or less of the fatalities. FARS data shown earlier in Exhibit III-4 indicated that on two-lane rural roads, the most harmful event in a nonintersection ROR crash is most likely to be an overturn (41 percent of 1999 ROR single-vehicle fatalities), an impact with a tree (29 percent), an impact with a utility pole (8 percent), or an impact with a ditch or embankment (5 percent). Again, most other roadside objects (e.g., culverts, posts, and guardrails) are found to be the most harmful event in less than 2 percent of the fatalities. These are essentially the same percentages of most harmful events found when all single-vehicle ROR fatalities are examined, regardless of roadway class, as shown in Exhibit V-19. This is not surprising when one considers that approximately two-thirds of the total ROR fatality problem is on two-lane roads.

Rural and urban interstate roads (which experience approximately 18 percent of the ROR fatalities) exhibit a slightly different pattern, since the roadsides on interstates are built to a much higher standard. “Overturn” is much more prevalent as the most harmful event (59 percent); guardrails and concrete traffic barriers are slightly more prevalent (6 percent and 2 percent, respectively); ditch and embankments are slightly less prevalent (3 percent); and utility pole impacts are virtually eliminated. Somewhat surprisingly, while less prevalent, trees are still the most harmful event in interstate ROR fatal crashes in 13 percent of the cases.

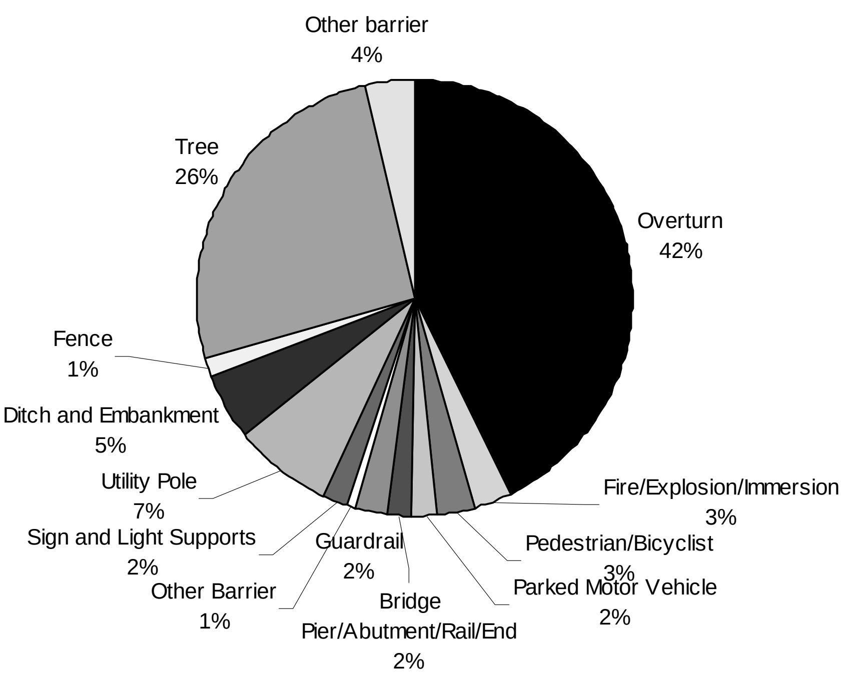
Because of the importance of tree impacts on all roads and utility pole impacts on two-lane roads, they have been designated as separate emphasis areas with separate guides. For that reason, this section will not concentrate on these areas in terms of specific treatment strategies.

Rollover Reduction

If one were concerned with addressing a significant proportion of ROR fatalities with roadside treatments other than those aimed at trees and utility poles, the above data would point to concentration on treatments that lessen rollovers. The issue is complex, in that roadway and roadside design are only one of many factors affecting rollovers. Important factors not under the control of the roadway engineer include driver control factors (e.g., speed control or steering or braking during attempted recovery) and vehicle factors (e.g., the higher rollover propensity of SUVs and pickups). In addition, treatments aimed at rollover prevention are, in general, expensive. They either involve the development and deployment of new roadside hardware to replace outdated installations that might produce vehicle rollovers (e.g., replacing outdated guardrail ends) or, more often, widening and flattening roadside slopes. There is also some initial evidence that certain soils may cause rollovers on sideslopes that are otherwise safe. Given the size of the problem, and the severity of rollovers, the effort and expense is often warranted.

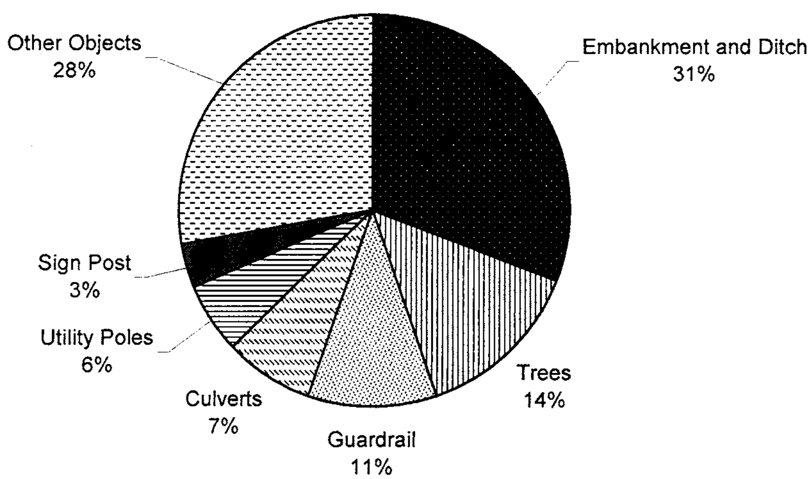
Because of the significance of the rollover problem, the FHWA initiated a major research effort in this area. While the results of that program will not be available until 2003, the initial phase of the effort—the experimental design of the research, which details the nature of the problem and possible avenues of research—has been completed (see Harkey et al., 2000). The roadside design features most likely to affect rollover include the sideslope (particularly fill slopes), ditch design, the nature of the soil on the slope, and the design of roadside hardware that might lead to rollovers (e.g., poorly designed guardrail ends). Unfortunately, little is known at this point concerning how soil types (or possible treatments) might affect rollover.

EXHIBIT V-19
Most Harmful Events for All 1999 Fatal Single-Vehicle ROR Crashes on All Roadway Classes



With respect to roadside hardware, the 1999 FARS data also indicate that, when a rollover occurs as a "subsequent event," the first thing struck is a ditch or embankment in approximately 31 percent of the cases (Exhibit V-20). Other "first-struck" objects include trees (14 percent of the fatal crashes with subsequent rollovers), guardrail (11 percent), culverts (7 percent), utility poles (6 percent), and sign posts (3 percent). There is no one type of *roadside hardware* that is related to a large proportion of subsequent fatal rollovers: the roadside embankment and ditch design are the major problem. The fact that 11 percent of the fatal subsequent rollovers follow impacts with guardrails does not mean that the guardrails are poorly designed or substandard. Some of these rollovers could have occurred after the vehicle struck the rail and either passed over or through it. Alternatively, the crashes could have occurred when the vehicle rebounded from the rail, "struck" something else, and subsequently overturned. In addition, these statistics concern only the small percentage of crashes that result in a fatality and do not imply that 11 percent of all guardrail impacts result in rollovers. At most, these percentages suggest that there is not currently a guardrail design that will eliminate rollover under every set of operating conditions. While improvements in hardware is a worthwhile goal, the most effective rollover-reduction program will result from concentrating on "earth factors" and would involve widening and flattening sideslopes (particularly fill slopes) and making improvements to ditches. A related design issue concerning whether current standards that recommend a "length of need" for a guardrail are sufficient for today's conditions is currently under study by the FHWA—that is, whether the guardrail extends back far enough from the "hazard" to prevent vehicles from entering an unsafe sideslope or other hazardous condition.

EXHIBIT V-20
Percentage of Subsequent Rollovers Related to Various "First Struck" Objects



The AASHTO *Roadside Design Guide* (2002) provides guidance concerning the recommended clear zone distance for given cut or fill slopes, design speed, and design ADT (Exhibits V21 and V-22). The guide also presents adjustment figures based on horizontal curvature. As noted in the recent *NCHRP Report 440* (Fitzpatrick et al., 2000), "The guidance curves provided [in the *Roadside Design Guide*] are based on limited empirical data that was then extrapolated to provide data for a wide range of roadside conditions; therefore, the numbers obtained from these curves represent a 'reasonable measure' of the degree of safety suggested for a particular roadway." Attempts are continually being made to update and improve these data. NCHRP Project 17-11, "Determination of Safe/Cost Effective Roadside Slopes and Associated Clear Distances," is aimed at increasing the understanding of roadside encroachment distances (i.e., the distance a vehicle strays from the travel lane) and rollover occurrence on roadside slopes.

EXHIBIT V-21
Clear Zone Distance Curves (Source: AASHTO *Roadside Design Guide,* 2002)

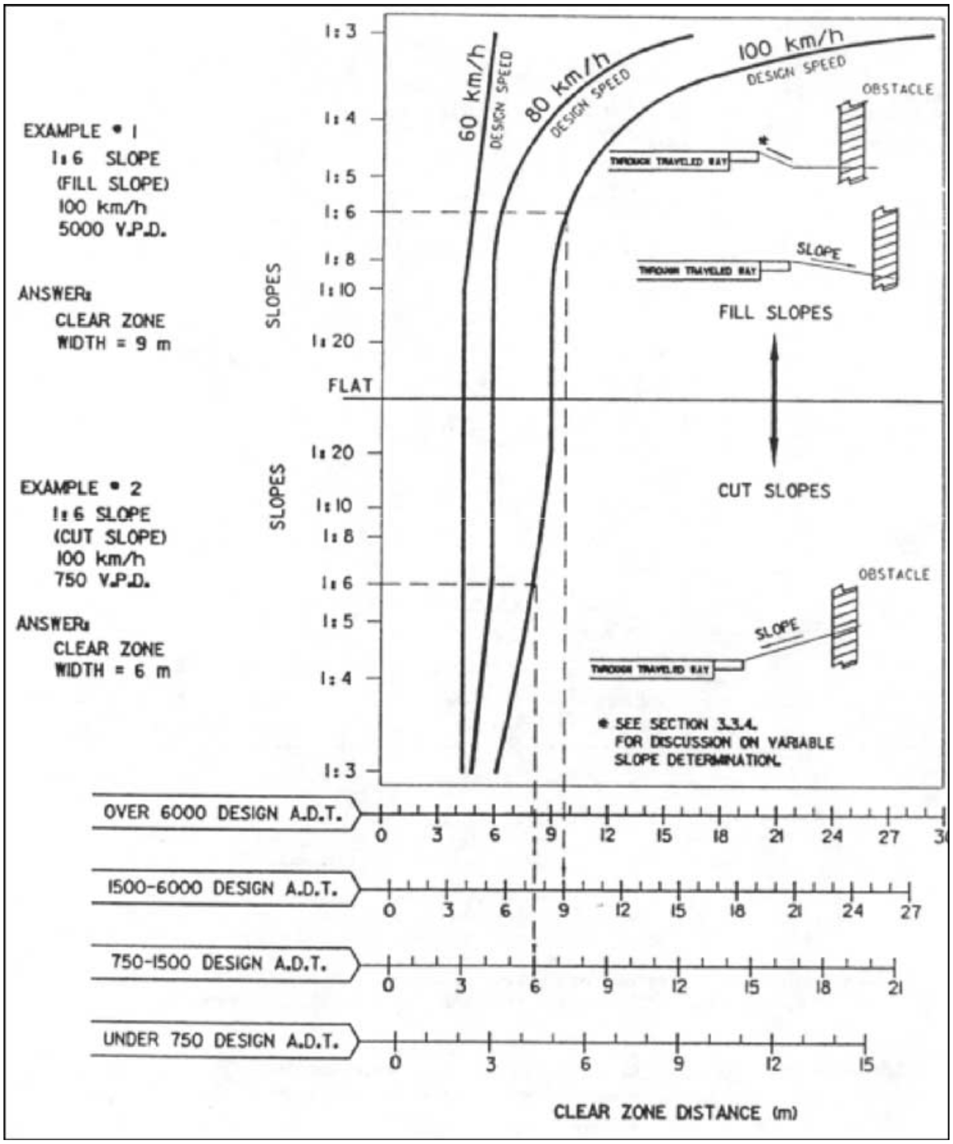


EXHIBIT V-22
Clear Zone Distances (in Feet from Edge of Driving Lane) (Source: AASHTO *Roadside Design Guide*, 2002)

