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Reducing Collisions on Horizontal Curves

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NCHRP

NATIONAL
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RESEARCH
PROGRAM

REPORT 500

Guidance for Implementation of the AASHTO Strategic Highway Safety Plan

Volume 7: A Guide for Reducing Collisions on Horizontal Curves

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 500

Guidance for Implementation of the AASHTO Strategic Highway Safety Plan

Volume 7: A Guide for Reducing Collisions on Horizontal Curves

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

Systematic, well-designed research provides the most effective approach to the solution of many problems facing highway administrators and engineers. Often, highway problems are of local interest and can best be studied by highway departments individually or in cooperation with their state universities and others. However, the accelerating growth of highway transportation develops increasingly complex problems of wide interest to highway authorities. These problems are best studied through a coordinated program of cooperative research.

In recognition of these needs, the highway administrators of the American Association of State Highway and Transportation Officials initiated in 1962 an objective national highway research program employing modern scientific techniques. This program is supported on a continuing basis by funds from participating member states of the Association and it receives the full cooperation and support of the Federal Highway Administration, United States Department of Transportation.

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The program is developed on the basis of research needs identified by chief administrators of the highway and transportation departments and by committees of AASHTO. Each year, specific areas of research needs to be included in the program are proposed to the National Research Council and the Board by the American Association of State Highway and Transportation Officials. Research projects to fulfill these needs are defined by the Board, and qualified research agencies are selected from those that have submitted proposals. Administration and surveillance of research contracts are the responsibilities of the National Research Council and the Transportation Research Board.

The needs for highway research are many, and the National Cooperative Highway Research Program can make significant contributions to the solution of highway transportation problems of mutual concern to many responsible groups. The program, however, is intended to complement rather than to substitute for or duplicate other highway research programs.

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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 seventh 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 of collisions that occur on horizontal curves. 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 seventh 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 volume of *NCHRP Report 500* was developed under NCHRP Project 17-18(3), the product of which is a series of implementation guides addressing the emphasis areas of AASHTO's Strategic Highway Safety Plan. The project was managed by CH2M Hill, and 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 team. Kelly Hardy, also of CH2M Hill, served as a technical specialist on the development of the guides.

The project team was organized around the specialized technical content contained in each guide, and the team included nationally recognized experts from many organizations. The following team of experts, selected based on their knowledge and expertise in this particular emphasis area, served as lead authors for the horizontal curve guide:

- Douglas W. Harwood
  Midwest Research Institute
- Darren J. Torbic
  Midwest Research Institute

Developing the volumes of *NCHRP Report 500* required 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 documents represent best practices in each emphasis area. The project team is grateful to the following list of people and their agencies for supporting the project through their participation in workshops and meetings and additional reviews of the horizontal curve guide:

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SECTION I

Summary

Introduction

The AASHTO Strategic Highway Safety Plan identified 22 goals that need to be pursued to achieve a significant reduction in highway crash fatalities. Two of the goals within the plan include *Keeping Vehicles on the Roadway* (Goal 15) and *Minimizing the Consequences of Leaving the Road* (Goal 16). Several emphasis areas have evolved from these two goals: run-off-road (ROR) crashes, head-on crashes, crashes with trees in hazardous locations, and curve-related crashes. This guide focuses on the crash types prevalent on horizontal curves and provides objectives and strategies to improve safety on curves.

Many of the strategies identified to improve the safety at horizontal curves are common to strategies to reduce ROR and head-on crashes. In cases where the guides dealing with the ROR and head-on crash emphasis areas provide thorough coverage of a particular strategy, the reader is directed to the specific sections of those guides for more detailed information. If particular issues that pertain specifically to horizontal curves are not covered in the ROR or head-on guides, these issues are discussed within the text of this guide.

General Description of the Problem

Statistics from the Fatality Analysis Reporting System (FARS) indicate that 42,815 people were killed in 38,309 fatal crashes on the U.S. highway system in 2002. Approximately 25 percent of these fatal crashes occurred along horizontal curves. These crashes occurred predominantly on two-lane rural highways that are often not part of the state DOT system. Considering these statistics and that the average accident rate for horizontal curves is about three times the average accident rate for highway tangents (Glennon et al., 1983), implementing strategies designed to improve the safety at horizontal curves will help achieve the overall goal of the AASHTO Strategic Highway Safety Plan.

Approximately 76 percent of curve-related fatal crashes were single-vehicle crashes in which the vehicle left the roadway and struck a fixed object or overturned, whereas 11 percent of curve-related fatal crashes were head-on crashes. Thus, ROR and head-on crashes accounted for 87 percent of the fatal crashes at horizontal curves, and the strategies for improving safety at horizontal curves focus on reducing the frequency and severity of these types of crashes. These strategies may not eliminate crashes with other vehicles, pedestrians, bicyclists, and trains that may be directly in the path of the vehicle, but crash statistics do not indicate that these types of collisions are prevalent on curves.

Objectives of the Emphasis Area

The two main objectives for improving safety along horizontal curves are to

- Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve and
- Minimize the adverse consequences of leaving the roadway at a horizontal curve.

Strategies designed to fulfill these objectives are presented in Exhibit I-1. Because the AASHTO Strategic Highway Safety Plan is geared toward low-cost, short-term safety improvements, the list of strategies presented in Exhibit I-1 is arranged in general terms from low-cost, short-term treatments to high-cost, long-term treatments.

EXHIBIT I-1
Objectives and Strategies for Improving Safety at Horizontal Curves

Objectives	Strategies
15.2 A Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve	15.2 A1 Provide advance warning of unexpected changes in horizontal alignment
	15.2 A2 Enhance delineation along the curve
	15.2 A3 Provide adequate sight distance
	15.2 A4 Install shoulder rumble strips
	15.2 A5 Install centerline rumble strips
	15.2 A6 Prevent edge dropoffs
	15.2 A7 Provide skid-resistant pavement surfaces
	15.2 A8 Provide grooved pavement
	15.2 A9 Provide lighting of the curve
	15.2 A10 Provide dynamic curve warning system
	15.2 A11 Widen the roadway
	15.2 A12 Improve or restore superelevation
	15.2 A13 Modify horizontal alignment
	15.2 A14 Install automated anti-icing systems
	15.2 A15 Prohibit/restrict trucks with very long semitrailers on roads with horizontal curves that cannot accommodate truck offtracking
15.2 B Minimize the adverse consequences of leaving the roadway at a horizontal curve	15.2 B1 Design safer slopes and ditches to prevent rollovers
	15.2 B2 Remove/relocate objects in hazardous locations
	15.2 B3 Delineate roadside objects
	15.2 B4 Add or improve roadside hardware
	15.2 B5 Improve design and application of barrier and attenuation systems

SECTION II

Introduction

The AASHTO Strategic Highway Safety Plan identified 22 goals that need to be pursued to achieve a significant reduction in highway crash fatalities. Two of the goals within the plan include *Keeping Vehicles on the Roadway* (Goal 15) and *Minimizing the Consequences of Leaving the Road* (Goal 16). Several emphasis areas have evolved from these two goals: run-off-road (ROR) crashes, head-on crashes, crashes with trees in hazardous locations, and curve-related crashes. This guide focuses on the crash types prevalent on horizontal curves and provides objectives and strategies to improve safety on curves.

The two main objectives for improving safety along horizontal curves are to

1. Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway and
2. Minimize the adverse consequences of leaving the roadway.

Many of the strategies identified to achieve these objectives are common strategies to reduce ROR and head-on crashes. In cases where the guides dealing with the ROR and head-on crash emphasis areas provide thorough coverage of a particular strategy, the reader is directed to the specific sections of those guides for more detailed information. If particular issues that pertain specifically to horizontal curves are not covered in the ROR or head-on guides, these issues are discussed within the text of this guide.

The most prevalent types of crashes that occur on horizontal curves are ROR and head-on crashes; therefore, the emphasis is to reduce the frequency and severity of these types of crashes. These strategies may not eliminate crashes with other vehicles, pedestrians, bicyclists, and trains that may be directly in the path of the vehicle, but crash statistics do not indicate that these types of collisions are prevalent on curves.

Within the guide, no distinction is made as to whether a strategy is more applicable at an isolated horizontal curve located between two long tangents or whether the strategy should be applied to horizontal curves located along curvilinear alignments. In general, all of the strategies have the potential to be effective in both instances. Similarly, all of the strategies may be used in combinations to improve safety. For example, if the horizontal alignment is modified to increase the radius of a curve, it may also be appropriate to enhance the delineation along the curve.

Management of safety on horizontal curves is a major challenge for highway agencies. It has been estimated that there are more than 10 million horizontal curves in the United States on two-lane highways alone. State highway agencies generally operate accident record systems, and, within the accident record systems, accident locations can be tied to specific locations on the roadway system. Safety problems on horizontal curves can be detected using such record systems, but only indirectly because very few highway agencies have inventory files that identify the locations or geometrics of horizontal curves in a form that can be linked to accident data. Thus, safety concerns can be identified that, upon investigation, turn out to involve horizontal curves. However, there are typically no formal means of reviewing all horizontal curves and identifying those with adverse safety performance. Many local agencies do not have accident record systems in which accidents can be linked to specific roadway locations; therefore, identification of horizontal curves with potential safety concerns can only be conducted manually, if at all. Given these constraints, safety management of horizontal curves should be conducted making full use of available accident record systems. In addition, agencies that cannot identify potential problems on horizontal curves by automated means should consider the use of other methods, including noting public complaints, skid marks, and damage to roadside hardware, trees, and utility poles. Where safety concerns related to horizontal curves are found, this guide provides a range of safety improvements that can be considered.

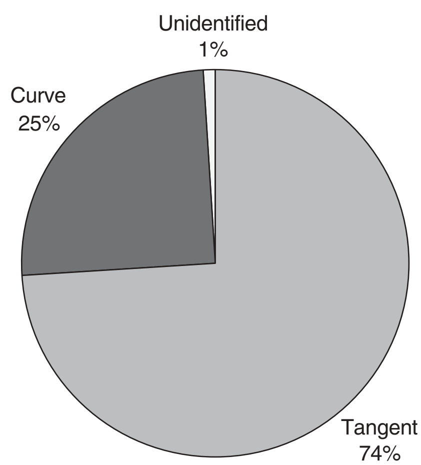
Section III

The Type of Problem Being Addressed

General Description of the Problem

Statistics from the Fatality Analysis Reporting System (FARS) indicate that 42,815 people were killed in 38,309 fatal crashes on the U.S. highway system in 2002. Approximately 25 percent of these fatalities occurred along horizontal curves (see Exhibit III-1). Curves are necessary and important elements of every highway. Considering these statistics and that the average accident rate for horizontal curves is about three times the average accident rate for highway tangents (Glennon et al., 1985), implementing strategies designed to improve the safety of horizontal curves will help achieve the overall goal of the AASHTO Strategic Highway Safety Plan.

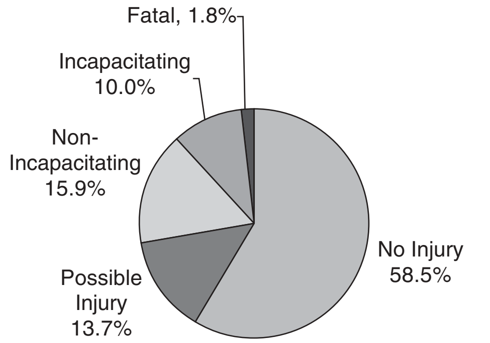
EXHIBIT III-1
Percentage of Fatalities by Roadway Alignment



Specific Attributes of the Problem

Accidents on horizontal curves cause a significant amount of pain and suffering to those involved in the accidents because of the nature of the collisions. For example, while only slightly less than 2 percent of all crashes on curved roadway segments are fatal crashes, approximately 40 percent involve some type of injury (see Exhibit III-2). Many of the more severe curve-related crashes (i.e., fatal) occur primarily in rural settings. Exhibit III-3 shows that about three-quarters of the fatal crashes occur in rural areas. Exhibit III-4 shows that more than 70 percent of the fatal crashes occur on secondary roads, which implies that many of these are on roads that are not under state DOT jurisdiction. Finally, Exhibit III-5 indicates that attention to the problem of crashes on curves should be directed primarily to two-lane highways in rural areas.