		Fill Slopes			Cut Slopes		
Design Speed	Design ADT	1:6 or Flatter	1:5 to 1:4	1:3	1:3	1:4 to 1:5	1:6 or Flatter
60 km/h or less	Under 750	2.0-3.0	2.0-3.0	[b]	2.0-3.0	2.0-3.0	2.0-3.0
	750-1500	3.0-3.5	3.5-4.5	[b]	3.0-3.5	3.0-3.5	3.0-3.5
	1500-6000	3.5-4.5	4.5-5.0	[b]	3.5-4.5	3.5-4.5	3.5-4.5
	Over 6000	4.5-5.0	5.0-5.5	[b]	4.5-5.0	4.5-5.0	4.5-5.0
70-80 km/h	Under 750	3.0-3.5	3.5-4.5	[b]	2.5-3.0	2.5-3.0	3.0-3.5
	750-1500	4.5-5.0	5.0-6.0	[b]	3.0-3.5	3.5-4.5	4.5-5.0
	1500-6000	5.0-5.5	6.0-8.0	[b]	3.5-4.5	4.5-5.0	5.0-5.5
	Over 6000	6.0-6.5	7.5-8.5	[b]	4.5-5.0	5.5-6.0	6.0-6.5
90km/h	Under 750	3.5-4.5	4.5-5.5	[b]	2.5-3.0	3.0-3.5	3.0-3.5
	750-1500	5.0-5.5	6.0-7.5	[b]	3.0-3.5	4.5-5.0	5.0-5.5
	1500-6000	6.0-6.5	7.5-9.0	[b]	4.5-5.0	5.0-5.5	6.0-6.5
	Over 6000	6.5-7.5	8.0-10.0 [a]	[b]	5.0-5.5	6.0-6.5	6.5-7.5
100 km/h	Under 750	5.0-5.5	6.0-7.5	[b]	3.0-3.5	3.5-4.5	4.5-5.0
	750-1500	6.0-7.5	8.0-10.0 [a]	[b]	3.5-4.5	5.0-5.5	6.0-6.5
	1500-6000	8.0-9.0	10.0-12.0 [a]	[b]	4.5-5.5	5.5-6.5	7.5-8.0
	Over 6000	9.0-10.0 [a]	11.0-13.5 [a]	[b]	6.0-6.5	7.5-8.0	8.0-8.5
110 km/h	Under 750	5.5-6.0	6.0-8.0	[b]	3.0-3.5	4.5-5.0	4.5-4.9
	750-1500	7.5-8.0	8.5-11.0 [a]	[b]	3.5-5.0	5.5-6.0	6.0-6.5
	1500-6000	8.5-10.0 [a]	10.5-13.0 [a]	[b]	5.0-6.0	6.5-7.5	8.0-8.5
	Over 6000	9.0-10.5 [a]	11.5-14.0 [a]	[b]	6.5-7.5	8.0-9.0	8.5-9.0

[a] Where a site-specific investigation indicates a high probability of continuing accidents or such occurrences are indicated by accident history, the designer may provide clear zone distances greater than 30 feet as indicated. Clear zones may be limited to 30 feet for practicality and to provide a consistent roadway template if previous experience with similar projects or designs indicates satisfactory performance.

[b] Since recovery is less likely on the unshielded, traversable 1:3 slopes, fixed objects should not be present in the vicinity of the toe of these slopes. Recovery of high-speed vehicles that encroach beyond the edge of shoulder may be expected to occur beyond the toe of slope. Determination of the width of the recovery area at the toe of slope should take into consideration right-of-way availability, environmental concerns, economic factors, safety needs, and accident histories. Also, the distance between the edge of the travel lane and the beginning of the 1:3 slope should influence the recovery area provided at the toe of slope.

Additional rollover (and other ROR) crash reduction could come from improved designs of roadside ditches. While the AASHTO *Roadside Design Guide* includes preferred foreslopes and backslopes for basic ditch configurations, these configurations are primarily seen on interstates and other higher-order roads and are often very different from the ditches on two-lane rural roads. Designs have not yet been developed to grade common two-lane shoulder-ditch combinations to reduce the chances of rollover and of vehicle encroachment across the ditch. Thus, based on today's knowledge, the best "rollover-prevention" program will be related to flattening and widening side slopes, particularly fill slopes.

In summary, based on research evidence to date, the set of strategies related to rollover (and ROR crash) reduction through changes in the "vertical" component of the sideslope (i.e., the degree and length or slope and related ditch design) would be considered "proven"[9] strategies.

[9] See explanation of ratings on page V-3.

Widening Clear Zones

Reducing rollover crashes is primarily accomplished by improvements to sideslopes and ditches. These are both components of the "clear zone"—the recovery area provided to vehicles that leave the roadway. In addition to modifying these "vertical" components of the clear zone, additional crash and fatality savings can be realized by modifying the width of the zone. The wider the object-free recovery area provided, the more likely an errant vehicle will either safely return to the travel lanes or stop on the roadside without a reportable crash. The width of the zone is normally set by either natural objects (e.g., trees, rock outcrops, embankments), or by roadside hardware (e.g., guardrails).

The question then becomes how wide to make the zone. While conventional wisdom (and the *Roadside Design Guide*) implies that a "safe clear zone width" on higher-speed roads is approximately 30 feet, *there is no single width that defines maximum safety*. Indeed, the guidance on clear zone width provided in the *Roadside Design Guide* is based on factors including design speed of the roadway, design ADT, the prevailing sideslope, and curvature. In general, the wider the better, up to some limit beyond which no significant number of vehicles will encroach.

Crash research provides a variety of approaches to answering the question of how wide a clear zone should be. For example, using crash, inventory, and ADT data from two states to study median widths (which act as "clear zones" for these freeways and other divided roads), Knuiman et al. (1993) found that accident rates continued to decrease as median widths increased up to about 80 feet. The effect was seen for head-on/opposite direction sideswipe crashes, as expected. A similar effect was also found for single- and multiple-vehicle crashes.

A 1995 study for the Texas DOT used a benefit-cost approach to establish guidelines for clear zone on suburban high-speed roadways with curb and gutter (Fambro et al., 1995). Based upon crash and roadside data and the ROADSIDE computer model, an appropriate and cost-beneficial clear zone width requirement was determined for such sections. "High-speed" was defined as a section with posted speed limits of 50 or 55 mph. The study focused on situations in which growth in traffic volume and frequency of turning movements necessitate the widening of an existing two-lane highway to four or more lanes. For this study, the baseline minimum clear zone width used in the calculation was approximately 10 feet. That is, even with added lanes, the existing right-of-way would allow at least 3.0 meters (10 feet) of clear zone. Based upon an incremental benefit-cost analysis for various combinations of baseline clear zone width, ADT, roadside hazard rating, and unit right-of-way acquisition cost, the study found the following in general:

- It is not cost-beneficial to purchase 5 feet or less of additional right-of-way (given an existing minimum clear zone of 10 feet), since the relatively high fixed cost for relocation of utility poles is still present even for the relatively modest safety benefits seen with these small right-of-way acquisitions.
- For unit right-of-way acquisition costs greater than $4 per square foot, it is not cost-beneficial to provide additional clear zone width through the purchase of additional right-of-way.
- For roadways with a low roadside hazard rating, it is not cost-beneficial to provide additional clear zone width beyond the existing baseline clear zone width of 10 feet or more.

These findings are for suburban roads rather than rural roads, and the fatality costs used in the calculations were $500,000. Higher fatality costs such as those used today would change these break-even points.

In summary, the determination of an optimum clear zone width may best be answered in some type of economic analysis—comparing the cost of widening the zone with the savings in crashes (along with other costs and benefits). Savings in crashes will be a function of the number of vehicles that leave the roadway (which is strongly related to ADT, alignment, and vehicle speeds); how far they encroach onto the roadside (a function of exit angle, speed, and driver braking and steering); and the nature of the object that will be struck at the far edge of the clear zone. In short, this is a complex prediction problem.

An economic analysis program has been developed to aid the user in this effort: the ROADSIDE computer program. Details of the program are found in the AASHTO *Roadside Design Guide*. A revised and improved version of this program (the *Roadside Safety Analysis Program*, or RSAP) is expected to be completed by the end of 2002 under NCHRP Project 22-9 (Sicking et al., 2003). In addition, both these programs are based on limited data concerning the critical factors of roadside encroachment rates and extents; AASHTO is currently updating these data as part of the work in NCHRP Project 17-11, being conducted by the Texas Transportation Institute.

The wider the clear zone, the safer it will be. While additional guidance on widths and slopes and economic analysis techniques should be developed within the next 1 to 5 years, the best current guidance on widths and slopes is in the AASHTO *Roadside Design Guide*. Based on the current research concerning crash-related effectiveness, strategies aimed at widening the clearzone are considered to have "proven" effectiveness.[10]

Improving Roadside Hardware and Natural Objects

The clear zone concept requires that no objects that can result in crashes be located in the zone. However, some objects must be located near the traveled way for a variety of reasons. These include hardware or objects related to traffic guidance or control (e.g., signs, some lighting supports); protection of more hazardous objects or situations (e.g., guardrails or median barriers); roadway design requirements (e.g., culverts); and traditional right-of-way uses (e.g., utility poles, mail boxes). Regardless of the reason, the best treatment for all objects is to remove them from the zone. If this cannot be done, alternative strategies include the following:

- Relocating the objects either farther from the traffic flow or to less hazardous locations (e.g., relocating utility poles from the outside to the inside of horizontal curves).
- Shielding or replacing "harder" objects with less hazardous breakaway devices (e.g., use of breakaway luminaire supports, or use of crash cushions in front of hazardous immovable objects).

The AASHTO *Roadside Design Guide* includes detailed discussion of this overall "forgiving roadside" strategy, along with design specifications, placement information and crash test

[10] See explanation of ratings on page V-3.

results for a large number of roadside hardware devices. The guide also includes criteria for use in determining which of the many alternative hardware types should be chosen for a specific application.

A final strategy for improving roadside hardware involves replacing less forgiving, older hardware with newer designs. The *Roadside Design Guide* is also a useful reference in this context, since it provides effectiveness information on both older and newer hardware designs. For example, there is a detailed discussion of the Breakaway Cable Terminal (BCT) guardrail end, including problems that have been experienced due to improper installation (e.g., a lack of critical "flare" from the roadway). The guide presents information on a series of possible replacement terminals, including the Modified Eccentric Loader Terminal (MELT) and others. The guide does not include information on older guardrail terminal designs such as blunt or turned-down ends. The clear implication is that these designs are much less safe than newer designs and should be replaced.

The *Roadside Design Guide* provides general direction for a number of different types of hardware regarding when an older, outdated piece of hardware should be replaced: "This device should no longer be used on new installations for higher volumes and speeds, and should be upgraded as required by the state's policies and practices during rehabilitation projects or as needed during maintenance operations." More detailed guidance is given for roadside barriers. The primary criterion is whether the older barrier meets current structural guidelines (based primarily on crash test results) or whether it meets current design and location guidelines (e.g., too short to protect the hazard or too close to the hazard, based upon barrier deflection characteristics).

In a limited number of cases, the FHWA required that states upgrade older hardware. The most recent example involves the BCT and MELT guardrail terminals. The FHWA and AASHTO agreed to use only terminals that pass new crash test standards in new construction and rehabilitation projects as of October 1, 1998. Since neither the BCT nor MELT passed the new standards, neither can be used in new construction or reconstruction projects. Unfortunately, as will be seen in the later Effectiveness section, most of the upgrading guidance cannot be based on accident studies, since almost none exist. Instead, it is based solely on crash test results. For more information on barriers and other safety devices that have been approved by the FHWA for use on National Highway System roads, see http://safety.fhwa.dot.gov/fourthlevel/pro_res_road_nchrp350.htm.

In summary, based upon current crash-related research, the relocation of "hard" objects farther from the roadway or their replacement with more forgiving designs (e.g., breakaway designs) are considered "proven"[11] strategies to reduce roadside harm. As will be seen below, the replacement of older "approved" barrier terminal designs with newer designs would be considered a "tried" strategy at this time, since sufficient real-world crash data have not been accumulated to move it into the "proven" category.

Delineation of Roadside Objects (Experimental Treatment)

The above described strategies for reducing roadside crash risk and severity have been evaluated to some extend either through crash testing or crash-based evaluations. At least

[11] See explanation of ratings on page V-3.

two states are currently pilot testing a low-cost *experimental*[12] strategy where roadside objects are delineated so that they are more visible to drivers at night. Pennsylvania is testing this strategy at sites with high ROR utility-pole and tree-related crash frequencies (particularly at night) where it was not feasible to remove or relocate the object either due to budget constraints or due to the object being on private property. The tree or utility pole is marked with a 4-inch round of reflective tape. (One round is used on each tree and each utility pole, except for poles at intersections where two rounds are used.) The treatment is being tested in 11 districts in over 50 counties. (See Appendix 1 for contact information.)

In the Iowa DOT pilot test, crash-prone utility poles that cannot be relocated or removed are being marked with a single band of 6-inch white reflective tape. Iowa identified corridors with high numbers of utility pole impacts from a statewide analysis and found that two 5- to 10-block corridors were in one city. One of the corridors was a four-lane street with higher speeds. The other included a 90-degree "bend" in the middle of the section. The Iowa DOT worked with the city (which owned the utility) in this effort. (See Appendix 6 for contact information.) They are now beginning to expand the pilot test to DOT districts.

The hypothesis is that such treatments could (a) provide additional guidance cues to the driver so that he or she is more likely to stay on the roadway (in the case of the regularly spaced utility poles); (b) make the hazard more visible (which might provide further "incentive" for staying on the roadway); or (c) provide "safer escape route" information to those vehicles that do leave the roadway (assuming the driver has time to react and to control the vehicle after leaving the roadway).

Pennsylvania has found that the utility pole tape can become detached and slide down the pole within a year in some cases. Iowa used an additional special adhesive to increase the life of the tape. Neither state has conducted what it considers to be a good evaluation of the utility pole tape, and so the utility pole tape's effectiveness is unknown. Therefore, the treatment must be considered *experimental*. It is unknown whether the additional visual input to the driver provided by these markings is beneficial or confusing. This should not be used in place of other nonexperimental treatment and should be pilot tested and evaluated before widespread use in any jurisdiction. (Note that these experimental strategies are not covered in Exhibit V-23.)

Targeting Roadside Improvements

Given the large number of miles of roadside and the expense of several of the important strategies (e.g., sideslope flattening or clear zone widening), it is important to target the various roadside improvement strategies to sites where they will be most beneficial. Targeting can be done in a number of ways, including the following:

- Using existing ROR crash data.
- Using computer programs like ROADSIDE and RSAP, which predict roadside crashes based upon roadway, roadside, and traffic descriptors.

[12] See explanation of ratings on page V-3.

- Correcting a "corridor" based upon the fact that the hardware or clear zones do not meet current agency standards. For example, Washington State uses this third approach, along with more traditional "high-hazard location" treatments.

Initial location of potential treatment sites might be accomplished using programs that states currently use to identify hazardous sections of roads. These programs could be modified to focus on ROR crashes. These initial candidates might be further examined by comparing ROR rates at these sites with overall ROR rates on similar highway classes (e.g., two-lane rural roads). Care must be taken to avoid selection bias resulting from regression to the mean.

Since the ROR crashes being targeted here are those occurring on "problem" roadsides, further office-based examination of potential sites might then be accomplished by review of agency photologs or videologs for these sites. Lastly, since the final decision concerning treatment alternatives and final implementation should be based upon cost-effectiveness, the ROADSIDE or RSAP program could be used to examine the benefits and costs of alternatives. A study of sideslope flattening in Washington State (Allaire et al., 1996) concluded that the use of benefit-cost analyses of roadside safety improvements should be included in all types of highway construction projects to better identify how best to use roadside safety funds.

Other innovative targeting schemes could be used if an agency has some form of roadside inventory or roadside hardware inventory. In this case, the inventory data could be either used alone or combined with the crash data to target treatment locations. For example, if an inventory of guardrail terminals exists or can be collected from "windshield surveys" or photo/videologs, an agency could target terminal upgrading efforts to designs known to have problems if installed improperly (e.g., the BCT device). Colorado has an inventory of certain classes of hardware and has attempted to develop such procedures.

Compatibility with Other Strategies

All roadside improvement strategies would appear to be compatible with other ROR strategies aimed at keeping the vehicle on the roadway. The roadside improvement strategies are aimed at vehicles that leave the roadway even in the presence of other treatments. In addition, since these strategies affect areas outside the shoulders, they are compatible with bicycle and other uses. Widening existing clear zones, through the removal of trees, is perhaps both the most effective and the most problematic (it is problematic when there is opposition to removal of trees alongside roadways). The reader is referred to Volume 3 of this report for a full discussion on this potential conflict.

EXHIBIT V-23
Strategy Attributes for Roadside Improvements

Technical Attributes	
Target	The targets for roadside improvement treatments are vehicles that leave the roadway, including those that return to the roadway out of control due to poor roadside design. However, the primary focus would be vehicles that strike objects on the roadside or overturn.
Expected Effectiveness	Three strategy areas have been covered for roadside improvements—rollover reduction due to flattening sideslopes, single-vehicle crash reduction due to flattening

EXHIBIT V-23 (Continued)
Strategy Attributes for Roadside Improvements

and widening sideslopes, and single-vehicle crash reduction and crash-severity reduction related to improvements in roadside hardware (e.g., replacing older hardware designs with newer designs). Historically, most roadside design and roadside hardware design improvements have been based on crash testing and recently on computer simulation. Due to the difficulty in collecting the necessary roadside inventory data to conduct a well-designed, accident-based study, few such studies exist. Thus, crash-based estimates of effectiveness are limited. Based upon these limited studies, the first two sets of strategies relating to sideslope and clear zone improvements are considered “proven” strategies. The replacement of older (approved) hardware with newer designs would be considered “tried” but not “proven” at this point due to the lack of crash-related evaluations. The following narrative describes some of the more important studies.

Zegeer, et al. (1987) examined the effects of sideslope on both rollover crashes and total single-vehicle crashes. They used field-measured crash, sideslope, cross section, and traffic data from approximately 1,800 miles on rural two-lane roads in three states. The rollover data were limited, making analysis of individual slope categories difficult. However, the authors found that rollover rates were significantly higher on slopes of 1:4 or steeper as compared with slopes of 1:5 or flatter. That is, in terms of rollover crashes, the 1:4 slopes were similar to the steeper 1:3 and 1:2 slopes. While the *Roadway Design Guide* would indicate the need for guardrail protection for 1:2 slopes, it would not for 1:3 slopes. The latter are generally considered to be “traversable – nonrecoverable,” indicating that the vehicle would be expected to either stop on such a slope or continue to the bottom of the slope without overturning.

Based upon the same study (and a much larger sample size), it is concluded that single-vehicle ROR crashes (which include, but are not limited to, rollovers) can be significantly reduced by flattening existing sideslopes to 1:4 or flatter. As shown in Exhibit V-24, the estimated reduction in single-vehicle ROR crashes on two-lane rural roads ranges up to approximately 27 percent (i.e., for flattening a 1:2 slope to 1:7 or flatter). Because ROR crashes are a major component of total crashes on two-lane rural roads, and because flatter and safer sideslopes can decrease some head-on and sideswipe crashes due to safer recoveries, the corresponding decrease in total crashes for this example is an estimated 15 percent. These estimates are made under the assumption that the clear zone width stays the same and that the resulting sideslope is relatively free of rigid objects.