EXHIBIT III-2
Severity Distribution
All crashes on curved-roadway segments



Source: GES 1999

EXHIBIT III-3
Location of Fatal Crashes on Horizontal Curves

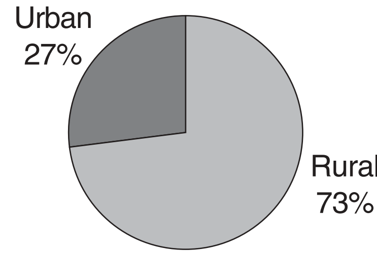
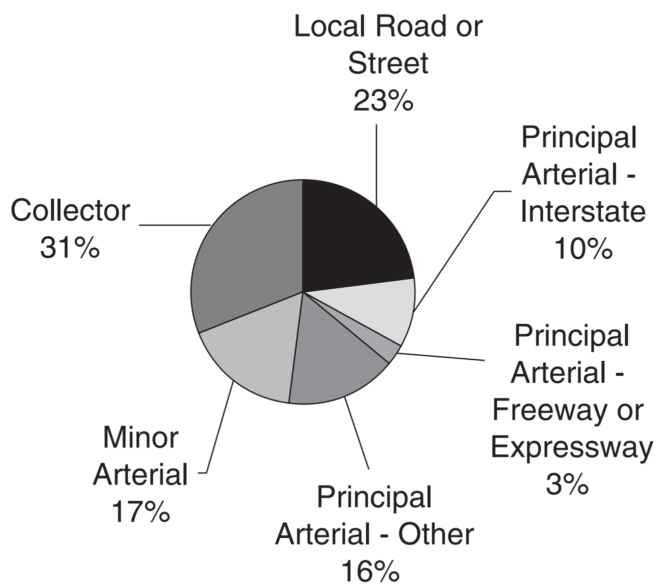


EXHIBIT III-4
Location of Fatal Crashes on Horizontal Curves
by Roadway Classification



The safety of curves is a reflection of both the roadway itself and the roadside environment. Exhibit III-6, which includes crashes of all severities along curved roadway segments (GES, 1999), shows that the first harmful event of a crash on a curved highway segment is just as likely to occur on the traveled way as off the traveled way. (The “Other” category includes locations such as within interchanges.)

The most prevalent types of crashes that occur at horizontal curves are run-off-road (ROR) and head-on crashes. Exhibit III-7 shows that 76 percent of curve-related fatal crashes were single-vehicle crashes in which the vehicle left the roadway and struck a fixed object or overturned, while 11 percent of curve-related fatal crashes were head-on crashes.

EXHIBIT III-5
Fatal Crashes on Horizontal Curves
By Number of Lanes and Rural vs. Urban

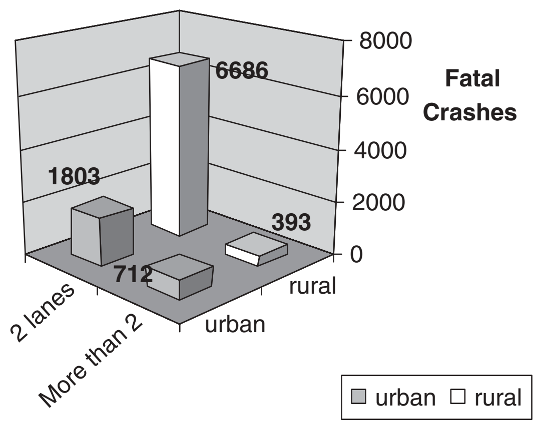


EXHIBIT III-6
Position of Crash Relative to Roadway
All crashes on curved-roadway segments

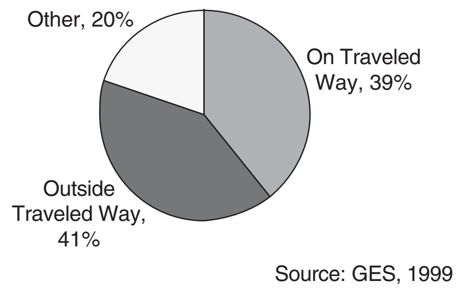
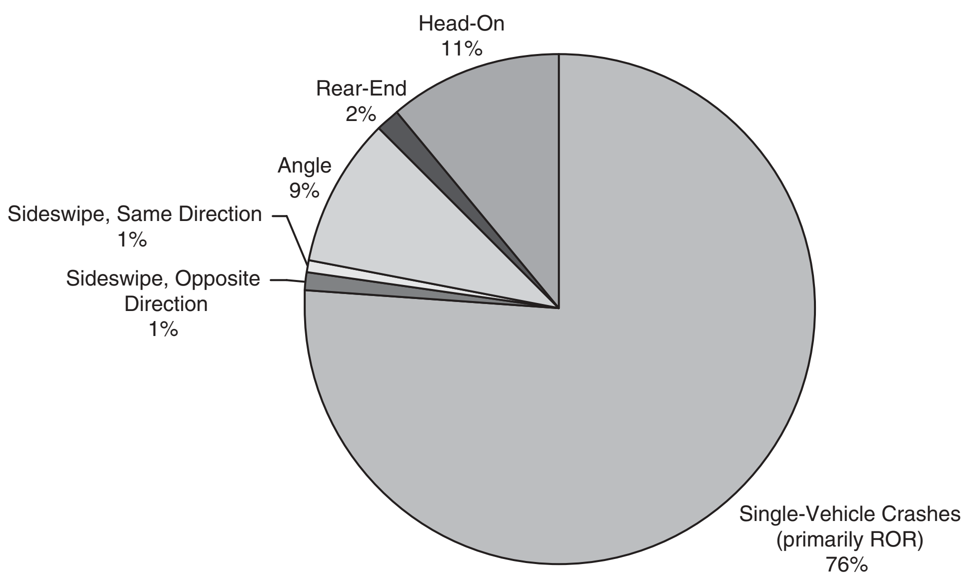


EXHIBIT III-7
Percentage of Curve-Related Fatal Crashes by Collision Type



Thus, ROR and head-on crashes accounted for 87 percent of the fatal crashes at horizontal curves. Accordingly, the strategies for improving safety at horizontal curves focus on reducing the frequency and severity of these specific types of crashes.

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 depend on such factors as the agency's procedures, the need for additional right-of-way (ROW), and the need to follow environmental impact processes. The range of costs also may vary for some of these strategies depending on many of the same factors. Placement in the exhibit is meant to reflect the most commonly expected application of the strategy.

EXHIBIT IV-1
Strategies Classified by Relative Cost and Time Necessary for Implementation

Relative Cost to Implement and Operate	Strategy
	Timeframe: Short (less than 1 year)
Low	15.2 A1 Provide advance warning of unexpected changes in horizontal alignment
	15.2 A2 Enhance delineation along the curve
	15.2 A3 Provide adequate sight distance[a]
	15.2 A4 Install shoulder rumble strips
	15.2 A5 Install centerline rumble strips
	15.2 A6 Prevent edge dropoffs[b]
	15.2 B2 Remove/relocate objects in hazardous locations[c]
	15.2 B3 Delineation of roadside objects
Moderate	—
Moderate to High	—
High	—
	Timeframe: Medium (1–2 years)
Low	
Moderate	15.2 A7 Provide skid-resistant pavement surfaces
	15.2 A8 Provide grooved pavement
	15.2 A9 Provide lighting of the curve
	15.2 A10 Provide dynamic curve warning system

(*continued on next page*)

EXHIBIT IV-1 (Continued)
Strategies Classified by Relative Cost and Time Necessary for Implementation

Relative Cost to Implement and Operate	Strategy
	15.2 A15 Prohibit/restrict trucks with very long semitrailers on roads with horizontal curves that cannot accommodate truck offtracking[d]
	15.2 B4 Add or improve roadside hardware
	15.2 B5 Improve design and application of barrier and attenuation systems
Moderate to High	15.2 A.11 Widen the roadway[e]
	15.2 A12 Improve or restore superelevation
	15.2 A14 Install automated anti-icing systems
	15.2 B1 Design safer slopes and ditches to prevent rollovers
High	—
	Timeframe: Long (more than 2 years)
Low	—
Moderate	—
Moderate to High	—
High	15.2 A13 Modify horizontal alignment

[a]Providing adequate sight distance can be costly if it involves redesigning the vertical curvature of the roadway or cutting back the slope of a hillside. It is assumed here, however, that most sight obstructions will be longitudinal barriers such as trees or foliage that may be cut back at minimal costs.

[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]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.

[d]This strategy is considered medium cost because it may consume a considerable number of staff-hours to develop such a policy and have it approved.

[e]Widening the roadway does not necessarily require acquisition of additional right-of-way (ROW). If ROW is needed, the cost will be moderate to high, and the time required will be long.

SECTION V

Description of Strategies

Objectives

The objectives for reducing the frequency and severity of curve-related crashes are to

- Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve and
- Minimize the adverse consequences of leaving the roadway at a horizontal curve.

Exhibit V-1 presents these objectives and their related strategies for improving safety at horizontal curves. Because the AASHTO Strategic Highway Safety Plan is geared toward low-cost, short-term safety improvements, the list of strategies presented in the exhibit is arranged from low-cost, short-term treatments to high-cost, long-term treatments.

EXHIBIT V-1
Objectives and Strategies for Improving Safety at Horizontal Curves

Objectives	Strategies
15.2 A Reduce the likelihood of a vehicle leaving its lane and either crossing the roadway centerline or leaving the roadway at a horizontal curve	15.2 A1 Provide advance warning of unexpected changes in horizontal alignment (T)
	15.2 A2 Enhance delineation along the curve (T)
	15.2 A3 Provide adequate sight distance (T)
	15.2 A4 Install shoulder rumble strips (P)
	15.2 A5 Install centerline rumble strips (T)
	15.2 A6 Prevent edge dropoffs (T)
	15.2 A7 Provide skid-resistant pavement surfaces (T)
	15.2 A8 Provide grooved pavement (T)
	15.2 A9 Provide lighting of the curve (T)
	15.2 A10 Provide dynamic curve warning system (T)
	15.2 A11 Widen the roadway (P)
	15.2 A12 Improve or restore superelevation (P)
	15.2 A13 Modify horizontal alignment (P)
	15.2 A14 Install automated anti-icing systems (T)
	15.2 A15 Prohibit/restrict trucks with very long semitrailers on roads with horizontal curves that cannot accommodate truck offtracking (T)

(*continued on next page*)

EXHIBIT V-1 (Continued)
Objectives and Strategies for Improving Safety at Horizontal Curves

Objectives	Strategies
15.2 B Minimize the adverse consequences of leaving the roadway at a horizontal curve	15.2 B1 Design safer slopes and ditches to prevent rollovers (P)
	15.2 B2 Remove/relocate objects in hazardous locations (P)
	15.2 B3 Delineate roadside objects (E)
	15.2 B4 Add or improve roadside hardware (T)
	15.2 B5 Improve design and application of barrier and attenuation systems (T)

See the following section for explanation of (E), (P), and (T) designations.

Explanation of Strategy Types

The strategies in this 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 used at a state or even a local level. 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 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 in the AASHTO guides have been classified into three types, each identified by a letter:

- 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 users judge which strategy is the most appropriate for the particular situation. Within the proven strategies, several references are made to accident modification factors (AMFs). For a detailed description of how to use AMFs, see Publication No. FHWA-RD-99/207 entitled *Prediction of the Expected Safety Performance of Rural Two-Lane Highways* by Harwood et al. (2000).
- 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 valid evaluations have not been found. These strategies, while frequently or even generally used, should be applied with caution; users should carefully consider the attributes cited in the guide and relate them to the specific conditions for which they are being considered. There can be some degree of assurance that implementation will not likely have a negative impact on safety and will very likely have a positive one. In this context, effectiveness refers to the likelihood of a strategy reducing either the severity or the frequency of

crashes. In some cases, the effectiveness of treatments may have been shown to have a desired impact on one or more presumed surrogates for crashes (e.g., speed), but the translation of that effect to actual crash experience has not yet been demonstrated. It is the intent that as these "tried" strategies are continually implemented 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" 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 be considered only after the others have been determined to be inappropriate or unfeasible. 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 evaluation 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" one.

  The classification of a traffic control device strategy as experimental means that the strategy has been used either on only a small scale or not at all. It is not meant to imply that the strategy has been approved for experimentation by the National Committee on Uniform Traffic Control Devices (http://www.ncutlo.org/news.html) or that approval for experimentation by that committee is needed for the strategy in question.