The Washington State DOT funded a study by Allaire et al. (1996) to determine whether past sideslope flattening projects had reduced ROR collision frequencies and severities. Unlike other studies, the authors were able to conduct a before/after study of the effects of slope flattening based upon a detailed review of 60 3R projects implemented in 1986–1991. Each of these 60 projects called for sideslope flattening in at least some portion of the project. The authors were not able to develop benefit estimates for specific degrees of flattening (e.g., flattening a 1:3 slope to 1:6) due to insufficient data on the precise “before” conditions. However, they were able to examine the before-to-after reductions in crashes by severity level for the treated sections and to compare these changes with a series of “control” changes. These comparisons included comparisons of actual ROR collision rate per mile (by severity level) in the after period with predicted after rates corrected for “other improvements” such as object removal and clear zone widening; predicted after rates based on the experience of the entire 3R project length, much of which did not include slope flattening; and predicted after rates based on changes in the statewide rate for similar

(*continued on next page*)

EXHIBIT V-23 (Continued)
Strategy Attributes for Roadside Improvements

	roads during the same time period. In almost all cases, a statistically significant benefit of slope flattening was found. The percent reduction in ROR collision rates varied by comparison and by injury severity class from approximately 3 to 50 percent. Based upon examination of the tables, the estimated "median" reduction in ROR crash rate is approximately 25 to 45 percent. Zegeer et al. (1987) also estimated the effects of clear zone widening on two-lane rural roads. If the existing recovery area measured from the edgeline is less than 10 to 15 feet, Exhibit V-25 presents the expected percentage reduction in "related crashes" (i.e., ROR, head-on, and sideswipe) due to clear zone widening by a given amount. For example, widening by 10 feet is predicted to result in a 25-percent reduction in these crashes. With respect to removing roadside hardware from the clear zone or relocating it farther from the travel way, a study by Zegeer et al. (1990) developed the effectiveness estimates shown in Exhibit V-26 for *two-lane rural roads.* As can be seen, for example, moving culvert headwalls from 5 to 15 feet from the roadway would result in an expected 40-percent reduction in culvert headwall collisions on two-lane rural roads. Placing guardrails an additional 5 feet from the roadway would be expected to reduce the corresponding guardrail accidents by 53 percent. These estimates are based upon the assumptions that removal of a specific object leaves a wider clear zone and that other potentially hazardous objects do not remain at the same distance from the roadway. For example, if the culverts are at the edge of a row of large trees, then it is likely that culvert crashes will only be replaced by additional tree crashes. The third strategy noted above involves the upgrading of existing roadside hardware. In a recent study, Ray (2000) examined the possible effects of upgrading guardrail terminals (e.g., BCT and MELT designs) to a newer design (the ET-2000) that does pass upgraded crash test standards. The author examined both past accident-based studies of the older designs in five states and recent data on the older and newer designs in three states. He used data from both police-reported and nonreported (maintenance) cases where available. He concluded that while the samples were small and the results varied greatly across the studies, he could detect no statistically significant difference in injury severity among the three designs for properly installed terminals. The author stressed the need for proper installation, since there is evidence that the BCT device was not installed properly (i.e., improper flare and offset from the travel lane) in a significant number of cases. And some data in earlier studies indicate that these improper installations are more hazardous (Morena and Schroeder, 1994; Agent and Pigman, 1991). Thus, one might expect an improvement from upgrading improperly installed BCT devices, for example.
Keys to Success	Keys to success would include accurate targeting; appropriate levels of funding (since most of these strategies can be relatively high cost); and a cooperative program among all agency divisions that can affect the roadside crash problem when a high-crash site is identified (e.g., traffic or safety engineering); during construction or reconstruction (e.g., roadway design division); or during normal maintenance operations (e.g., roadway maintenance forces). Appropriate targeting and analysis will require the development and regular use of methods for identifying sites with ROR crash problems related to the roadside.
Potential Difficulties	As noted above, simple clearing and grading to create small additions to the clear zone (e.g., 5 to 10 feet) on steeper sideslopes (e.g., 1:3 or 1:4) under high-speed conditions may not prove to be effective, since the vehicles entering the roadside may continue, due to the effect of the slope, to either overturn or traverse the clear zone and strike objects at its far edge. The other potential pitfall could be public reaction to tree cutting without appropriate public education, as well as coordination with environmental and other public groups.

EXHIBIT V-23 (Continued)
Strategy Attributes for Roadside Improvements

Appropriate Measures and Data	The most appropriate measures will depend upon the strategy implemented, but would include *process measures* such as *miles of roadside treated, number and type of hazardous objects removed or relocated,* and *number and type of older devices upgraded.* *Impact measures* must include both *crash frequency or rate* and *crash severity,* since some strategies will be successful even if only severity is affected. Since targeting and site analysis appear to be keys to success, data needs would include accident, roadway and roadside inventory, and traffic data of sufficient accuracy and detail. The data most often missing are for the roadside inventory.
Associated Needs	As noted above, since tree clearing is a major component of some of these strategies, and since the public can view such tree removal negatively, there is a need for public information before tree-related strategies are employed. See Volume 3 of this report for more information.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	While the primary agency would be the highway agency responsible for the right-of-way, certain strategies would clearly require participation of other agencies and public and private groups (e.g., strategies involving tree removal or utility pole relocation or removal). (See note on the need for a cooperative, multiagency program under “Keys to Success” above.) Since cooperation among various governmental and private groups is necessary if tree clearing is anticipated, see the more detailed discussion in Volume 3 of this report. An organizational safety philosophy is needed that includes willingness to implement more than just low-cost improvements to optimize results. Many of these strategies are higher-cost strategies, but offer higher potential payoff.
Issues Affecting Implementation Time	The timeframe required will depend on the strategy chosen. It could be relatively short for treatments such as replacing older hardware at a specific location, but much longer if applied to an entire corridor or route system or if the treatment involved new right-of-way acquisition.
Costs Involved	Costs of these strategies can vary widely depending on the strategy chosen. Factors include whether new right-of-way is required or whether the treatment can be implemented as part of other rehabilitation or original construction efforts.
Training and Other Personnel Needs	Since most of these strategies are being implemented by many state highway agencies as part of construction or rehabilitation, there would appear to be no special personnel or training needs for implementing these strategies.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

EXHIBIT V-24
Percentage Reduction of Single-Vehicle and Total Crashes Due to Sideslope Flattening on Two-Lane Rural Roads (From Zegeer et al., 1987)

Sideslope Before Condition	Sideslope After Condition							
	1:4		1:5		1:6		1:7 or Flatter	
	SV	Total	SV	Total	SV	Total	SV	Total
1:2	10	6	15	9	21	12	27	15
1:3	8	5	14	8	19	11	26	15
1:4	0	-	6	3	12	7	19	11
1:5	-	-	0	-	6	3	14	8
1:6	-	-	-	-	0	-	8	5

EXHIBIT V-25
Percent Reductions in "Related Accidents" Due to Increasing the Roadside Clear Recovery Distance on Two-Lane Rural Roads*

Amount of Increased Roadside Recovery Distance, meters (feet)	Percent Reduction in Related Accident Types (i.e., ROR+head-on+sideswipe)
1.5 (5)	13%
2.4 (8)	21
3.1 (10)	25
3.7 (12)	29
4.6 (15)	35
6.2 (20)	44

*Note that "related accidents" would be the total of ROR, head-on, and sideswipe crashes.

EXHIBIT V-26
Percent Reductions in Specific Types of Obstacle Accidents Due to Clearing/Relocating Obstacles Farther from the Roadway (Zegeer et al., 1990)

Increase in Obstacle Distance in meters (feet)	Mailboxes, Culverts, and Signs (%)	Guardrails (%)	Fences/Gates (%)
0.9 (3)	14	36	20
1.5 (5)	23	53	30
2.4 (8)	34	70	44
3.1 (10)	40	78	52
4.0 (13)	N.F.	N.F.	N.F.
4.6 (15)	N.F.	N.F.	N.F.

Notes:
N.F. = generally not feasible to relocate obstacles to specified distance.
The table is only appropriate for obstacle distance of 30 feet or less and only on two-lane roadways.

Information on Agencies or Organizations Currently Implementing this Strategy

Many state and local agencies implement clear zone policies for roadway construction. Some are implementing programs aimed at improving the clear zone, including programs focused upon flattening roadside slopes. Examples include the Washington State DOT 3R program, Washington's utility pole relocation program (which will be covered in an upcoming volume of this report), and Pennsylvania's tree removal program (see Volume 3 of this report). As required by FHWA, all states are using newer guardrail end terminal designs in new construction and reconstruction, and other hardware is often upgraded in major reconstruction projects. No states have been identified that are currently replacing older hardware on a systemwide basis. Finally, the Pennsylvania DOT is exploring the use of single-faced concrete barriers (instead of guardrail) in urban/suburban locations where the right-of-way is restricted and there is no option to relocate utility poles or to improve sideslopes.

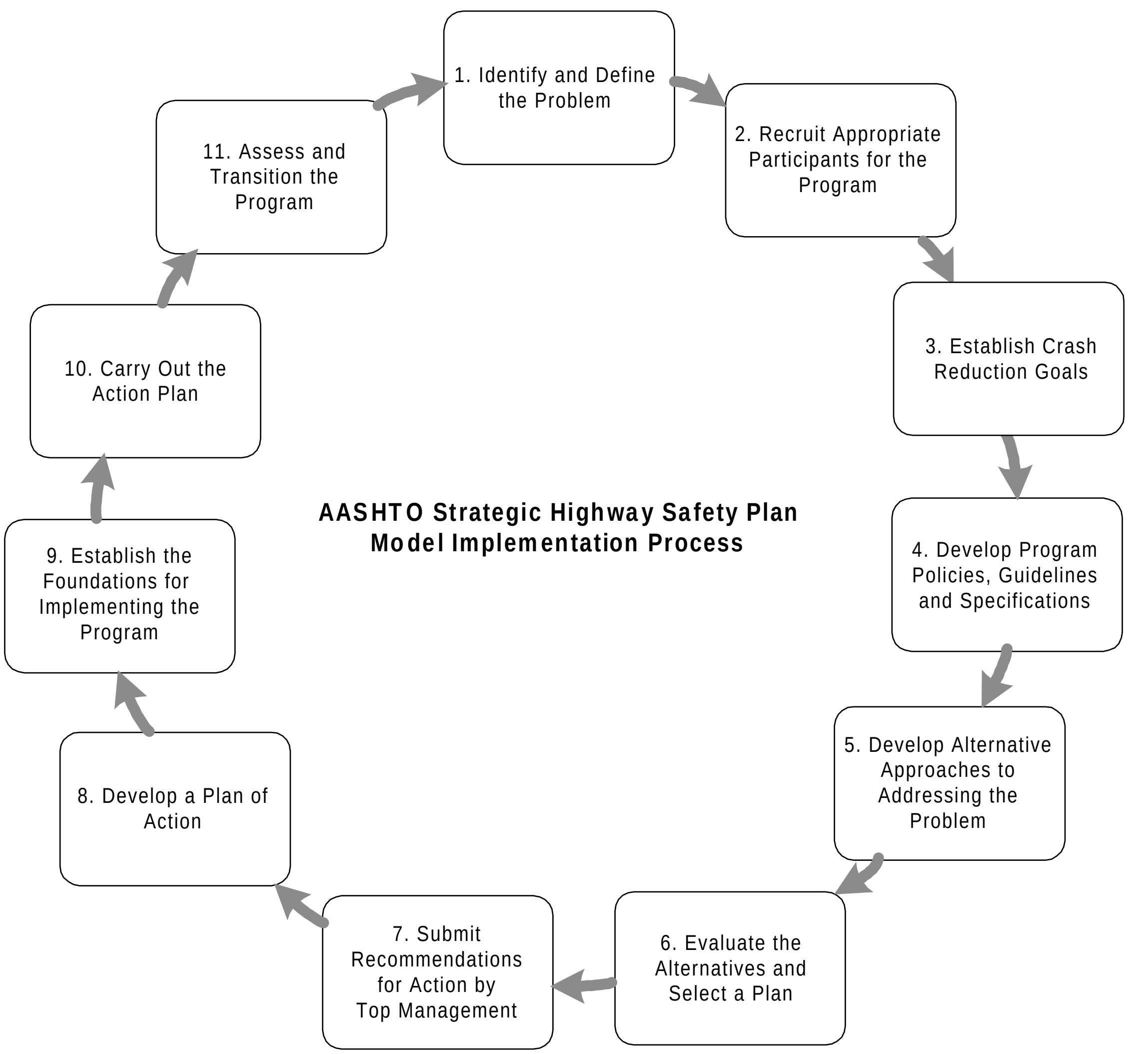
SECTION VI

Guidance for Implementation of the AASHTO Strategic Highway Safety Plan

Outline for a Model Implementation Process

Exhibit VI-1 gives an overview of an 11-step model process for implementing a program of strategies for any given emphasis area of the AASHTO Strategic Highway Safety Plan. After a short introduction, each of the steps is outlined in further detail.