Related Strategies for Creating a Truly Comprehensive Approach

It is recommended that related strategies be included as candidates in any program planning process to create a truly comprehensive approach to the highway safety problems associated with this emphasis area. There are five types of related strategies:

- **Public Information and Education (PI&E) Programs.** Many highway safety programs can be effectively enhanced with a properly designed PI&E campaign. The primary goal with PI&E campaigns in highway safety is to reach an audience across an entire jurisdiction or a significant part of it. However, it may be desirable 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, where PI&E campaigns are deemed unique for the emphasis area, the strategy is explained in detail. As additional guides are completed for the AASHTO plan, they may 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 pro-

grams that enforce an effective law against driving under the influence (DUI) or driving without seatbelts. 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 the nature of how they must be performed, are conducted at specific locations. The effect (e.g., lower speeds, greater use of seatbelts, 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 seatbelt 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 it is desired to try an innovative and untried method, a pilot program is recommended. Within this guide, where the application of enforcement programs is deemed appropriate, the application is often in support of some other strategy. The other strategy may target either a whole system or a specific location. When enforcement programs are recommended for a strategy, the description for that strategy will suggest this possibility (see the attribute area for each strategy entitled "Associated Needs"). In some cases, where an enforcement program is deemed unique for the emphasis area, the strategy will be explained in detail. As additional guides are completed for the AASHTO plan, they may address the details regarding the design and implementation of enforcement strategies. For this particular emphasis area, speed enforcement may be particularly applicable. The reader is also directed to the FHWA report synthesizing speed research (http://www.fhwa.dot.gov/tfhrc/safety/pubs/speed/spdtoc.htm).

- **Strategies to Improve Emergency Medical and Trauma System Services.** Treatment of injured parties at highway crashes can have a significant impact on the level of severity and length of time that an individual spends in treatment. This is especially true with 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 that are included here are often thought of as simply support services, they can be critical to the success of a comprehensive highway safety program. Therefore, for this emphasis area, an effort should be made to determine if there are improvements that can be made to this aspect of the system, especially for programs that focus on location-specific (e.g., corridors) or area-specific (e.g., rural areas) issues. As additional guides are completed for the AASHTO plan, they may address the details regarding the design and implementation of emergency medical systems strategies.

- **Strategies Directed at Improving the Safety Management System.** The management of the highway safety system is foundational to success. There should be in place a sound organizational structure, as well as infrastructure of laws, policies, etc., to monitor, control, direct, and administer a comprehensive approach to highway safety. It is important that a comprehensive program not be limited to one jurisdiction, such as a state department of transportation (DOT). Local agencies often have the majority of the road system and its related safety problems to deal with. They also know, better than others, what the problems are. For example, the state of California created a task force composed of professionals from different fields to study the safety issues of some state highway corridors. The goal was to study the safety history of roadway segments with high-accident locations and to recommend improvements that could be implemented. This is an example of a program that could be employed on a larger scale to examine horizontal curve improvements. However, programs such as this require dedicated funding to be developed. As additional guides are completed for the AASHTO plan, they may address the details regarding the design and implementation of strategies for improving safety management systems. When that occurs, the appropriate links will be added from this emphasis area guide.

- **Strategies that Are Detailed in Other Emphasis Area Guides.** Crash statistics show that run-off-road (ROR) and head-on crashes are the most prevalent types of crashes at horizontal curves. Therefore, the strategies for improving safety at horizontal curves address ROR and head-on crashes. Implementation guides, similar to this one, have already been developed to address ROR and head-on crashes, and many of the strategies presented in this guide are common to strategies presented in the ROR and head-on guides (Volumes 6 and 4, respectively, of this report). For example, Strategy 15.2 A4 is to install shoulder rumble strips. Installation of shoulder rumble strips is also addressed in the ROR guide under Strategy 15.1 A1.

  When strategies for reducing curve-related crashes relate to strategies presented in the ROR or head-on guides, the strategies are presented in both guides for complete coverage of the topic. For these common strategies, this implementation guide on reducing curve-related crashes presents information on the expected effectiveness of the strategies. The reader is then referred to the ROR or head-on crash guides for additional information related to the strategies such as keys to success, potential difficulties, organizational, institutional, and policy issues. If particular issues that pertain specifically to horizontal curves are not covered in the ROR or head-on guide, these details are covered within the text of this guide. In this way, duplication of the topic is minimized, while complete coverage of the topic is still provided.

  When strategies for reducing curve-related crashes relate to strategies presented in detail in another guide, information on the strategy, specifically related to curves, is generally presented in the following manner:

  - General description of strategy,
  - Summary of effectiveness of treatments (presented in ROR or head-on guides),
  - Effectiveness of treatments (not discussed in ROR or head-on guides, or recent studies not included within ROR or head-on guides), and
  - Special issues pertaining to horizontal curves.

Objective 15.2 A—Reduce the Likelihood of a Vehicle Leaving its Lane and either Crossing the Roadway Centerline or Leaving the Roadway at a Horizontal Curve

Strategy 15.2 A1: Provide Advance Warning of Unexpected Changes in Horizontal Alignment (T)

General Description

The intent of this strategy is to provide advance warning to a driver that the horizontal alignment of the roadway is about to change and that the driver must alter the path, and possibly the speed, of the vehicle downstream of the warning to negotiate the curve safely. Advance warning of alignment changes should be provided to a driver when changes in alignment are unexpected. This typically occurs in situations where curves are sharper than anticipated or after a long tangent section of roadway.

Advance warning of alignment changes can be conveyed to the driver in numerous ways. The traditional approach is through the use of roadway signing. In the case of a "Curve" sign, the sign not only prepares the driver for a change in alignment, but it also provides information on whether the alignment turns to the left or to the right downstream of the sign. An advisory speed sign can be used to indicate a recommended speed through the curve. Flashing beacons can also be used with the "Curve" and advisory speed signs to draw more attention to these respective signs. Other methods of advance warning that have been used on a more limited basis include warning messages placed on the pavement and rumble strips in advance of the curve. These measures have been used primarily in advance of very sharp curves. In the case of rumble strips, the rumble strips are typically used in conjunction with "Curve" signs and advisory speed signs and are installed to call attention to the advisory speed signs. Note that installation of rumble strips in advance of curves may cause undesirable driving behaviors such as drivers purposely crossing over into the opposing lane to avoid the rumble strips. Also, some motorists (particularly truckers and motorcyclists) do not like the effects (vibration and sound) generated from the rumble strips. Other methods of advance warning involve pavement markings that try to cause a driver to reduce the speed of his/her vehicle through visual deception. These methods can include transverse lines with decreasing spacing or edgelines that give the appearance of a narrowing lane width. Research is underway in National Cooperative Highway Research Program (NCHRP) Project 3-61 to develop a methodology by which horizontal curve information can be conveyed to motorists in a more consistent and reliable fashion.

This strategy focuses on providing drivers with advance warning of the horizontal curve. In some cases it is sufficient just to heighten the awareness of the driver that he/she is approaching a change in alignment. In other situations, advance warning treatments try to influence the speed of the driver on the approach to the curve. Affecting speeds on the tangent sections preceding horizontal curves is particularly important because excessive speed is a significant factor in crashes at horizontal curves. Moreover, research has shown that drivers do not fully adjust their speeds on the approach. The speed at which a vehicle enters a curve relates more to the speed of the vehicle as it approaches the curve (which is based in part on the driver's response to the preceding alignment) than to the sharpness of the curve (Retting and Farmer, 1998).

This strategy closely relates to Strategy 15.1 A4 in the guide for addressing ROR accidents (Volume 6 of this report), which pertains to enhanced delineation of sharp curves for reducing ROR crashes. Strategy 15.1 A4 focuses on innovative and experimental on-pavement markings (nontraditional treatments) that provide advance warning of horizontal curves. Strategy 15.2 A1 pertains to both traditional and nontraditional advance warning treatments at horizontal curves. These treatments do not provide the driver with a view of the curve. On the other hand, Strategy 15.2 A2 focuses on delineation treatments installed along the curve, which provide the driver with a picture of the sharpness of the curve.

Summary of Effectiveness of Nontraditional Treatments at Horizontal Curves

This section provides a brief summary of what is known about the safety effectiveness of nontraditional treatments that provide advance warning to horizontal curves, as presented in the ROR guide. Several variations of nontraditional pavement marking treatments have been experimented with to improve safety at horizontal curves. The two most promising treatments are the pavement arrow (Exhibit V-2) and transverse striping treatments. In general, these nontraditional pavement marking treatments have reduced both speeds and accidents at horizontal curves in experiments conducted by a few agencies. However, it has yet to be determined how effective these nontraditional pavement marking treatments will be when installed on a broader basis and over the long term at a given site.

EXHIBIT V-2
Pavement Arrow
(Retting and Farmer, 1998)

Effectiveness of Traditional Advance Warning Treatments at Horizontal Curves

The *Manual on Uniform Traffic Control Devices* (MUTCD) (USDOT, 2003) indicates that horizontal alignment signs (Turn [W1-1], Curve [W1-2], Reverse Turn [W1-3], Reverse Curve [W1-4], or Winding Road [W1-5]) may be used in advance of situations where the horizontal roadway alignment changes. The One-Direction Large Arrow (W1-6) sign may be used on the outside of the turn or curve. If the change in horizontal alignment is 135 degrees or more, the Hairpin Curve (W1-11) sign may be used. If the change in horizontal alignment is approximately 270 degrees, such as on a cloverleaf ramp, the 270-degree Loop (W1-15) sign may be used. Additional warning also may be provided by use of the "Advisory Speed" plaque (W13-1) that is intended to indicate the maximum recommended speed around a curve. The MUTCD states that the Advisory Speed plaque shall be used where an engineering study indicates a need to advise road users of the advisory speed for a condition.

Research suggests that the proliferation of curve warning signs, especially those supplemented with advisory speed plates, may have lessened the average motorist's respect for the messages that they convey (Lyles, 1980). However, because of tort liability concerns, many highway agencies prefer to use traditional advance warning and curve signs even if research indicates that these signs may be ineffective. The findings from studies that investigated the effectiveness of traditional advance warning signs are summarized in the following paragraphs.

Lyles (1980) examined the effectiveness of five sign treatments for controlling driver speeds in the vicinity of hazardous horizontal curves on rural two-lane highways. Sign treatments ranged from the standard curve warning sign to a regulatory speed zone sign in conjunction with a curve warning sign. The effectiveness of the signs was evaluated based on speeds of motorists as they approached and negotiated the horizontal curves and whether vehicles crossed over center and edgeline markings. Lyles found that no sign, or group of signs, was consistently more effective than another in decreasing the potential hazard at horizontal curves.

Zwahlen (1983) examined the effectiveness of advisory speed plates in causing drivers to reduce their speeds through curves. He concluded that advisory speed signs are not more effective in causing drivers to reduce their speeds through curves than the curve signs alone are, at least not in dry weather, and that further research was needed to determine the effectiveness of advisory speed signs in adverse weather conditions. Zwahlen recommended that advisory speed sign maintenance, especially new installations, be given a low priority.

Ritchie (1972) examined the choice of speed in driving through curves as a function of advisory speed and curve signs. He found that motorists drove faster and produced more lateral acceleration when (a) a curve sign was present, and (b) an advisory speed sign was present, than under the opposite conditions. In addition, motorists exceeded advisory speed signs of 24 to 56 km/h (15 to 35 mph), but motorists did not exceed advisory speed signs of 72 to 80 km/h (45 to 50 mph). Ritchie concluded that advance warning signs serve to reduce uncertainty and allow drivers to proceed with greater confidence.

One of the reasons for the low percentage of compliance with posted advisory speeds on curves may be that the criteria for setting advisory speeds on curves are outdated due to advances in vehicle characteristics. The current criteria for setting advisory speeds on curves have remained essentially unchanged for more than 50 years. Chowdhury et al. (1998) evaluated the validity of current criteria for determining advisory speeds on horizontal curves and concluded that the criteria are not valid for modern vehicles. At most curves, posted advisory speeds were well below the prevailing traffic speed and below the recommended values suggested by the two methods for determining advisory speeds, namely the ball-bank indicator and the *Traffic Control Devices Handbook* (TCDH) (Institute of Transportation Engineers, 2001).

While the previously mentioned studies suggest that traditional advance warning treatments are not effective in decreasing the potential hazard at horizontal curves, several studies suggest otherwise. Hammer (1968) evaluated the effectiveness of various types of minor improvements in reducing accidents. Two of the minor improvements included in the evaluation were the installation of curve warning signs and advisory speed signs at horizontal curves. Hammer found that curve warning signs reduced accidents by 18 percent at horizontal curves and that installation of both curve warning and advisory speed signs reduced accidents by 22 percent. Leisch (1971) also reported advisory speed signs to be effective in reducing accidents at horizontal curves.

Hanscom (1976) evaluated a slightly different scenario. He evaluated the effects of signing to warn drivers of wet weather skidding hazards at horizontal curves. Three curved highway sections were treated using five experimental sign treatments. The primary measure of effectiveness was mean speed at the critical curve locations. In particular, the target sample was the highest quartile speed group of vehicles arriving in advance of the curve. Significant speed reductions were observed at critical curve locations during conditions of wet pavements when warning signs were supplemented with flashing beacons. Therefore, Hanscom recommended that activated warning signs be used at critical curve locations as a skidding accident countermeasure.

Several other types of traditional advance warning treatments that have not necessarily been evaluated for their safety effectiveness at horizontal curves include oversized warning signs and double-posted signs. The MUTCD (USDOT, 2003) indicates that oversized warning signs may be used where speed, volume, and other factors result in conditions where greater visibility or emphasis would be desired, such as at unexpected or sharp horizontal curves. Agencies have also double-posted warning signs to draw greater attention to warning signs.

In summary, none of the studies designed to evaluate the effectiveness of traditional advance warning treatments at horizontal curves question the importance of providing a curve warning sign in advance of unexpected or sharp curves, but conflicting results have been obtained on the effectiveness of advisory speed signs. The most recent studies suggest that advisory speed signs do not garner respect from the average motorist. These studies conclude that advisory speed signs do not effectively reduce speeds at horizontal curves.

Before drawing conclusions regarding the effectiveness of advisory speed signs on improving safety at horizontal curves, two issues should be considered. First, of the studies cited above, only Hammer evaluated the effectiveness of advisory speed signs using accident data. The other studies used speed as the measure for evaluating the effectiveness for advisory speed signs. Second, Hanscom is the only reference cited above that recommends targeting the highest quartile speed group of vehicles when evaluating the effectiveness of advance warning treatments based upon speed. He suggests that these vehicles are the vehicles most likely to be involved in accidents at horizontal curves.

Strategy Attributes

The ROR guide presents attributes under Strategy 15.1 A4 that are common to this strategy. The reader is, therefore, directed to that guide for more detailed information related to this strategy. However, three additional points should be considered in addition to what is presented within the ROR crash guide.

First, for higher compliance with posted advisory speed signs, a new set of criteria should be developed for setting advisory speeds. Chowdhury et al. (1998) recommended determining the advisory speed based on a sample of vehicle speeds, but other alternatives should be investigated as well. If a new set of criteria is developed for setting advisory speed, curves currently posted with advisory speed signs will have to be re-evaluated and new advisory speeds will have to be posted, and in some cases the advisory speed signs may be removed completely. A public information effort may be needed to re-educate the driving public until drivers once again respect this type of advisory sign.

Second, an important key to success is identifying sites where treatments of this nature have the potential to improve safety. This strategy targets curves where changes in alignment are unexpected and drivers may need to reduce their speeds to negotiate the curve safely.

Third, in several of the studies previously mentioned, speed, or more specifically change in speed, has been used as a surrogate measure for evaluating the effectiveness of a treatment. Such a relationship should be established by further research. If speed is studied as a surrogate measure, consideration should be given to Hanscom's recommendation of targeting the highest quartile speed group of vehicles when evaluating the effectiveness of both traditional and nontraditional advance warning treatments.

Strategy 15.2 A2: Enhance Delineation Along the Curve (T)

General Description

This strategy focuses on providing the driver with better visual cues to recognize the presence and geometry of the curve. Various methods are available to provide delineation along a curve. Some traditional delineation devices such as chevrons, post-mounted delineators, and delineators placed on guardrail are located outside the roadway shoulder along the curve, while others, such as lane lines or edgelines and raised pavement markers, are placed on the surface of the traveled way. Several nontraditional devices, such as light-emitting diode (LED) in-pavement luminaires and LED barrier-mounted guidance tubes, have also been used for delineation purposes.

Agencies generally implement three levels of delineation based on the context of the location:

- For tangents,
- For most curves, and
- For problem curves (e.g., high-accident locations).

This strategy primarily addresses delineation along problem curves, but it may also be applied to most curves.

Enhanced delineation of a curve serves two purposes. First, it can provide a better view of the curve on the approach tangent. The degree to which this works well depends in part upon a combination of road factors, including horizontal and vertical alignments, obstructions on the inside of the curve, and the types of delineation devices used. Delineation helps prepare the driver for the approaching change in horizontal alignment. Roadside delineators are particularly effective in providing this advanced view of the curve. In many cases, delineation devices increase the preview sight distance on the approach tangent. Second, as the driver traverses the curve, the delineation device provides a continuous feature for positive guidance. This helps the driver position his/her vehicle within the proper travel lane while negotiating the curve.

This strategy is related to Strategy 15.1 A6 in the ROR guide, pertaining to better pavement markings at appropriate locations. Strategy 15.1 A6 in the ROR crash guide does not provide detailed information on post-mounted delineators or chevrons. Therefore, a more detailed discussion of these types of roadside delineation is provided below.

Summary of Effectiveness of Better Pavement Markings

This section provides a brief summary of the safety effectiveness of better pavement markings, as presented in the ROR guide. "Better pavement markings" are pavement markings that are more durable, are all-weather, or have a higher retroreflectivity than traditional pavement markings. Raised pavement markings and wider edgelines are two approaches to enhancing delineation at a curve. These treatments are designed to help drivers who might leave the roadway because of inability to see the edge of the pavement along the horizontal curve.

The actual safety benefits of such treatments are difficult to assess. Raised pavement markers provide for increased delineation of the driving path and enhance the ability of the driver to track the roadway, particularly under nighttime, wet-weather, or adverse-weather conditions. Raised pavement markers also can provide tactile and auditory warnings to drivers, similar to rumble strips, when vehicles traverse the markers. When used at isolated curves rather than continuously along the alignment, raised pavement markers may provide greater emphasis to the change in roadway alignment. Several studies have noted significant reductions in accidents because of the installation of raised pavement markers. Despite the noted advantages of raised pavement markers and the positive research, some studies have indicated an increase in nighttime accidents after the installation of raised pavement markers. Therefore, the safety effectiveness of raised pavement markers is questionable. Concerning wider edgelines such as 20-mm (8-in.) edgelines versus 10-mm (4-in.) edgelines, the effectiveness of raised pavement markers in reducing ROR crashes has not been satisfactorily demonstrated in the research literature, although the New York DOT indicates that wider edgelines have the potential to reduce ROR crashes on two-lane roads by 10 to 15 percent.

Post-Mounted Delineators and Chevrons

Post-mounted delineators and chevrons are two types of delineation treatments that are installed outside of the roadway. They are intended to warn drivers of an approaching curve and provide tracking information and guidance to the drivers. While they are intended to act as a warning, it should also be remembered that the posts, placed along the roadside, represent a possible object with which an errant vehicle can crash. Design of posts to minimize damage and injury is an important part of the considerations to be made when selecting these treatments.

In *NCHRP Report 440,* Fitzpatrick et al. (2000a) report the results of several studies on post-mounted delineators. They report that post-mounted delineators reduce the accident rate only on relatively sharp curves during periods of darkness. In addition, highways with post-mounted delineators have lower accident rates than highways without post-mounted delineators, and the cost of post-mounted delineators are justified for highways with average daily traffic (ADT) exceeding 1,000 vehicles per day. Fitzpatrick et al. do not quantify the effectiveness of post-mounted delineators in reducing curve-related crashes. Bali et al. (1978) provide similar results.

Krammes and Tyer (1991) evaluated the operational effectiveness of raised pavement markers as an alternative to post-mounted delineators at horizontal curves on two-lane rural highways. They evaluated nighttime speed and lateral placement data from five sites. For both short-term and intermediate-term analyses, vehicle operations with raised pavement markers compared favorably with operations when post-mounted delineators were present. Vehicle operations were not significantly affected on the inside lane of the curve, but significant differences were observed on the outside lane of the curve. Speeds at the midpoint of the curve were consistently 1.6 to 4.8 km/h (1 to 3 mph) higher with the raised pavement markers, and the mean lateral placement of vehicles was consistently 0.3 to 0.6 m (1 to 2 ft) further from the centerline at the midpoint of the curve with the raised pavement markers than with the post-mounted delineators. In addition, the variability in lateral placement of vehicles at the midpoint of the curve was less with raised pavement markers than with post-mounted delineators.

Zador et al. (1987) examined the short- and long-term effects of chevrons, post-mounted delineators, and raised pavement markers on the speed and placement of vehicles traveling on curves on rural two-lane highways. In general, all three delineation treatments affected driver behavior at night. Vehicle paths were shifted away from the centerline on horizontal curves where raised pavement markers and chevrons were installed and toward the centerline on curves where post-mounted delineators were used. Vehicle speed and placement variability were also slightly reduced with the use of chevrons and raised pavement markers. Zador et al. did not conclude that one delineation treatment was superior to the others and indicated that the primary benefit of any of these delineation treatments may simply be that they help drivers better recognize that they are approaching a curve.

Agent and Creasey (1986) investigated the ability of various traffic control devices to delineate horizontal curves so drivers would perceive the curve and slow to an appropriate speed and so drivers would have improved guidance through the curve. The investigation consisted of both laboratory tests and field data collection. The laboratory tests suggested that increasing the height of the post-mounted delineator while maintaining the distance from the post to the pavement edge, and keeping the post spacing constant, made a curve appear sharper than other delineator devices. From speed data, encroachment data, and some accident data, Agent and Creasey found that pavement markings had a greater effect on drivers than post-mounted delineators installed on the roadside did. In addition, chevrons had slightly more influence on speeds and encroachments than other post-mounted delineators did.

Jennings and Demetsky (1985) evaluated the effectiveness of three post-mounted delineator systems in controlling ROR crashes. The post-mounted delineator systems were evaluated based upon changes in speed and lateral placement of vehicles within the travel lane. Jennings and Demetsky found that drivers reacted most favorably to chevron signs on sharp curves greater than or equal to 7 degrees (radius of 250 m [820 ft]) and to standard post-mounted delineators on curves less than 7 degrees.

In summary, the safety effectiveness of enhanced delineation at a horizontal curve is difficult to assess because many of the research results are conflicting. Part of the difficulty arises because several of the studies use modifications in speed and lateral placement as surrogate measures to evaluate safety rather than actual crash data. The general conclusions that may be drawn regarding the safety effectiveness of enhanced delineation at horizontal curves are that post-mounted delineators may improve safety at sharp curves and that chevrons are more effective than standard post-mounted delineators are. At this point, no quantitative estimates of the safety effectiveness of enhanced delineation treatments can be made. Zador et al. may have summarized the safety effectiveness of enhanced delineation best by indicating that the primary benefit may simply be that enhanced delineation treatments help drivers better recognize that they are approaching a horizontal curve.

Strategy Attributes

The ROR guide presents attributes common to Strategies 15.2 A2 and 15.1 A6. The reader is directed to the ROR guide for more detailed information related to this strategy.

Strategy 15.2 A3: Provide Adequate Sight Distance (T)

General Description

Sight distance is a fundamental element in geometric design. The amount of sight distance provided to the driver is a function of the three-dimensional features of the highway—the cross section (roadside), vertical alignment (grades and vertical curves), and horizontal alignment. At horizontal curves, obstructions that limit the driver's sight distance come in many shapes and forms. The road surface may be the sight obstruction if the horizontal curve is located on a crest vertical curve. Physical features outside of the traveled way—such as trees or bushes, guardrail or concrete barriers, and the backslope of a cut section—also can limit the driver's sight distance. As trees and other roadside vegetation mature, the sight distance at a horizontal curve may change. Motor vehicles and other road users can also create temporary sight obstructions. Efforts should be made to ensure that obstructions do not reduce the sight distance at a horizontal curve to less than the minimum stopping sight distance.

The available stopping sight distance on a roadway should be sufficiently long to enable a vehicle traveling at or near the design speed to stop before reaching a stationary object in its path (AASHTO, 2001). Providing at least the minimum stopping sight distance at every point along a roadway is critical for safe operations.

Stopping sight distance is the sum of (1) the distance traversed by the vehicle from the instant the driver sees an object necessitating a stop to the instant the brakes are applied (i.e., the brake reaction distance) and (2) the distance needed to stop the vehicle from the instant the brakes are applied (i.e., the braking distance). Furthermore, drivers have other sight distance needs in addition to stopping for hazards in the paths of their vehicles. A driver needs an adequate view of the roadway alignment and roadway features ahead for safe control and guidance of the vehicle (Gattis and Duncan, 1995). This sight distance to the roadway surface and other appurtenances ahead is referred to as preview sight distance (PVSD). A roadway designed with geometric design features adequate to the design speed would in many cases provide sufficient PVSD; however, a roadway with constrained design features, or a roadway section that does not conform to current geometric design policies, could have inadequate PVSD.

Current design policy does not identify where lack of sight distance may produce a significant safety risk. *NCHRP Report 400* (Fambro et al., 1997) suggests that most locations with limited stopping sight distance experience very few accidents. However, limited stopping sight distance may be a greater concern where an intersection or driveway is present along a horizontal curve. Objective 17.1 C in the unsignalized intersection guide provides more detailed information about intersection sight distance.