EXHIBIT VI-1



Purpose of the Model Process

The process described in this section is provided as a model rather than a standard. Many users of this guide will already be working within a process established by their agency or working group. It is not suggested that their process be modified to conform to this one. However, the model process may provide a useful checklist. For those not having a standard process to follow, it is recommended that the model process be used to help establish an appropriate one for their initiative. Not all steps in the model process need to be performed at the level of detail indicated in the outlines below. The degree of detail and the amount of work required to complete some of these steps will vary widely, depending upon the situation.

It is important to understand that the process being presented here is assumed to be conducted only as a part of a broader, strategic-level safety management process. The details of that process, and its relation to this one, may be found in a companion guide. (The companion guide is a work in progress at this writing. When it is available, it will be posted online at http://transportation1.org/safetyplan.)

Overview of the Model Process

The process (see Exhibit VI-1, above) must be started at top levels in the lead agency's organization. This would, for example, include the CEO, DOT secretary, or chief engineer, as appropriate. Here, decisions will have been made to focus the agency's attention and resources on specific safety problems based upon the particular conditions and characteristics of the organization's roadway system. This is usually, but not always, documented as a result of the strategic-level process mentioned above. It often is publicized in the form of a "highway safety plan." Examples of what states produce include Wisconsin DOT's Strategic Highway Safety Plan (see Appendix A) and Iowa's Safety Plan (available at http://www.iowasms.org/toolbox.htm).

Once a "high-level" decision has been made to proceed with a particular emphasis area, the first step is to describe, in as much detail as possible, the problem that has been identified in the high-level analysis. The additional detail helps confirm to management that the problem identified in the strategic-level analysis is real and significant and that it is possible to do something about it. The added detail that this step provides to the understanding of the problem will also play an important part in identifying alternative approaches for dealing with it.

Step 1 should produce endorsement and commitments from management to proceed, at least through a planning process. With such an endorsement, it is then necessary to identify the stakeholders and define their role in the effort (Step 2). It is important at this step to identify a range of participants in the process who will be able to help formulate a comprehensive approach to the problem. The group will want to consider how it can draw upon potential actions directed at

- Driver behavior (legislation, enforcement, education, and licensing),
- Engineering,

- Emergency medical systems, and
- System management.

With the establishment of a working group, it is then possible to finalize an understanding of the nature and limitations of what needs to be done in the form of a set of program policies, guidelines, and specifications (Steps 3 and 4). An important aspect of this is establishing targets for crash reduction in the particular emphasis area (Step 3). Identifying stakeholders, defining their roles, and forming guidelines and policies are all elements of what is often referred to as "chartering the team." In many cases, and in particular where only one or two agencies are to be involved and the issues are not complex, it may be possible to complete Steps 1 through 4 concurrently.

Having received management endorsement and chartered a project team—the foundation for the work—it is now possible to proceed with project planning. The first step in this phase (Step 5 in the overall process) is to identify alternative strategies for addressing the safety problems that have been identified while remaining faithful to the conditions established in Steps 2 through 4.

With the alternative strategies sufficiently defined, they must be evaluated against one another (Step 6) and as groups of compatible strategies (i.e., a total program). The results of the evaluation will form the recommended plan. The plan is normally submitted to the appropriate levels of management for review and input, resulting ultimately in a decision on whether and how to proceed (Step 7). Once the working group has been given approval to proceed, along with any further guidelines that may have come from management, the group can develop a detailed plan of action (Step 8). This is sometimes referred to as an "implementation" or "business" plan.

Plan implementation is covered in Steps 9 and 10. There often are underlying activities that must take place prior to implementing the action plan to form a foundation for what needs to be done (Step 9). This usually involves creating the organizational, operational, and physical infrastructure needed to succeed. The major step (Step 10) in this process involves doing what was planned. This step will in most cases require the greatest resource commitment of the agency. An important aspect of implementation involves maintaining appropriate records of costs and effectiveness to allow the plan to be evaluated after-the-fact.

Evaluating the program, after it is underway, is an important activity that is often overlooked. Management has the right to require information about costs, resources, and effectiveness. It is also likely that management will request that the development team provide recommendations about whether the program should be continued and, if so, what revisions should be made. Note that management will be deciding on the future for any single emphasis area in the context of the entire range of possible uses of the agency's resources. Step 11 involves activities that will give the desired information to management for each emphasis area.

To summarize, the implementation of a program of strategies for an emphasis area can be characterized as an 11-step process. The steps in the process correspond closely to a 4-phase approach commonly followed by many transportation agencies:

- Endorsement and chartering of the team and project (Steps 1 through 4),
- Project planning (Steps 5 through 8),
- Plan implementation (Steps 9 and 10), and
- Plan evaluation (Step 11).

Details about each step follow. The Web-based version of this description is accompanied by a set of supplementary material to enhance and illustrate the points.

The model process is intended to provide a framework for those who need it. It is not intended to be a how-to manual. There are other documents that provide extensive detail regarding how to conduct this type of process. Some general ones are covered in Appendix B and Appendix C. Others, which relate to specific aspects of the process, are referenced within the specific sections to which they apply.

Implementation Step 1: Identify and Define the Problem

General Description

Program development begins with gathering data and creating and analyzing information. The implementation process being described in this guide is one that will be done in the context of a larger strategic process. It is expected that this guide will be used when the strategic process, or a project-level analysis, has identified a potentially significant problem in this emphasis area.

Data analyses done at the strategic level normally are done with a limited amount of detail. They are usually the top layer in a "drill-down" process. Therefore, while those previous analyses should be reviewed and used as appropriate, it will often be the case that further studies are needed to completely define the issues.

It is also often the case that a core technical working group will have been formed by the lead agency to direct and carry out the process. This group can conduct the analyses required in this step, but should seek, as soon as possible, to involve any other stakeholders who may desire to provide input to this process. Step 2 deals further with the organization of the working group.

The objectives of this first step are as follows:

1. Confirm that a problem exists in this emphasis area.
2. Detail the characteristics of the problem to allow identification of likely approaches for eliminating or reducing it.
3. Confirm with management, given the new information, that the planning and implementation process should proceed.

The objectives will entail locating the best available data and analyzing them to highlight either geographic concentrations of the problem or over-representation of the problem within the population being studied.

Identification of existing problems is *a responsive approach*. This can be complemented by a *proactive approach* that seeks to identify potentially hazardous conditions or populations.

For the responsive type of analyses, one generally begins with basic crash records that are maintained by agencies within the jurisdiction. This is usually combined, where feasible, with other safety data maintained by one or more agencies. The other data could include

- Roadway inventory,
- Driver records (enforcement, licensing, courts), or
- Emergency medical service and trauma center data.

To have the desired level of impact on highway safety, it is important to consider the highway system as a whole. Where multiple jurisdictions are responsible for various parts of the system, they should all be included in the analysis, wherever possible. The best example of this is a state plan for highway safety that includes consideration of the extensive mileage administered by local agencies. To accomplish problem identification in this manner will require a cooperative, coordinated process. For further discussion on the problem identification process, see Appendix D and the further references contained therein.

In some cases, very limited data are available for a portion of the roads in the jurisdiction. This can occur for a local road maintained by a state or with a local agency that has very limited resources for maintaining major databases. Lack of data is a serious limitation to this process, but must be dealt with. It may be that for a specific study, special data collection efforts can be included as part of the project funding. While crash records may be maintained for most of the roads in the system, the level of detail, such as good location information, may be quite limited. It is useful to draw upon local knowledge to supplement data, including

- Local law enforcement,
- State district and maintenance engineers,
- Local engineering staff, and
- Local residents and road users.

These sources of information may provide useful insights for identifying hazardous locations. In addition, local transportation agencies may be able to provide supplementary data from their archives. Finally, some of the proactive approaches mentioned below may be used where good records are not available.

Maximum effectiveness often calls for going beyond data in the files to include special supplemental data collected on crashes, behavioral data, site inventories, and citizen input. Analyses should reflect the use of statistical methods that are currently recognized as valid within the profession.

Proactive elements could include

- Changes to policies, design guides, design criteria, and specifications based upon research and experience;
- Retrofitting existing sites or highway elements to conform to updated criteria (perhaps with an appropriate priority scheme);
- Taking advantage of lessons learned from previous projects;
- Road safety audits, including on-site visits;
- Safety management based on roadway inventories;
- Input from police officers and road users; and
- Input from experts through such programs as the NHTSA traffic records assessment team.

The result of this step is normally a report that includes tables and graphs that clearly demonstrate the types of problems and detail some of their key characteristics. Such reports should be presented in a manner to allow top management to quickly grasp the key findings and help them decide which of the emphasis areas should be pursued further, and at what level of funding. However, the report must also document the detailed work that has been done, so that those who do the later stages of work will have the necessary background.