If the available sight distance is found to be less than the minimum stopping sight distance, the sight obstruction should be removed or the roadway should be realigned to provide at least minimum stopping sight distance. The safety effectiveness of increasing sight distance will be a function of the amount of the sight restriction, the traffic volume exposed to it, and the presence of other conditions contributing to risk. For additional information on stopping sight distance, see *NCHRP Report 400* (Fambro et al., 1997).

EXHIBIT V-3
Strategy Attributes for Providing Adequate Sight Distance (T)

Technical Attributes	
Target	Drivers of vehicles approaching a curve with limited sight distance.
Expected Effectiveness	It is difficult to determine the expected safety benefits of improving the sight distance at a horizontal curve when the available sight distance is slightly less than the minimum stopping sight distance. The accident statistics do not provide a sufficient amount of information to determine the expected safety benefits. There is some indication from research (see *NCHRP Report 400*) that improving locations with substantial sight distance restrictions offers safety benefits.
Keys to Success	Seasonal changes and growth of roadside vegetation can alter the available sight distance at horizontal curves. Therefore, one of the keys to success is developing a program to periodically check the offset to roadside vegetation along horizontal curves. Another key to success is to institute a policy that requires checking horizontal sight distance when any installation is made along a curve, such as new guardrail or attenuation devices, as well as barriers used during construction and maintenance activities.
Potential Difficulties	There is a lack of data to show the effect of inadequate sight distance on safety. Thus, at horizontal curves where the available sight distance is less than the minimum stopping sight distance, it might be difficult to justify spending funds to improve sight distance, unless there is a documented history of crashes due to inadequate sight distance. This is particularly true when the cost to improve the sight distance could be extremely high, such as at a bridge pier, a backslope of a cut section, or the roadway surface.
Appropriate Measures and Data	*Process measures* of program effectiveness would include the *number of horizontal curves* where the sight distance was improved and the change in minimum sight distance. *Impact measures* include *the number of total crashes reduced* at these locations and changes in total crashes. Surrogate measures, such as lane position, or lane departures, may be appropriate for short-term evaluation. Accurate crash and exposure data are needed for before and after periods on treated sections and similar comparison groups to evaluate the effectiveness of this treatment. Geometric data on the curve (i.e., length and degree of horizontal curvature, as well as vertical geometry along the curve) and available sight distance are needed also.
Associated Needs	Available sight distances can be determined from roadway plans. However, a combination of the use of video logs and site visits may be required to identify actual sight obstructions and to measure available sight distances in the field.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	None identified.
Issues Affecting Implementation Time	The type of sight obstruction will affect the implementation time. When the sight obstruction is roadside vegetation (trees, shrubs, etc.), routine trimming can be scheduled to eliminate the obstruction so that the implementation time will be short. However, when the sight obstruction is a bridge pier, a backslope of a cut section, or the roadway surface, eliminating the obstruction may require realignment of the

EXHIBIT V-3 (Continued)
Strategy Attributes for Providing Adequate Sight Distance (T)

	roadway or some major earth work that could require an environmental review. In this case, not only would the construction time be longer, but an environmental review would also extend the implementation time.
Costs Involved	The type of sight obstruction is the major determinant of cost. The costs may only include maintenance costs. However, they could include costs for replacement of installations or realignment of the curve, in which case design, construction, and maintenance costs will be involved.
Training and Other Personnel Needs	No special needs identified.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy 15.2 A4: Install Shoulder Rumble Strips (P)

General Description

This strategy focuses on issues related to the safety effectiveness of shoulder rumble strips at horizontal curves (Exhibit V-4). While shoulder rumble strips are designed primarily to reduce ROR crashes, they can also reduce head-on crashes. Head-on crashes may occur when a vehicle leaves the roadway and its driver overcompensates while trying to recover control of the vehicle, sending the vehicle into the opposing traffic lane.

EXHIBIT V-4
Shoulder Rumble Strips
(http://safety.fhwa.dot.gov/programs/rumble.htm)

One of the unique issues related to the safety effectiveness of shoulder rumble strips at horizontal curves concerns the departure angle for vehicles that leave the roadway. Studies indicate that an average departure angle for ROR crashes ranges between 3 and 8 degrees (Hall, 1991; O'Hanlon and Kelley, 1974). In these studies, it is not clear whether the analyses included crashes that occurred along tangent sections of highway, crashes that occurred at horizontal curves, or both. Regardless, the research results indicate that ROR crashes typically occur at shallow departure angles. However, the departure angle is a function of the horizontal alignment. If a vehicle drifts to the right along a tangent section of roadway at an angle of 3 degrees, the vehicle follows a certain path onto the roadside. If the same vehicle path occurs along a horizontal curve, the result will be a larger departure angle because of the curvature of the roadway. This has two implications on the effectiveness of shoulder rumble strips at horizontal curves. First, because the vehicle crosses the rumble strips at a greater angle, an inattentive driver has less exposure time to the stimuli (i.e., vibration and noise) generated by the rumble strips. Second, if the shoulder width on the curve is the same as on an adjacent tangent, the driver has less time to regain control of the vehicle before it leaves the shoulder.

This strategy is the same as Strategy 15.1 A1 provided in the ROR guide. The section below provides a summary of the effectiveness of shoulder rumble strips. Following that is a section that presents special issues concerning shoulder rumble strips at horizontal curves.

Summary of Safety Effectiveness of Shoulder Rumble Strips

Shoulder rumble strips have proven to be an effective measure in reducing the number of ROR crashes on freeways. Numerous studies have quantified the reductions in ROR crashes to varying degrees. In general, the studies indicate that ROR crashes were reduced by 20 to 50 percent because of the installation of shoulder rumble strips. The section of this guide on the description of the problem indicates that horizontal curve fatal crashes primarily occur on rural two-lane highways. Because little is known about the effectiveness of shoulder rumble strips on two-lane highways, the ROR guide suggests that one might assume a similar experience to what has been documented on rural freeways—a 20- to 30-percent reduction in single-vehicle ROR crashes. However, the reader should review the considerations that are listed below before making such an estimate.

Strategy Attributes

The ROR guide presents attributes common to this strategy under strategy 15.1 A1. The reader is directed to the ROR guide for more detailed information. In addition, however, several issues should be pointed out, particularly regarding the installation of shoulder rumble strips at horizontal curves.

Studies concerning the safety effectiveness of shoulder rumble strips have used crash data collected over long segments of highway, meaning that the study segments included both tangents and horizontal curves. No distinction was made in these studies between tangent and horizontal curve sections, and there are no studies that analyze the effectiveness of shoulder rumble strips at horizontal curves only. It might thus be assumed that similar safety benefits apply to the application of shoulder rumble strips along both types of alignments (tangents and curves). However, it should be recognized that the effectiveness of shoulder rumble strips in reducing ROR crashes depends on various elements, including the frequency with which vehicles in the traffic stream run off the road, the vehicle departure angle, the vehicle speed, the shoulder width, and the roadside environment. The vehicle departure angle is of particular interest in this case.

It is, therefore, a complex issue to speculate on the specific effectiveness of shoulder rumble strips specifically on curves. Consider some of the following attributes:

1. The proportion of vehicles that run off the road is expected to be significantly greater on a curve than on a tangent section of road.
2. Hall (1991) and Elefteriadou et al. (2001) have conducted research on shoulder rumble strips and vehicle departure angle. Vehicle departure angle is a function of the steering angle and the curvature of the roadway. As the vehicle departure angle increases, the exposure time to stimuli generated by shoulder rumble strips and the available recovery distance decreases, making it less likely that the errant vehicle can recover in the available time.
3. Shoulder rumble strips installed along horizontal curves can also serve as an effective means of locating the edge of the travel way during inclement weather (FHWA, 2001). When drivers have difficulty seeing the edgeline along a horizontal curve (such as under heavy rain, light snow, or foggy conditions), a shoulder rumble strip can help drivers maintain their proper lane position.
4. The potential difficulties most often associated with shoulder rumble strips include snow removal (i.e., potential damage to snow plows and rumble strips), drainage, shoulder maintenance, noise, motorcycle use, and bicycle use. Each of these potential difficulties is discussed in the ROR guide. Snow removal, drainage, maintenance, noise, and motorcycle use are often listed as potential difficulties, but experience has shown that these concerns can often be dealt with or dismissed through sensible policies and targeted application of the solution.

Incompatibility between shoulder rumble strips and bicycle use is a concern in some locales. For example, a moratorium on the installation of ground-in rumble strips where bicycles were allowed was initiated in California until further research on the subject is completed (Bucko and Khorashadi, 2001). The three most comprehensive studies on the effects that rumble strips have on bicyclists were conducted in Pennsylvania, California, and Colorado by Elefteriadou et al. (2000), Bucko and Khorashadi, and Outcalt (2001a), respectively. Each study included bicycle and motor vehicle testing of various rumble strip designs. In general, the rumble strips that provided the greatest amount of stimuli (i.e., noise and vibration) to alert an inattentive or drowsy driver also were the most uncomfortable for the bicyclists to traverse. Likewise, the rumble strips that were the most comfortable for the bicyclists generated the least amount of stimuli in a motor vehicle to alert a drowsy or otherwise inattentive driver. In all three studies, compromises were made when selecting the rumble strip design most compatible for both types of road users.

Shoulder width is a major issue to consider before installing shoulder rumble strips. For further details on designs used by some states, see Appendix 1.

Finally, the impact of rumble strips on pavement performance is an issue that is often overlooked. Because rumble strips reduce the effective structural cross section of the pavement, rumble strips may reduce the overall pavement life or require greater total pavement thicknesses if significant loadings are anticipated to the shoulder or rumble strip area. Elefteriadou et al. (2001) provide some discussion of pavement integrity issues related to rumble strip installation.

For additional information on shoulder rumble strips, *Synthesis of Shoulder Rumble Strip Practices and Policies* was recently published by SAIC (2001), and FHWA published *Technical Advisory for Roadway Shoulder Rumble Strips* (FHWA, 2001). Both documents are available from the FHWA rumble strip Web site (http://safety.fhwa.dot.gov/programs/rumble.htm).

It should be noted that the ROR guide addresses the use of mid-lane rumble strips (Strategy 15.1 A3), which serve a similar purpose to shoulder rumble strips except that mid-lane rumble strips are installed in the center of the travel lane instead of on the shoulder.

Strategy 15.2 A5: Install Centerline Rumble Strips (T)

General Description

Centerline rumble strips are installed primarily to reduce head-on and sideswipe crashes along undivided roadways. Their primary function is to alert drowsy or otherwise inattentive drivers that their vehicles are encroaching upon the opposing lane through tactile and auditory stimulation. Centerline rumble strips may also discourage drivers from cutting across the inside of a curve. There is no standard design for centerline rumble strips, but generally the rumble strips are either (1) located along the width of the centerline pavement markings (Exhibit V-5), extending into the travel lane by as much as 0.5 m (1.5 ft) (Exhibit V-6), or (2) placed on either side of the centerline (Exhibit V-7). Some states install rumble strips continuously along the centerline, while other states install centerline rumble using a skip pattern.

Installing centerline rumble strips directly relates to Strategy 18.1 A1 in the guide for addressing head-on collisions, which is centerline rumble strips for two-lane roads. Centerline rumble strips are a relatively new strategy for reducing head-on crashes. Subsequently, little information is available on the safety effectiveness of this type of rumble strip. The section immediately following this one summarizes the effectiveness of centerline rumble strips as presented in the head-on guide, as well as the results of three recent studies on centerline rumble strips. The final section under this strategy discusses strategy attributes that relate to applying centerline rumble strips at horizontal curves.