Specific Elements

1. Define the scope of the analysis
    - 1.1. All crashes in the entire jurisdiction
    - 1.2. A subset of crash types (whose characteristics suggest they are treatable, using strategies from the emphasis area)
    - 1.3. A portion of the jurisdiction
    - 1.4. A portion of the population (whose attributes suggest they are treatable using strategies from the emphasis area)
2. Define safety measures to be used for responsive analyses
    - 2.1. Crash measures
        - 2.1.1. Frequency (all crashes or by crash type)
        - 2.1.2. Measures of exposure
        - 2.1.3. Decide on role of frequency versus rates
    - 2.2. Behavioral measures
        - 2.2.1. Conflicts
        - 2.2.2. Erratic maneuvers
        - 2.2.3. Illegal maneuvers
        - 2.2.4. Aggressive actions
        - 2.2.5. Speed
    - 2.3. Other measures
        - 2.3.1. Citizen complaints
        - 2.3.2. Marks or damage on roadway and appurtenances, as well as crash debris
3. Define measures for proactive analyses
    - 3.1. Comparison with updated and changed policies, design guides, design criteria, and specifications
    - 3.2. Conditions related to lessons learned from previous projects
    - 3.3. Hazard indices or risk analyses calculated using data from roadway inventories to input to risk-based models
    - 3.4. Input from police officers and road users
4. Collect data
    - 4.1. Data on record (e.g., crash records, roadway inventory, medical data, driver-licensing data, citations, other)
    - 4.2. Field data (e.g., supplementary crash and inventory data, behavioral observations, operational data)
    - 4.3. Use of road safety audits, or adaptations
5. Analyze data
    - 5.1. Data plots (charts, tables, and maps) to identify possible patterns, and concentrations (See Appendixes Y, Z and AA for examples of what some states are doing)

- 5.2. Statistical analysis (high-hazard locations, over-representation of contributing circumstances, crash types, conditions, and populations)
- 5.3. Use expertise, through road safety audits or program assessment teams
- 5.4. Focus upon key attributes for which action is feasible:
  - 5.4.1. Factors potentially contributing to the problems
  - 5.4.2. Specific populations contributing to, and affected by, the problems
  - 5.4.3. Those parts of the system contributing to a large portion of the problem

6. Report results and receive approval to pursue solutions to identified problems (a*pprovals being sought here are primarily a confirmation of the need to proceed and likely levels of resources required*)
   - 6.1. Sort problems by type
     - 6.1.1. Portion of the total problem
     - 6.1.2. Vehicle, highway/environment, enforcement, education, other driver actions, emergency medical system, legislation, and system management
     - 6.1.3. According to applicable funding programs
     - 6.1.4. According to political jurisdictions
   - 6.2. Preliminary listing of the types of strategies that might be applicable
   - 6.3. Order-of-magnitude estimates of time and cost to prepare implementation plan
   - 6.4. Listing of agencies that should be involved, and their potential roles (including an outline of the organizational framework intended for the working group). Go to Step 2 for more on this.

Implementation Step 2: Recruit Appropriate Participants for the Program

General Description

A critical early step in the implementation process is to engage all the stakeholders that may be encompassed within the scope of the planned program. The stakeholders may be from outside agencies (e.g., state patrol, county governments, or citizen groups). One criterion for participation is if the agency or individual will help ensure a comprehensive view of the problem and potential strategies for its resolution. If there is an existing structure (e.g., a State Safety Management System Committee) of stakeholders for conducting strategic planning, it is important to relate to this, and build on it, for addressing the detailed considerations of the particular emphasis area.

There may be some situations within the emphasis area for which no other stakeholders may be involved other than the lead agency and the road users. However, in most cases, careful consideration of the issues will reveal a number of potential stakeholders to possibly be involved. Furthermore, it is usually the case that a potential program will proceed better in the organizational and institutional setting if a high-level "champion" is found in the lead agency to support the effort and act as a key liaison with other stakeholders.

Stakeholders should already have been identified in the previous step, at least at a level to allow decision makers to know whose cooperation is needed, and what their potential level of involvement might be. During this step, the lead agency should contact the key individuals in each of the external agencies to elicit their participation and cooperation. This will require identifying the right office or organizational unit, and the appropriate people in each case. It will include providing them with a brief overview document and outlining for them the type of involvement envisioned. This may typically involve developing interagency agreements. The participation and cooperation of each agency should be secured to ensure program success.

Lists of appropriate candidates for the stakeholder groups are recorded in Appendix K. In addition, reference may be made to the NHTSA document at http://www.nhtsa.dot.gov/safecommunities/SAFE%20COMM%20Html/index.html, which provides guidance on building coalitions.

Specific Elements

1. Identify internal "champions" for the program
2. Identify the suitable contact in each of the agencies or private organizations who is appropriate to participate in the program
3. Develop a brief document that helps sell the program and the contact's role in it by
    - 3.1. Defining the problem
    - 3.2. Outlining possible solutions
    - 3.3. Aligning the agency or group mission by resolving the problem
    - 3.4. Emphasizing the importance the agency has to the success of the effort

   - 3.5. Outlining the organizational framework for the working group and other stakeholders cooperating on this effort
   - 3.6. Outlining the rest of the process in which agency staff or group members are being asked to participate
   - 3.7. Outlining the nature of commitments desired from the agency or group for the program
   - 3.8. Establishing program management responsibilities, including communication protocols, agency roles, and responsibilities
   - 3.9. Listing the purpose for an initial meeting
4. Meet with the appropriate representative
   - 4.1. Identify the key individual(s) in the agency or group whose approval is needed to get the desired cooperation
   - 4.2. Clarify any questions or concepts
   - 4.3. Outline the next steps to get the agency or group onboard and participating
5. Establish an organizational framework for the group
   - 5.1. Roles
   - 5.2. Responsibilities

Implementation Step 3: Establish Crash Reduction Goals

General Description

The AASHTO Strategic Highway Safety Plan established a national goal of saving 5,000 to 7,000 lives annually by the year 2003 to 2005. Some states have established statewide goals for the reduction of fatalities or crashes of a certain degree of severity. Establishing an explicit goal for crash reduction can place an agency "on the spot," but it usually provides an impetus to action and builds a support for funding programs for its achievement. Therefore, it is desirable to establish, within each emphasis area, one or more crash reduction targets.

These may be dictated by strategic-level planning for the agency, or it may be left to the stakeholders to determine. (The summary of the Wisconsin DOT Highway Safety Plan in Appendix A has more information.) For example, Pennsylvania adopted a goal of 10 percent reduction in fatalities by 2002,[1] while California established a goal of 40 percent reduction in fatalities and 15 percent reduction in injury crashes, as well as a 10 percent reduction in work zone crashes, in 1 year.[2] At the municipal level, Toledo, Ohio, is cited by the U.S. Conference of Mayors as having an exemplary program. This included establishing specific crash reduction goals (http://www.usmayors.org/uscm/uscm_projects_services/health/traffic/best_traffic_initiative_toledo.htm). When working within an emphasis area, it may be desirable to specify certain types of crashes, as well as the severity level, being targeted.

There are a few key considerations for establishing a quantitative goal. The stakeholders should achieve consensus on this issue. The goal should be challenging, but achievable. Its feasibility depends in part on available funding, the timeframe in which the goal is to be achieved, the degree of complexity of the program, and the degree of controversy the program may experience. To a certain extent, the quantification of the goal will be an iterative process. If the effort is directed at a particular location, then this becomes a relatively straightforward action.

Specific Elements

1. Identify the type of crashes to be targeted
    - 1.1. Subset of all crash types
    - 1.2. Level of severity
2. Identify existing statewide or other potentially related crash reduction goals
3. Conduct a process with stakeholders to arrive at a consensus on a crash reduction goal
    - 3.1. Identify key considerations
    - 3.2. Identify past goals used in the jurisdiction
    - 3.3. Identify what other jurisdictions are using as crash reduction goals
    - 3.4. Use consensus-seeking methods, as needed

[1] Draft State Highway Safety Plan, State of Pennsylvania, July 22, 1999
[2] Operations Program Business Plan, FY 1999/2000, State of California, Caltrans, July 1999

Implementation Step 4: Develop Program Policies, Guidelines, and Specifications

General Description

A foundation and framework are needed for solving the identified safety problems. The implementation process will need to be guided and evaluated according to a set of goals, objectives, and related performance measures. These will formalize what the intended result is and how success will be measured. The overlying crash reduction goal, established in Step 3, will provide the context for the more specific goals established in this step. The goals, objectives, and performance measures will be used much later to evaluate what is implemented. Therefore, they should be jointly outlined at this point and agreed to by all program stakeholders. It is important to recognize that evaluating any actions is an important part of the process. Even though evaluation is not finished until some time after the strategies have been implemented, it begins at this step.

The elements of this step may be simpler for a specific project or location than for a comprehensive program. However, even in the simpler case, policies, guidelines, and specifications are usually needed. Furthermore, some programs or projects may require that some guidelines or specifications be in the form of limits on directions taken and types of strategies considered acceptable.

Specific Elements

1. Identify high-level policy actions required and implement them (legislative and administrative)
2. Develop goals, objectives, and performance measures to guide the program and use for assessing its effect
    - 2.1. Hold joint meetings of stakeholders
    - 2.2. Use consensus-seeking methods
    - 2.3. Carefully define terms and measures
    - 2.4. Develop report documenting results and validate them
3. Identify specifications or constraints to be used throughout the project
    - 3.1. Budget constraints
    - 3.2. Time constraints
    - 3.3. Personnel training
    - 3.4. Capacity to install or construct
    - 3.5. Types of strategies not to be considered or that must be included
    - 3.6. Other

Implementation Step 5: Develop Alternative Approaches to Addressing the Problem

General Description

Having defined the problem and established a foundation, the next step is to find ways to address the identified problems. If the problem identification stage has been done effectively (see Appendix D for further details on identifying road safety problems), the characteristics of the problems should suggest one or more alternative ways for dealing with the problem. It is important that a full range of options be considered, drawing from areas dealing with enforcement, engineering, education, emergency medical services, and system management actions.

Alternative strategies should be sought for both location-specific and systemic problems that have been identified. Location-specific strategies should pertain equally well to addressing high-hazard locations and to solving safety problems identified within projects that are being studied for reasons other than safety.

Where site-specific strategies are being considered, visits to selected sites may be in order if detailed data and pictures are not available. In some cases, the emphasis area guides will provide tables that help connect the attributes of the problem with one or more appropriate strategies to use as countermeasures.

Strategies should also be considered for application on a systemic basis. Examples include

1. Low-cost improvements targeted at problems that have been identified as significant in the overall highway safety picture, but not concentrated in a given location.
2. Action focused upon a specific driver population, but carried out throughout the jurisdiction.
3. Response to a change in policy, including modified design standards.
4. Response to a change in law, such as adoption of a new definition for DUI.

In some cases, a strategy may be considered that is relatively untried or is an innovative variation from past approaches to treatment of a similar problem. Special care is needed to ensure that such strategies are found to be sound enough to implement on a wide-scale basis. Rather than ignoring this type of candidate strategy in favor of the more "tried-and-proven" approaches, consideration should be given to including a pilot-test component to the strategy.

The primary purpose of this guide is to provide a set of strategies to consider for eliminating or lessening the particular road safety problem upon which the user is focusing. As pointed out in the first step of this process, the identification of the problem, and the selection of strategies, is a complex step that will be different for each case. Therefore, it is not feasible to provide a "formula" to follow. However, guidelines are available. There are a number of texts to which the reader can refer. Some of these are listed in Appendix B and Appendix D.

In addition, the tables referenced in Appendix G provide examples for linking identified problems with candidate strategies.