EXHIBIT V-5
Centerline Rumble Strips
(Photo Provided by PennDOT)

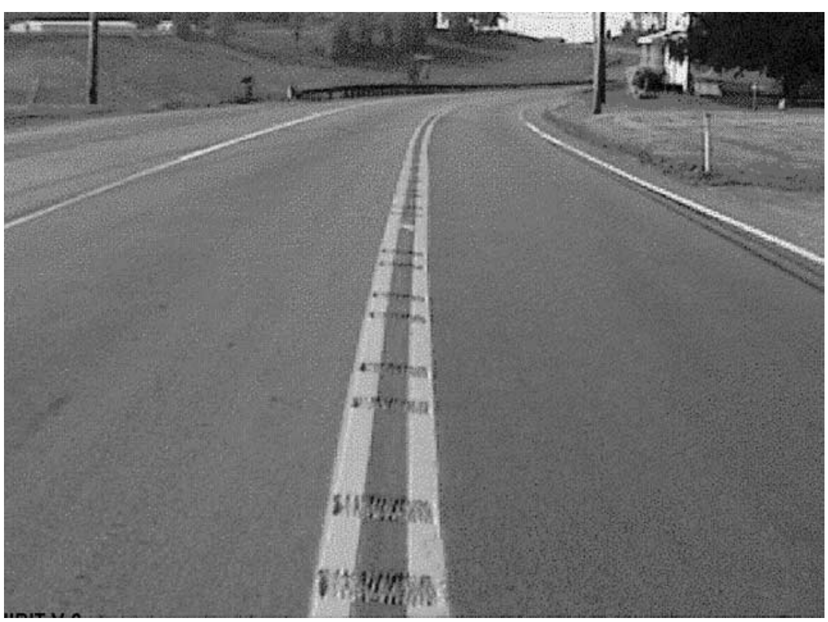


EXHIBIT V-6
Centerline Rumble Strips
(Photo Provided by Caltrans)

EXHIBIT V-7
Centerline Rumble Strips
(Photo Provided by MnDOT)

Summary of Safety Effectiveness of Centerline Rumble Strips

The head-on guide identifies two studies that showed centerline rumble strips to be effective in reducing head-on crashes. Centerline rumble strips were installed on a two-lane, undivided rural highway in Delaware (Perrillo, 1998). During the 36-month before period, there were 6 fatal crashes, 14 injury crashes, and 19 property damage only crashes. During the 24-month after period, there were 0 fatal crashes, 12 injury crashes, and 6 property damage only crashes. It was concluded that the centerline rumble strips reduced the total number of crashes and the severity of the crashes. In California, improvements were made to a 32-km (20-mi) segment of a rural two-lane highway to reduce the number of head-on crashes (Fitzpatrick et al., 2000a). The improvements included replacing the double yellow stripes with centerline rumble strips and raised profile thermoplastic traffic striping. In addition, raised pavement markers were installed between the rumble strips and raised profile thermoplastic. Using 34 months of before data and 25 months of after data, an evaluation showed that the centerline rumble strips and other improvements reduced the crash frequency from an average of 4.5 crashes per month in the before period to 1.9 crashes per month in the after period.

Rys et al. (2003) conducted a study to determine the most effective centerline rumble strip pattern for use on Kansas roadways. A survey of the few agencies that currently use centerline rumble strips found that there was no generally accepted pattern as to the types and dimensions of these rumble strips. Using information gathered on some of the patterns currently used, a test section of roadway was prepared by installing 12 different sections of centerline rumble strips of varying dimensions and spacing. Seven test vehicles were chosen to represent an accurate range of roadway traffic, and two measurements were taken in each automobile: interior noise level and steering wheel vibration level. Based on their findings, Rys et al. recommended that further testing be conducted on two of the centerline rumble strip patterns to more clearly determine which is most beneficial: either the continuous pattern that is 305 mm (12 in.) on the center and 305 mm (12 in.) long or the alternating pattern that is 305 mm and 610 mm (12 in. and 24 in.) on the center and 305 mm (12 in.) long. The authors noted that each of these patterns rated high in both noise level and vibration created; both were installed along urban and rural roadways in Kansas for continued testing during the 2003 year.

Mahoney et al. (2003) conducted a before-after study to determine whether centerline rumble strips have an effect on the lateral displacement of vehicles. Data were collected on eight roadway sections (four test and four comparative sections) in rural settings so that an operational analysis, rather than a safety analysis, could be performed on centerline rumble strips. To reduce the effect of outside influences on the lateral placement, tangent segments were chosen with minimal grade, no roadside barriers, and nominal horizontal curvature. The data analysis revealed that the mean lateral placement of vehicles shifted 140 mm (5.5 in.) away from the center of the lane subsequent to centerline rumble strip installation along roadway sections with 3.6-m (12-ft) lanes, and the mean lateral placement of vehicles shifted 76 mm (3 in.) away from the center of the lane subsequent to centerline rumble strip installation along roadway sections with 3.3-m (11-ft) lanes. Introduction of centerline rumble strips also decreased the amount of lateral placement variance that, in previous studies, had been shown to possibly increase traffic safety. The effects of centerline rumble strips on vehicle speed were inconclusive.

In 2001, Colorado DOT completed a before-after evaluation of 27 km (17 mi) of centerline rumble strips installed along a winding, two-lane mountain road (Outcalt, 2001b). The analysis used 44 months of before data and 44 months of after data. The resulting crash data and associated percent changes are shown in Exhibit V-8.

EXHIBIT V-8
Colorado Before-After Crash Summary of Centerline Rumble Strips (Outcalt, 2001b)

	Before Period 7/1/92–3/1/96 (44 months)	After Period 7/1/96–3/1/00 (44 months)	Percent Change
Head-on crashes	18	14	
Head-on crashes per million vehicles	2.91	1.92	–34%
Sideswipe opposite direction crashes	24	18	
Sideswipe opposite direction crashes per million vehicles	3.88	2.46	–36.5%
Average ADT	4628	5463	+18%

Strategy Attributes

The head-on guide presents attributes common to Strategy 15.2 A5 and Strategy 18.1 A1. The reader is directed to the guide for addressing head-on collisions for more detailed information related to this strategy. In addition, several issues should be highlighted concerning the effectiveness of centerline rumble strips, policy issues, and potential difficulties.

When considering the expected effectiveness of centerline rumble strips in reducing head-on crashes at horizontal curves, similar issues to those discussed in Strategy 15.2 A4 should be considered.

Arizona, California, Colorado, Delaware, Kansas, Maryland, Massachusetts, Minnesota, Oregon, Pennsylvania, Virginia, Washington, and Wyoming are among the states that have installed centerline rumble strips. To learn more about Minnesota DOT's experiences with centerline rumble strips see http://www.dot.state.mn.us/d3/newsrels/03/10/06_rumble_strips.html. These installations have primarily been on an experimental basis. After agencies have sufficient experience with this new technique, a written policy should result for centerline rumble strips. The policies may include guidelines or recommendations regarding the type of sites at which to install centerline rumble strips, as well as design specifications and pavement thickness requirements.

The possibility of centerline rumble strips adversely affecting motorcyclists and inhibiting passing maneuvers is mentioned in the guide for addressing head-on collisions. However, experiences in Pennsylvania, Washington, and Minnesota suggest that this may be more a perceived problem than an actual problem. In Connecticut, however, centerline rumble strips were installed on a short section (less than 1.6 km [1 mi]) of a state route that carried a high percentage of truck traffic. The centerline rumble strips were removed after approximately 8 months because of complaints about noise.

Other potential disadvantages of centerline rumble strips include decreased visibility of centerline pavement markings, potential drainage problems, and snow removal difficulties. However, experience has not proven these potential disadvantages to be significant or insurmountable. In fact, the opposite may be true in some cases. At least one agency with centerline rumble strip installations has noted that the visibility of centerline pavement markings is not diminished because of centerline rumble strips and that centerline pavement markings are even visible when the rumble strips are filled with water. Likewise, at horizontal curves where greater superelevation can be expected, interruption of drainage flow patterns should be minimal. Concerning snow removal difficulties, no agency has indicated a reduction in pavement life because of centerline rumble strips. But centerline rumble strips have only recently been implemented, so more time is necessary to adequately address this issue. However, at least one agency has received comments that motorists perceived the centerline rumble strips as beneficial during snowy conditions because the motorists were still able to hear and feel the rumble strips in that kind of weather. An added benefit of centerline rumble strips is that they may extend centerline marking life because they decrease the number of vehicles crossing the markings.

Finally, the primary purpose of centerline rumble strips is to reduce head-on and sideswipe crashes. Centerline rumble strips also have the potential to reduce ROR crashes that occur to the left. If vehicles traveling on the inside of a curve cross the centerline, the centerline rumble strips alert the driver as soon as the vehicle encroaches on the centerline. This maximizes the recovery time and distance for vehicles that can run off the road to the left.

Strategy 15.2 A6: Prevent Edge Dropoffs (T)

General Description

Preventing edge dropoffs, also referred to as edgedrops, can reduce both ROR and head-on crashes by enabling a driver to recover an errant vehicle in a more controlled fashion. Edge dropoffs are a significant difference in elevation between the edge of traveled way and shoulder (Exhibit V-9). Edge dropoffs may occur after resurfacing or as the result of weather

EXHIBIT V-9
Example of Edge Dropoff
(ROR guide)

or vehicle-related settlement and can occur whether the shoulder is paved or not. Edge dropoffs may be more common on curves than on tangents.

Edge dropoffs of more than 10 mm (4 in.) have been shown to contribute to loss of control. Drivers who inadvertently drift onto the shoulder find their right wheel caught against the dropoff. This may induce overcorrecting by the driver, with resultant sudden loss of control or steering into the opposing lane. This behavior may be exacerbated when the driver is tracking a horizontal curve.

The best practice is to always retain the travel lane and shoulder at the same elevation, where they meet. Where this cannot be achieved, such as on roadways with unpaved shoulders, an alternative is to smooth the transition between the traveled way and shoulder surfaces using a wedge of pavement that allows vehicles to safely return to the roadway. For example, during pavement work in the state of Idaho, "moulding shoes" are sometimes equipped on the outside of the pavers to provide safe asphalt slopes. Georgia is also working on a 30-degree asphalt fillet. This strategy is related to strategies under the section in the ROR guide entitled "Apply Shoulder Treatments" (Strategy 15.1 A8).

Reference is usually made to edge dropoffs in the context of the boundary between the traveled-way pavement and the shoulder surface. Edge dropoffs can also occur at the boundary between the shoulder surface and roadside. Efforts should be made to prevent both types of edge dropoffs.

Particular care should be taken to minimize the potential risks of edge dropoffs in work zones. Edge dropoffs can commonly occur in work zones as the result of overlays, pavement replacement, or shoulder construction. The depth of these elevation differentials can vary from approximately 2.54 mm (1 in.), when a flexible overlay is applied, to several meters, when major reconstruction is undertaken. McDonald et al. (2002) reviewed temporary traffic control strategies in numerous states addressing edge dropoff differentials and analyzed crash data and litigation related to edge dropoffs. McDonald et al. also developed recommendations for mitigating edge dropoffs in work zones.

Summary of Effectiveness of Preventing Edge Dropoffs

The ROR guide indicates that little is known about the safety effectiveness of edgedrop treatments because it is difficult to specifically define the percentage of crashes that are caused by edge dropoffs. Regardless of the percentage, it has been proposed that a simple 45-degree-angle asphalt fillet at the lane edge would virtually eliminate this type of crash for shoulder dropoffs (Humphreys and Parham, 1994).

Strategy Attributes

The ROR crash guide presents attributes common to this strategy under Strategy 15.1 A8. The reader is directed to that guide for more detailed information related to this strategy.

Strategy 15.2 A7: Provide Skid-Resistant Pavement Surfaces (T)

General Description

Current design criteria for horizontal curves are formulated to provide comfort to the driver in tracking the curve while keeping vehicles from skidding on wet pavements. The criteria are based upon the standard curve formula that provides that a portion of the lateral acceleration developed by the vehicle will be resisted by superelevation and the remainder by tire-pavement friction. A vehicle will skid during braking and maneuvering when frictional demand exceeds the available friction at the tire-pavement interface.

Much research has been conducted to address curve operations, driver speed, vehicle paths, and safety. Harwood and Mason (1994) evaluated the margin of safety against skidding for a passenger car and truck on a horizontal curve. The margin of safety was defined as the difference between the available tire-pavement friction and the friction demand of the vehicle as it tracks the curve. The authors determined that existing design criteria provide an adequate margin of safety against vehicles skidding off the roadway, assuming vehicles do not exceed the design speed of the roadway and vehicles traverse the curve on a path that follows a constant radius equal to the radius of the curve.

The likelihood of skidding increases when these assumed conditions are violated. Several studies have shown that under real-world conditions both of these assumptions are violated to some degree (Bonneson, 2000; Glennon et al., 1985; Glennon and Weaver, 1972), with the result being that at many curve sites the assumed margin of safety may actually be overestimated. Where this is the case and there is evidence of loss of control because of skidding, several solutions are evident. Solutions may include modifications to the alignment and roadside to control speeds, changing the superelevation along the curve, and/or providing pavement surfaces with better skid resistance. Strategy 15.2 A7, however, focuses upon providing pavement surfaces with better skid resistance.