The second part of this step is to assemble sets of strategies into alternative "program packages." Some strategies are complementary to others, while some are more effective when combined with others. In addition, some strategies are mutually exclusive. Finally, strategies may be needed to address roads across multiple jurisdictions. For instance, a package of strategies may need to address both the state and local highway system to have the desired level of impact. The result of this part of the activity will be a set of alternative "program packages" for the emphasis area.

It may be desirable to prepare a technical memorandum at the end of this step. It would document the results, both for input into the next step and for internal reviews. The latter is likely to occur, since this is the point at which specific actions are being seriously considered.

Specific Elements

1. Review problem characteristics and compare them with individual strategies, considering both their objectives and their attributes
    - 1.1. Road-user behavior (law enforcement, licensing, adjudication)
    - 1.2. Engineering
    - 1.3. Emergency medical services
    - 1.4. System management elements
2. Select individual strategies that do the following:
    - 2.1. Address the problem
    - 2.2. Are within the policies and constraints established
    - 2.3. Are likely to help achieve the goals and objectives established for the program
3. Assemble individual strategies into alternative program packages expected to optimize achievement of goals and objectives
    - 3.1. Cumulative effect to achieve crash reduction goal
    - 3.2. Eliminate strategies that can be identified as inappropriate, or likely to be ineffective, even at this early stage of planning
4. Summarize the plan in a technical memorandum, describing attributes of individual strategies, how they will be combined, and why they are likely to meet the established goals and objectives

Implementation Step 6: Evaluate Alternatives and Select a Plan

General Description

This step is needed to arrive at a logical basis for prioritizing and selecting among the alternative strategies or program packages that have been developed. There are several activities that need to be performed. One proposed list is shown in Appendix P.

The process involves making estimates for each of the established performance measures for the program and comparing them, both individually and in total. To do this in a quantitative manner requires some basis for estimating the effectiveness of each strategy. Where solid evidence has been found on effectiveness, it has been presented for each strategy in the guide. In some cases, agencies have a set of crash reduction factors that are used to arrive at effectiveness estimates. Where a high degree of uncertainty exists, it is wise to use sensitivity analyses to test the validity of any conclusions that may be made regarding which is the best strategy or set of strategies to use. Further discussion of this may be found in Appendix O.

Cost-benefit and cost-effectiveness analyses are usually used to help identify inefficient or inappropriate strategies, as well as to establish priorities. For further definition of the two terms, see Appendix Q. For a comparison of the two techniques, see Appendix S. Aspects of feasibility, other than economic, must also be considered at this point. An excellent set of references is provided within online benefit-cost guides:

- One is under development at the following site, maintained by the American Society of Civil Engineers: http://ceenve.calpoly.edu/sullivan/cutep/cutep_bc_outline_main.htm

- The other is *Guide to Benefit-Cost Analysis in Transport Canada*, September 1994, http://www.tc.gc.ca/finance/bca/en/TOC_e.htm. An overall summary of this document is given in Appendix V.

In some cases, a strategy or program may look promising, but no evidence may be available as to its likely effectiveness. This would be especially true for innovative methods or use of emerging technologies. In such cases, it may be advisable to plan a pilot study to arrive at a minimum level of confidence in its effectiveness, before large-scale investment is made or a large segment of the public is involved in something untested.

It is at this stage of detailed analysis that the crash reduction goals, set in Step 3, may be revisited, with the possibility of modification.

It is important that this step be conducted with the full participation of the stakeholders. If the previous steps were followed, the working group will have the appropriate representation. Technical assistance from more than one discipline may be necessary to go through more complex issues. Group consensus will be important on areas such as estimates of effectiveness, as well as the rating and ranking of alternatives. Techniques are available to assist in arriving at consensus. For example, see the following Web site for an overview: http://web.mit.edu/publicdisputes/practices/cbh_ch1.html.

Specific Elements

1. Assess feasibility
    1.1. Human resources
    1.2. Special constraints
    1.3. Legislative requirements
    1.4. Other
    1.5. This is often done in a qualitative way, to narrow the list of choices to be studied in more detail (see, for example, Appendix BB)
2. Estimate values for each of the performance measures for each strategy and plan
    2.1. Estimate costs and impacts
        2.1.1. Consider guidelines provided in the detailed description of strategies in this material
        2.1.2. Adjust as necessary to reflect local knowledge or practice
        2.1.3. Where a plan or program is being considered that includes more than one strategy, combine individual estimates
    2.2. Prepare results for cost-benefit and/or cost-effectiveness analyses
    2.3. Summarize the estimates in both disaggregate (by individual strategy) and aggregate (total for the program) form
3. Conduct a cost-benefit and/or cost-effectiveness analysis to identify inefficient, as well as dominant, strategies and programs and to establish a priority for the alternatives
    3.1. Test for dominance (both lower cost and higher effectiveness than others)
    3.2. Estimate relative cost-benefit and/or cost-effectiveness
    3.3. Test productivity
4. Develop a report that documents the effort, summarizing the alternatives considered and presenting a preferred program, as devised by the working group (for suggestions on a report of a benefit-cost analysis, see Appendix U).
    4.1. Designed for high-level decision makers, as well as technical personnel who would be involved in the implementation
    4.2. Extensive use of graphics and layout techniques to facilitate understanding and capture interest
    4.3. Recommendations regarding meeting or altering the crash reduction goals established in Step 3.

Implementation Step 7: Submit Recommendations for Action by Top Management

General Description

The working group has completed the important planning tasks and must now submit the results and conclusions to those who will make the decision on whether to proceed further. Top management, at this step, will primarily be determining if an investment will be made in this area. As a result, the plan will not only be considered on the basis of its merits for solving the particular problems identified in this emphasis area (say, vis-à-vis other approaches that could be taken to deal with the specific problems identified), but also its relative value in relation to investments in other aspects of the road safety program.

This aspect of the process involves using the best available communication skills to adequately inform top management. The degree of effort and extent of use of media should be proportionate to the size and complexity of the problem being addressed, as well as the degree to which there is competition for funds.

The material that is submitted should receive careful review by those with knowledge in report design and layout. In addition, today's technology allows for the development of automated presentations, using animation and multimedia in a cost-effective manner. Therefore, programs involving significant investments that are competing strongly for implementation resources should be backed by such supplementary means for communicating efficiently and effectively with top management.

Specific Elements

1. Submit recommendations for action by management
    - 1.1. "Go/no-go" decision
    - 1.2. Reconsideration of policies, guidelines, and specifications (see Step 3)
    - 1.3. Modification of the plan to accommodate any revisions to the program framework made by the decision makers
2. Working group to make presentations to decision makers and other groups, as needed and requested
3. Working group to provide technical assistance with the review of the plan, as requested
    - 3.1. Availability to answer questions and provide further detail
    - 3.2. Assistance in conducting formal assessments

Implementation Step 8: Develop a Plan of Action

General Description

At this stage, the working group will usually detail the program that has been selected for implementation. This step translates the program into an action plan, with all the details needed by both decision makers, who will have to commit to the investment of resources, and those charged with carrying it out. The effort involves defining resource requirements, organizational and institutional arrangements needed, schedules, etc. This is usually done in the form of a business plan, or plan of action. An example of a plan developed by a local community is shown in Appendix X.

An evaluation plan should be designed at this point. It is an important part of the plan. This is something that should be in place before Step 9 is finished. It is not acceptable to wait until after the program is completed to begin designing an evaluation of it. This is because data are needed about conditions before the program starts, to allow comparison with conditions during its operation and after its completion. It also should be designed at this point, to achieve consensus among the stakeholders on what constitutes "success." The evaluation is used to determine just how well things were carried out and what effect the program had. Knowing this helps maintain the validity of what is being done, encourages future support from management, and provides good intelligence on how to proceed after the program is completed. For further details on performing evaluations, see Appendix L, Appendix M, and Appendix W.

The plan of action should be developed jointly with the involvement of all desired participants in the program. It should be completed to the detail necessary to receive formal approval of each agency during the next step. The degree of detail and complexity required for this step will be a function of the size and scope of the program, as well as the number of independent agencies involved.

Specific Elements

1. Translation of the selected program into key resource requirements
    - 1.1. Agencies from which cooperation and coordination is required
    - 1.2. Funding
    - 1.3. Personnel
    - 1.4. Data and information
    - 1.5. Time
    - 1.6. Equipment
    - 1.7. Materials
    - 1.8. Training
    - 1.9. Legislation
2. Define organizational and institutional framework for implementing the program
    - 2.1. Include high-level oversight group
    - 2.2. Provide for involvement in planning at working levels
    - 2.3. Provide mechanisms for resolution of issues that may arise and disagreements that may occur
    - 2.4. Secure human and financial resources required

3. Detail a program evaluation plan
    3.1. Goals and objectives
    3.2. Process measures
    3.3. Performance measures
        3.3.1. Short-term, including surrogates, to allow early reporting of results
        3.3.2. Long-term
    3.4. Type of evaluation
    3.5. Data needed
    3.6. Personnel needed
    3.7. Budget and time estimates
4. Definition of tasks to conduct the work
    4.1. Develop diagram of tasks (e.g., PERT chart)
    4.2. Develop schedule (e.g., Gantt chart)
    4.3. For each task, define
        4.3.1. Inputs
        4.3.2. Outputs
        4.3.3. Resource requirements
        4.3.4. Agency roles
        4.3.5. Sequence and dependency of tasks
5. Develop detailed budget
    5.1. By task
    5.2. Separate by source and agency/office (i.e., cost center)
6. Produce program action plan, or business plan document

Implementation Step 9: Establish Foundations for Implementing the Program

General Description

Once approved, some "groundwork" is often necessary to establish a foundation for carrying out the selected program. This is somewhat similar to what was done in Step 4. It must now be done in greater detail and scope for the specific program being implemented. As in Step 4, specific policies and guidelines must be developed, organizational and institutional arrangements must be initiated, and an infrastructure must be created for the program. The business plan or action plan provides the basis (Step 7) for this. Once again, the degree of complexity required will vary with the scope and size of the program, as well as the number of agencies involved.

Specific Elements

1. Refine policies and guidelines (from Step 4)
2. Effect required legislation or regulations
3. Allocate budget
4. Reorganize implementation working group
5. Develop program infrastructure
    - 5.1. Facilities and equipment for program staff
    - 5.2. Information systems
    - 5.3. Communications
    - 5.4. Assignment of personnel
    - 5.5. Administrative systems (monitoring and reporting)
6. Set up program assessment system
    - 6.1. Define/refine/revise performance and process measures
    - 6.2. Establish data collection and reporting protocols
    - 6.3. Develop data collection and reporting instruments
    - 6.4. Measure baseline conditions

Implementation Step 10: Carry Out the Action Plan

General Description

Conditions have been established to allow the program to be started. The activities of implementation may be divided into activities associated with field preparation for whatever actions are planned and the actual field implementation of the plan. The activities can involve design and development of program actions, actual construction or installation of program elements, training, and the actual operation of the program. This step also includes monitoring for the purpose of maintaining control and carrying out mid- and post-program evaluation of the effort.