Summary of Effectiveness of Providing Better Skid-Resistant Pavement Surfaces

This strategy directly relates to Strategy 15.1 A7 in the ROR guide on skid-resistant pavement surfaces. Although further details may be found there, this section provides a brief summary of the safety effectiveness of providing better skid-resistant pavement surfaces, as presented in the ROR guide. New York State 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. 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 support earlier findings that improving the skid resistance at locations with high wet-road accident frequencies results in reductions of 50 percent for wet-road accidents and 20 percent for total accidents. While these results could be subject to some regression-to-the-mean bias, there is an indication that improving the skid resistance of pavement surfaces reduces wet-road and total accidents. Some states, including California, resurface short roadway segments such as horizontal curves with open-graded asphalt friction courses to improve skid resistance and safety.

Strategy Attributes

The ROR guide presents attributes common to this strategy, under Strategy 15.1 A7. The reader is directed to the ROR guide for more detailed information related to this strategy. The signalized intersection guide also discusses similar treatments under Strategy 17.2 G2.

In conjunction with this strategy, an agency should consider scheduling routine pavement friction tests and creating a pavement friction inventory program. Ideally, this type of program would include the entire roadway network within an agency's jurisdiction, but at a minimum it should include the highest-volume roadways. Caltrans operates an Office of Pavement Rehabilitation, which includes a program of pavement friction inventory (http://www.dot.ca.gov/hq/esc/Translab/opr.htm). Routine pavement friction tests should be conducted on both tangent and curve sections of a highway. Research conducted by NYDOT in the late 1990s revealed that, under high-volume conditions, significant reductions in friction occurred at curves, compared with tangent sections of the same road segment treated with the same surface treatment.

Finally, drainage is an important issue to consider when implementing this strategy. As the water film thickness on the pavement increases, the likelihood of hydroplaning increases. Therefore, any drainage problems should be corrected in conjunction with this strategy. While checking for and/or correcting any drainage problems, deficiencies in the superelevation and pavement edge profiles should also be checked and improved if found deficient.

Strategy 15.2 A8: Provide Grooved Pavement (T)

General Description

Pavement grooving is a technique by which longitudinal or transverse cuts are introduced on a surface to increase skid resistance and to reduce the number of wet-weather crashes. The grooves increase skid resistance by improving the drainage characteristics of the pavement and by providing a rougher pavement surface. Several studies show that grooved pavements reduce wet-weather crashes. However, some potential adverse effects should be considered before this strategy is implemented, including the potential of increased noise pollution, accelerated wearing of pavements, and negative effects on steering.

This strategy is related to Strategy 15.2 A7 in this guide and Strategy 15.1 A7 in the ROR guide. Those strategies focus on improving skid resistance by means of changing the pavement aggregates, placing overlays, or adding texture to the pavement surface. Strategy 15.2 A8 focuses strictly on providing grooved pavement. While pavement grooving is a way to add texture to the pavement surface, its primary objective is to improve the drainage and to mitigate hydroplaning. The grooves decrease the water film thickness on a pavement surface and allow for greater tire-pavement surface interaction during adverse weather conditions. Because pavement grooving is such a unique approach to increasing the skid resistance of a pavement, it is treated separately. The section immediately following this one presents results of studies that evaluated the safety effectiveness of pavement grooving. That is followed by a section that presents attributes unique to pavement grooving that should be considered before this type of treatment is implemented.

Safety Effectiveness of Pavement Grooving

Numerous studies on the safety effectiveness of pavement grooving have been conducted, but none of these studied have controlled for regression to the mean so the results should be considered with caution. Wong (1990) performed a before-after evaluation of the effectiveness of pavement grooving based upon data from one site in California. The site was a two-lane highway with steep vertical grades and sharp horizontal curves. Based upon accident data from a 3-year before period and a 1-year after period, Wong found a 72-percent reduction in wet-pavement accidents, while only finding a reduction of about 7 percent in dry-pavement accidents. Wong concluded that pavement grooving was effective in reducing wet-pavement accidents.

Zipkes (1976) analyzed the frequency of accidents and the percentage of accidents on wet and dry pavement surfaces during a 7-year period to evaluate the effect of pavement grooving. Accident data were obtained for a 44-km (27-mi) section of highway near Geneva, Switzerland. Transverse grooves were cut into the pavement with varying groove distances over a 2-km (1.2-mi) section of highway. Grooving of the polished road surfaces reduced the hazard of accidents when drainage conditions were unfavorable. Zipkes indicated that the advantage of grooving is the reduction of water-film thickness, which leads to better contact between the tire and the road surface for the transmission of forces.

Smith and Elliott (1975) evaluated the safety effectiveness of grooving 518 lane-km (322 lane-mi) of freeways in Los Angeles, while 1,200 lane-km (750 lane-mi) of ungrooved pavement were used as a control. The analysis was conducted using 2 years of before data and 2 years of after data. Only fatal and injury accidents were included in the evaluation. Smith and Elliott found that pavement grooving resulted in a 69-percent reduction of wet-pavement accident rates. Sideswipe and hit object accidents were reduced to the largest extent. Pavement grooving did not change the dry-pavement accident rates.

Mosher (1968) synthesized results from studies conducted by state highway departments on the effects of pavement grooving. Information for the report was obtained from 17 states, including Colorado, Florida, Georgia, Idaho, Illinois, Indiana, Louisiana, Minnesota, Missouri, Nebraska, New York, Ohio, Pennsylvania, Texas, Utah, Wisconsin, and Wyoming. Some sections of highway had longitudinal grooves, while other sections had transverse grooving. Pavement grooving proved very effective, reducing crashes by 30 to 62 percent.

Farnsworth (1968) evaluated the effects of pavement grooving on five sections of California highways. Farnsworth measured the coefficients of friction before grooving and after grooving and found that pavement grooving increased the coefficients of friction, changing the friction values from below critical to above critical. Analysis of accident data revealed a reduction in wet-pavement accidents at each of the sites.

NYDOT evaluated the safety effectiveness of pavement grooving based on the installation of grooves at 41 sites. NYDOT found that wet-road accidents were reduced by 55 percent, and total accidents (dry and wet) were reduced by 23 percent. The results were statistically significant at the 95th percentile. Regression to the mean was not addressed in the analysis.

Strategy Attributes

Pavement grooving involves making several shallow cuts of a uniform depth, width, and shape in the surface of the pavement (Mosher, 1968). Grooves may be cut longitudinally along the pavement (parallel to the direction of travel) or in the transverse direction (perpendicular to the direction of travel). Transverse grooving has been used to a lesser extent than longitudinal grooving, partially because most grooving equipment lends itself more readily to placing grooves parallel to the roadway. Grooves cut in the longitudinal direction have proven most effective in increasing directional control of the vehicle, while transverse grooving is most effective where vehicles make frequent stops, such as intersections, crosswalks, and toll booths. When pavements are grooved, it is important that the pavement contain nonpolishing aggregate.

While studies have indicated that pavement grooving reduces wet-pavement accidents, there have been several concerns associated with pavement grooving (Mosher, 1968). One concern has been the effect that pavement grooving has on the durability of various pavement types. For example, one of the most frequently asked questions by engineers in northern climates is, "What will water freezing in the grooves do to the concrete pavement?" In an examination of grooved pavement in Minnesota after one winter, there appeared to be no deterioration in the grooved pavement because of the freeze-thaw cycles. Concern also has been expressed about grooves in asphalt pavement losing their effectiveness because the material can be flexible enough to "flow" back together, particularly during hot weather. This phenomenon has been observed under certain conditions with a fairly new asphalt pavement or with a pavement with low aggregate content. Concern has also been expressed over the loss of effectiveness because of grooved pavements wearing down under high-traffic conditions.

Complaints also have been received that longitudinal grooves adversely affect the steering of certain automobiles and motorcycles. In general, no severe problems have been encountered. This finding is supported by research conducted by Martinez (1977), who studied the effects of pavement grooving on friction, braking, and vehicle control by computer simulation and full-scale testing. Martinez considered automobiles, motorcycles, and automobile and towed-vehicle combinations in his evaluation.

In Iowa, residents living adjacent to I-380 near Cedar Rapids complained that transverse grooving was the cause of an especially annoying tonal characteristic within the traffic noise (Ridnour and Schaaf, 1987). As a result of the complaints, the surface texture of a section of I-380 was modified. The transverse grooving was replaced with longitudinal grooving. A before-after analysis of the traffic noise levels showed that the surface modification lowered overall traffic noise levels by reducing a high-frequency component of the traffic noise spectrum.

Strategy 15.2 A9: Provide Lighting of the Curve (T)

General Description

Approximately 51 percent (4,977) of the 9,791 fatal crashes that occurred at horizontal curves in 2002 took place during nighttime hours. To a large extent, these crashes may be attributed to reduced visibility at night.

There is evidence to show that providing fixed-source lighting in urban and suburban areas, where there are concentrations of pedestrians and intersectional interferences, reduces nighttime crashes. The need for lighting on streets and highways in rural areas is much less than on streets and highways on urban areas. The need for lighting on rural highways is seldom justified except in critical areas, such as sharp curves (AASHTO, 2001).

EXHIBIT V-10
Strategy Attributes for Providing Lighting of the Curve (T)

Technical Attributes	
Target	Drivers of vehicles approaching a horizontal curve who have difficulty seeing the curve during non-daylight hours.
Expected Effectiveness	The expected safety effectiveness of providing lighting at a horizontal curve is difficult to assess. Providing lighting at a horizontal curve helps to enhance the driver's available sight distance during nighttime conditions. In addition, lighting at a horizontal curve helps to provide advance warning of unexpected changes in horizontal alignment, and it helps to enhance delineation along a curve, particularly during adverse weather conditions. However, factors other than ambient light may be involved.
Keys to Success	Many crashes occur during nighttime hours at horizontal curves. However, not all of these crashes are attributed to reduced visibility. It is important to diagnose the problem and determine if the accident pattern is correctable by providing lighting.
Potential Difficulties	There are two potential difficulties associated with providing lighting at horizontal curves. First, the cost might be prohibitive, especially in rural areas. Second, luminaire supports (i.e., poles) are additional fixed objects that a vehicle could strike when it leaves the roadway. When a decision is made to provide lighting at a curve, the luminaire supports should be located in the least hazardous locations along the curve. Consideration should be given to the use of break-away poles. See the guide for utility poles for more information on minimizing the risk of poles.
Appropriate Measures and Data	Process measures of program effectiveness would include the number of horizontal curves where lighting was provided. Impact measures include the number and rate of nighttime crashes and the ratio of day-to-night crashes.
Associated Needs	A highway lighting plan would have to be developed when implementing this strategy. It is anticipated that the state DOT or local roadway agency would develop its own highway lighting plans from its own specifications or AASHTO's *Informational Guide for Roadway Lighting.*
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	Providing power to certain locations may require installation of power lines across multiple government jurisdictions. This will require the cooperation and coordination of multiple government agencies and the power company.
Issues Affecting Implementation Time	The availability of a power source at the horizontal curve will affect the implementation time. In urban and suburban areas, this is not a significant matter, but in rural areas, if overhead or underground power lines do not run along the right-of-way (ROW) near the location of the curve, providing a cost-effective approach for supplying electricity at the horizontal curve will increase the implementation time.
Costs Involved	There are several types of costs associated with providing lighting of a curve, including the cost of providing a permanent source of power to the location, the cost for the luminaire supports (i.e., poles), and the cost for routinely replacing the bulbs and maintenance of the luminaire supports. The cost for providing a permanent source of power to the location could be high if the curve is located in a remote rural area. In some cases, solar-powered lighting may be appropriate. An example is shown in Appendix 2.

EXHIBIT V-10 (Continued)
Strategy Attributes for Providing Lighting of the Curve (T)

	In many cases, local municipalities may be required to take responsibility for operational and maintenance costs associated with lighting. Some municipalities may be reluctant to take over these responsibilities, even if separate funds (i.e., state funds) are provided for capital costs.
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.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy 15.2 A10: Provide Dynamic Curve Warning System (T)

General Description

The purpose of this strategy is to reduce the speed of high-speed vehicles on their approach and as they navigate through a horizontal curve. A typical system combines a radar device with a variable message sign. The system measures the speeds of approaching vehicles and provides messages to drivers who are traveling at excessive speeds to slow down to a recommended, or advisory, speed (Exhibit V-11). Dynamic curve warning systems can also incorporate cameras to provide visual surveillance of curves. These systems can be developed using off-the-shelf technology. The main hypotheses regarding this type of strategy are that a dynamic warning device has a much greater effect on high-speed vehicles than a static curve warning sign and that the dynamic system significantly improves the ability of high-speed vehicles to successfully navigate through the curve.