Specific Elements

1. Conduct detailed design of program elements
    - 1.1. Physical design elements
    - 1.2. PI&E materials
    - 1.3. Enforcement protocols
    - 1.4. Etc.
2. Conduct program training
3. Develop and acquire program materials
4. Develop and acquire program equipment
5. Conduct pilot tests of untested strategies, as needed
6. Program operation
    - 6.1. Conduct program "kickoff"
    - 6.2. Carry out monitoring and management of ongoing operation
        - 6.2.1 Periodic measurement (process and performance measures)
        - 6.2.2 Adjustments as required
    - 6.3 Perform interim and final reporting

Implementation Step 11: Assess and Transition the Program

General Description

The AASHTO Strategic Highway Safety Plan includes improvement in highway safety management. A key element of that is the conduct of properly designed program evaluations. The program evaluation will have been first designed in Step 8, which occurs prior to any field implementation. For details on designing an evaluation, please refer to Step 8. For an example of how the New Zealand Transport Authority takes this step as an important part of the process, see Appendix N.

The program will usually have a specified operational period. An evaluation of both the process and performance will have begun prior to the start of implementation. It may also continue during the course of the implementation, and it will be completed after the operational period of the program.

The overall effectiveness of the effort should be measured to determine if the investment was worthwhile and to guide top management on how to proceed into the post-program period. This often means that there is a need to quickly measure program effectiveness in order to provide a preliminary idea of the success or need for immediate modification. This will be particularly important early in development of the AASHTO Strategic Highway Safety Plan, as agencies learn what works best. Therefore, surrogates for safety impact may have to be used to arrive at early/interim conclusions. These usually include behavioral measures. This particular need for interim surrogate measures should be dealt with when the evaluation is designed, back in Step 8. However, a certain period, usually a minimum of a couple of years, will be required to properly measure the effectiveness and draw valid conclusions about programs designed to reduce highway fatalities when using direct safety performance measures.

The results of the work is usually reported back to those who authorized it and the stakeholders, as well as any others in management who will be involved in determining the future of the program. Decisions must be made on how to continue or expand the effort, if at all. If a program is to be continued or expanded (as in the case of a pilot study), the results of its assessment may suggest modifications. In some cases, a decision may be needed to remove what has been placed in the highway environment as part of the program because of a negative impact being measured. Even a "permanent" installation (e.g., rumble strips) requires a decision regarding investment for future maintenance if it is to continue to be effective.

Finally, the results of the evaluation using performance measures should be fed back into a knowledge base to improve future estimates of effectiveness.

Specific Elements

1. Analysis
   - 1.1 Summarize assessment data reported during the course of the program
   - 1.2 Analyze both process and performance measures (both quantitative and qualitative)

  - 1.3 Evaluate the degree to which goals and objectives were achieved (using performance measures)
  - 1.4 Estimate costs (especially vis-à-vis pre-implementation estimates)
  - 1.5 Document anecdotal material that may provide insight for improving future programs and implementation efforts
  - 1.6 Conduct and document debriefing sessions with persons involved in the program (including anecdotal evidence of effectiveness and recommended revisions)
2. Report results
3. Decide how to transition the program
  - 3.1 Stop
  - 3.2 Continue as is
  - 3.3 Continue with revisions
  - 3.4 Expand as is
  - 3.5 Expand with revisions
  - 3.6 Reverse some actions
4. Document data for creating or updating database of effectiveness estimates

SECTION VII

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SECTION VIII
Glossary

Acronym or Term	Meaning	Comments
3R	Rehabilitation, Resurfacing, and Restoration	Refers to type of project that is intended to be less comprehensive than complete reconstruction
AAA	American Automobile Association	
AAAM	Association for the Advancement of Automotive Medicine	
AAMVA	American Association of Motor Vehicle Administrators	
AASHTO	American Association of State Highway and Transportation Officials	
ADAT	Aggressive Driving Apprehension Team	Washington State Patrol
ADT	Average Daily Traffic	
AG	Aggressive Driving	
AMA	American Medical Association	
AMF (or CMF)	Accident Modification Factor	Also may be referred to as Crash Modification Factor
ARTBA	American Road and Transportation Builders Association	
ASCE	American Society of Civil Engineers	
AWS	Accident Warning System	
B/C	Benefit-Cost Ratio	
BCT	Breakaway Cable Terminal	End treatment for guardrail
CAE	Computer Aided Engineering	
CCS	Collision Countermeasure System	
CDL	Commercial Driver's License	
CHSIM	Comprehensive Highway Safety Improvement Model	Recently changed name to *The Safety Analyst*
CSD	Context-Sensitive Design	
DDC-ADD	Defensive Driving Course—Attitudinal Dynamics of Driving	

Acronym or Term	Meaning	Comments
DDSS	Design Decision Support System	
DES	Detailed Engineering Studies	
DMV	Department of Motor Vehicles	
DOT	Department of Transportation	
DUI/DWI	Driving Under the Influence (of alcohol or drugs)/Driving While Impaired	
DUS	Driving Under Suspension (of driver's license)	
DWR	Driving While Revoked	
DWS	Driving While Suspended	
EM	Electronic Monitoring	
FARS	Fatality Analysis Reporting System	Formerly referred to as Fatal Accident Reporting System
FHWA	Federal Highway Administration	Division of the U.S. Department of Transportation
F+I	Fatal Plus Injury (crash)	
GHSA	Governors Highway Safety Association	Formerly NAGHSR (National Association of Governors' Highway Safety Representatives)
Green Book	AASHTO Policy on Geometric Design of Highways	
H.A.D.	Halt Aggressive Driving	Lubbock, Texas
HAL	High Accident Location	
HCM	Highway Capacity Manual	TRB publication
HES	Hazard Elimination Study	
HO	Head On (accident)	
HOS	Hours of Service	For commercial vehicle drivers
HRR	Highway Research Record	TRB publication
HSIS	Highway Safety Information System	
HSM	Highway Safety Manual	
IES	Illumination Engineering Society	
IHSDM	Interactive Highway Safety Design Model	
IID	Ignition Interlock Device	
ISD	Intersection Sight Distance	

Acronym or Term	Meaning	Comments
ITE	Institute of Transportation Engineers	
LCCA	Life Cycle Cost Analysis	
MAB	Medical Advisory Board	State-level organization
MADD	Mothers Against Drunk Driving	
MUTCD	Manual of Uniform Traffic Control Devices	FHWA publication
NCHRP	National Cooperative Highway Research Program	
NHI	National Highway Institute	FHWA training office
NHTSA	National Highway Traffic Safety Administration	Division of the U.S. Department of Transportation
NSC	National Safety Council	
NTSB	National Transportation Safety Board	
NYSTA	New York State Thruway Authority	
PCR	Police Crash Report	
PDO	Property Damage Only (accident)	
PI&E	Public Information & Education	
RDG	Roadside Design Guide	AASHTO publication
RID	Remove Intoxicated Drivers	Citizen group
ROR	Run-Off-Road (accident)	
ROW	Right-of-Way	
RPM	Raised Pavement Marker	
RSA	Road Safety Audit	
RSPM	Raised Snowplowable Pavement Marker	
SADD	Students Against Destructive Decisions	
SBPD	Santa Barbara Police Department (California)	
SHSP	Strategic Highway Safety Plan	
SKARP	Skid Accident Reduction Program	
SPF	Safety Performance Function	
SSD	Stopping Sight Distance	
SUV	Sports Utility Vehicle	
SV	Single Vehicle (accident)	

Acronym or Term	Meaning	Comments
TCD	Traffic Control Device	
TRB	Transportation Research Board	
TRR	Transportation Research Record	TRB Publication
TRRL	Transport and Road Research Laboratory	United Kingdom organization
TSIMS	Transportation Safety Information Management System	Developed by AASHTO
TTI	Texas Transportation Institute	
TWLTL	Two-Way, Left-Turn Lane	
U/S/R	Unlicensed/Suspended/Revoked	Drivers without licenses, or whose licenses have been suspended or revoked
UVC	Uniform Vehicle Code	Model national traffic law
WSP	Washington State Patrol	

See also: Glossary of Transportation Terms online
http://transweb.sjsu.edu/comglos2.htm#P

Appendixes

The following appendixes are not published in this report. However, they are available online at http://transportation1.org/safetyplan.

1 Description of Pennsylvania DOT Strategies for Reducing ROR Harm
2 Description of Maryland DOT Program for Shoulder Rumble Strips on Two-Lane Roads
3 Description of Kansas DOT Policy Requiring Milled-In Rumble Strips
4 Description of North Carolina DOT Experimental Programs with Edgeline Profile Marking and Rumble Strips for Narrow Paved Shoulders
5 Description of New York DOT Skid Accident Reduction Program (SKARP)
6 Description of Iowa DOT Experimental Program to Delineate Hazardous Utility Poles

A Wisconsin Department of Transportation 2001 Strategic Highway Safety Plan
B Resources for the Planning and Implementation of Highway Safety Programs
C South African Road Safety Manual
D Comments on Problem Definition
E Issues Associated with Use of Safety Information in Highway Design: Role of Safety in Decision Making
F Comprehensive Highway Safety Improvement Model
G Table Relating Candidate Strategies to Safety Data Elements
H What Is a Road Safety Audit?
I Illustration of Regression to the Mean
J Fault Tree Analysis
K Lists of Potential Stakeholders
L Conducting an Evaluation
M Designs for a Program Evaluation
N Joint Crash Reduction Programme: Outcome Monitoring
O Estimating the Effectiveness of a Program During the Planning Stages
P Key Activities for Evaluating Alternative Program
Q Definitions of Cost-Benefit and Cost-Effectiveness
R FHWA Policy on Life Cycle Costing
S Comparisons of Benefit-Cost and Cost-Effectiveness Analysis
T Issues in Cost-Benefit and Cost-Effectiveness Analyses
U Transport Canada Recommended Structure for a Benefit-Cost Analysis Report
V Overall Summary of Benefit-Cost Analysis Guide from Transport Canada
W Program Evaluation—Its Purpose and Nature
X Traffic Safety Plan for a Small Department
Y Sample District-Level Crash Statistical Summary
Z Sample Intersection Crash Summaries
AA Sample Intersection Collision Diagram
BB Example Application of the Unsignalized Intersection Guide

Abbreviations used without definitions in TRB publications:

AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
APTA	American Public Transportation Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
FAA	Federal Aviation Administration
FHWA	Federal Highway Administration
FMCSA	Federal Motor Carrier Safety Administration
FRA	Federal Railroad Administration
FTA	Federal Transit Administration
IEEE	Institute of Electrical and Electronics Engineers
ITE	Institute of Transportation Engineers
NCHRP	National Cooperative Highway Research Program
NCTRP	National Cooperative Transit Research and Development Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
TCRP	Transit Cooperative Research Program
TRB	Transportation Research Board
U.S.DOT	United States Department of Transportation