EXHIBIT V-11
Sequence of Messages on Dynamic Curve Warning System in California
(Photo Provided by Caltrans)

Several dynamic curve warning systems have also been deployed specifically to reduce the likelihood of a truck rollover crash. In 1998, 207 trucks were involved in fatal rollover accidents on the U.S. highway system (Baker et al., 2001). Truck rollover accidents often occur at exit ramps and at tight curves that require a more reduced speed than the normal travel speed on the freeway. Therefore, many of the dynamic curve warning systems designed to reduce rollover crashes have been deployed at freeway exit ramps. Exhibit V-12 illustrates such a system.

EXHIBIT V-12
Freeway Ramp Example of Dynamic Curve Warning System
(McGee and Strickland, 1994)

EXHIBIT V-13
Strategy Attributes for Dynamic Curve Warning System (T)

Technical Attributes	
Target	Drivers of vehicles approaching a curve at an undesirable speed.
Expected Effectiveness	The safety effectiveness of dynamic curve warning systems is not completely known because very few systems have been installed, but preliminary evaluations of several systems are promising. Evaluation results from three studies are presented below. Three truck rollover warning systems were installed at three ramps on the Capital Beltway (I-495) in Virginia and Maryland (Strickland and McGee, 1996). The objective of these systems is to identify a truck of a certain type that is traveling toward a curved ramp whose speed is likely to approach or exceed the rollover threshold speed. The device is then to warn the driver of the truck to slow down before reaching the curve. The primary components of the system include weigh-

EXHIBIT V-13 (Continued)
Strategy Attributes for Dynamic Curve Warning System (T)

	in-motion detectors, speed loop detectors, height detectors, fiber-optic signs, and controllers to operate the systems. Based on an analysis of speed data, it was concluded that all three systems significantly impacted truck speeds and that the systems caused truck drivers to reduce their speeds before entering ramps, when their speed was exceeding the maximum safe speed. Before installing the rollover warning systems, a combined total of 10 truck rollover accidents occurred at the sites. After 3 years of operation, no rollover crashes were reported. In Minnesota, a dynamic curve warning system was installed on the approach to a 4-degree curve along a county highway (Preston and Schoenecker, 1999). The section of highway is a two-lane road with a posted speed limit of 89 km/h (55 mph), which is frequently used by unfamiliar drivers. A field test was conducted over a 4-day period to evaluate the effectiveness of the system. Vehicle speed and navigation measures were used to evaluate the system. The general effect of the system on vehicle speeds was relatively small. However, the dynamic system had a much greater effect on high-speed vehicles than the static curve warning sign. In addition, the dynamic system significantly improved the ability of high-speed vehicles to successfully navigate the curve. A 2000 report researches the effects of dynamic curve warning signs installed on five curves along a rural stretch of the California Interstate System that experienced relatively low volumes of traffic (Tribbett et al., 2000). The objective was to determine whether signs displaying information concerning the upcoming curve and the driver's actual speed would have any effect on the driver's approach to handling the horizontal curve. Analysis showed that significant truck speed reduction was found for three of the five curves and significant passenger vehicle speed reduction was observed at two of the five curves after the warning systems had been installed.
Key to Success	The key to a successful dynamic curve warning system is identifying vehicles that are actually traveling above the maximum safe speed and conveying this message to the drivers soon enough that they can adjust their speeds before reaching the curve. When a dynamic warning system provides a false warning to motorists to reduce their speeds, the system loses credibility. A false warning would include a message to motorists traveling at a safe speed that they should reduce their speed to successfully navigate the curve.
Potential Difficulties	Determining the maximum safe speed for a particular vehicle entering a horizontal curve is a very difficult task in the field. Many factors come into play, such as loads, suspension, vehicle size and configuration, and quality of the tires. Many algorithms, ranging from the very simple to the very complex, can be used to determine if vehicles are exceeding the maximum safe speed. Another issue to consider is adverse weather conditions. The target speed, or maximum recommended safe speed, may be different given the weather conditions. The challenge is developing a system sophisticated enough to minimize false readings while still being cost-effective to deploy. As systems become more complex, the cost of components increases. Another potential difficulty that could be associated with deploying a dynamic curve warning system is identifying the proper location for this type of treatment. This issue involves several aspects. First, an agency must determine that the types of accidents occurring at a particular curve are correctable with this treatment. Second, the geometrics near the curve, including both the horizontal and vertical alignments, must be compatible with such a system. Sight lines must be available

(*continued on next page*)

EXHIBIT V-13 (Continued)
Strategy Attributes for Dynamic Curve Warning System (T)

	for radar equipment and possible video equipment. Weigh-in-motion devices may need to be installed as well. Third, if the curve warning system is for an off ramp, difficulties arise in identifying those vehicles that are exiting. Thus, careful consideration should be given to locating dynamic curve warning systems. It also must be remembered that the placement of these devices at the roadside can result in a fixed-object hazard for vehicles that may run off the road. A power source must also be available.
Appropriate Measures and Data	In the evaluation of these systems, process measures would include the number of curves treated or the number of systems deployed. Impact measures involve comparison of crash frequencies or rates (with the study appropriately designed) for the before period and after period. A particular comparison of interest might be the number of rollover-related crashes in the before period to the number in the after period. The change in speed for vehicles entering selected curves would also be an impact measure. Consideration should be given to targeting the highest quartile speed group of vehicles when evaluating the effectiveness of the system based on speed. A surrogate measure might also include the number of encroachments onto the shoulder along the curve.
Associated Needs	Depending on the complexity of the system, many highway agencies may not have the technical expertise to develop and deploy a dynamic curve warning system. Therefore, many agencies will have to contract with an outside consultant to implement this strategy.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	Proprietary issues concerning ownership of the software and actual algorithms could arise during contractual arrangements.
Issues Affecting Implementation Time	The complexity of the system will affect the implementation time. For example, the primary components of the system installed in Minnesota were a radar device and a dynamic message sign. The systems installed in Virginia and Maryland involved weigh-in-motion devices, loop detectors, and height detectors. The algorithm for identifying vehicles exceeding the maximum safe speed was much more complicated for the system installed in Virginia than for the system used in Minnesota. Simple systems can be installed in a short timeframe, while the more complex systems might take a year or two from conception to implementation.
Costs Involved	The complexity of the system will affect the cost. Further details are provided in Appendix 3.
Training and Other Personnel Needs	There appear to be no special personnel or training needs for implementing this strategy because most of the work will be conducted by an outside contractor if the system is complex. Agencies should have the technical expertise to develop and install simple systems.
Legislative Needs	None identified.
Other Key Attributes	
	In addition to the systems identified above, dynamic curve warning systems have been installed in several other states, including Pennsylvania, Colorado, and Missouri. Similar systems have also been installed in the United Kingdom.

Strategy 15.2 A11: Widen the Roadway (P)

General Description

It is common practice to widen the traveled way on horizontal curves to make operating conditions on curves comparable to those on tangents. As noted in the AASHTO (2001) policy, widening the traveled way on horizontal curves is necessary for one of two reasons, either (1) the design vehicle occupies a greater width in negotiating the curve because of off-tracking or (2) drivers experience difficulty in steering their vehicles along the center of the lane. Roadway widening, however, can entail more than just widening the travel lanes. It can include widening the shoulders, providing shoulders where none previously existed, providing a buffer zone in the middle of the roadway, or various combinations of the above. By widening the traveled way, drivers have more space within the lane to maneuver their vehicles through the curve, allowing more room for driver error without serious consequences. By widening the shoulders or providing a shoulder where one previously did not exist, drivers have more recovery area to regain control of their errant vehicles before encroaching on the roadside.

The section immediately following this provides a brief summary of the safety effectiveness of widening the roadway as presented in the ROR guide.

Summary of Effectiveness of Roadway Widening

Two strategies in the ROR guide pertain to roadway widening: Strategies 15.1 A5 (improved highway geometry for horizontal curves) and 15.1 A8 (apply shoulder treatments). These may be referenced for further details.

Strategy 15.1 A5, on improving highway geometry for horizontal curves, provides accident reduction factors for widening lanes and/or shoulders on horizontal curves. Widening a lane may reduce accidents by 5 to 21 percent. Widening a paved shoulder may reduce accidents by 4 to 33 percent, and widening unpaved shoulders may reduce accidents by 3 to 29 percent.

Strategy 15.1 A8, on applying shoulder treatments, provides one set of accident modification factors for widening a paved shoulder on a two-lane rural highway and a second set of accident modification factors for various shoulder types and widths. The accident modification factors were developed by a panel of experts charged with developing prediction models on the expected safety performance of rural two-lane highways. The accident modification factors for widening a paved shoulder width vary as a function of shoulder width and average daily traffic. The base case used is a 1.8-m (6-ft) paved shoulder, and the accident modification factors range from 0.87 to 1.50. Regarding the accident modification factors for shoulder type, the base case is a paved shoulder. Depending on the shoulder width, the accident modification factors range from 1.00 to 1.03 for gravel shoulders, from 1.00 to 1.07 for composite shoulders, and from 1.00 to 1.14 for turf shoulders.

Strategy Attributes

The ROR guide presents attributes common to this strategy under Strategies 15.1 A5 and 15.1 A8. The reader is directed to that guide for more detailed information related to this strategy.

Finally, there is concern that widening the roadway may increase operating speeds. Because speed is such a critical factor related to safety at horizontal curves, roadway widening may worsen safety.

Strategy 15.2 A12: Improve or Restore Superelevation (P)

General Description

Superelevation is one of the key geometric elements of curve design. Designers select a superelevation rate consistent with the design speed, the selected curve radius, and their jurisdiction's policy for maximum superelevation. Superelevation works with friction between the tires and pavement to counteract the forces on the vehicle associated with cornering.

Many curves may have inadequate superelevation because of vehicles traveling at higher speeds than were originally designed for, because of loss of effective superelevation after resurfacing, or because of changes in design policy after the curve was originally constructed. For whatever reason, curves with inadequate superelevation may pose safety problems, particularly if the actual superelevation is less than the optimal superelevation as recommended by AASHTO policy (AASHTO, 2001).

Accident prediction models indicate that inadequate superelevation increases curve accidents (Zegeer et al., 1992). There is no evidence, however, that safety is adversely affected along a curve where the actual superelevation is greater than that recommended by AASHTO policy. Therefore, research results indicate that safety can be enhanced when the superelevation is improved or restored along curves where the actual superelevation is less than the optimal superelevation. The following section presents the safety effectiveness of improving or restoring superelevation along curves. The discussion is then concluded with a section that presents other issues relevant to this strategy.

Safety Effectiveness of Improving or Restoring Superelevation

Improving the superelevation of a curve can reduce curve accidents where there is a superelevation deficiency (Zegeer et al., 1991). Superelevation deficiency is the numerical difference between the optimal superelevation (as determined from AASHTO policy) and the actual superelevation of a given curve. Based on estimates from Zegeer et al. (1991), an improvement of 0.01 to 0.019 in superelevation (e.g., increasing superelevation from 0.04 to 0.05 to meet AASHTO policy) would be expected to yield an accident reduction of 5 percent. An improvement of 0.02 or greater in superelevation would be expected to yield an accident reduction of 10 percent.

In 2000, an expert panel used the Zegeer work to develop accident modification factors (AMFs) for the superelevation of a horizontal curve on two-lane highways (Harwood et al., 2000). The following relationships were developed based on the expert panel's judgement:

$$AMF = 1.00 \text{ for } SD < 0.01 \tag{1}$$

$$AMF = 1.00 + 6(SD - 0.01) \text{ for } 0.01 \leq SD < 0.02 \tag{2}$$

$$AMF = 1.06 + 3(SD - 0.02) \text{ for } SD \geq 0.02 \tag{3}$$

where

SD = superelevation deficiency.

These relationships indicate that there is no effect on safety until the superelevation deficiency reaches 0.01, which is consistent with the Zegeer work.

Strategy Attributes

During routine pavement projects, deficiencies in superelevation should be addressed (Zegeer et al.). There are several other issues related to superelevation that should be considered during routine pavement projects and during original construction. First, it is important to limit the slope break between the elevated edge of pavement and the adjacent shoulder. This can be achieved by designing the shoulder to be sloped upward at approximately the same rate as, or at a lesser rate than, the superelevated traveled way or by flattening the shoulder on the outside of the curve. AASHTO (2001) provides guidance on maximum recommended algebraic differences between the traveled way and the shoulder slopes.

EXHIBIT V-14
Example AMFs for Superelevation Deficiency

SD	AMF
0.009	1.00
0.0199	1.06
0.0299	1.09
0.0399	1.12

The second issue is proper transition from the normal cross slope along the tangent to the fully superelevated cross slope along the curve. For reasons of safety and comfort, the rotation of the pavement should be effected over a length that is sufficient to make such rotation imperceptible to drivers. Normal practice, in the absence of spiral transition curves, is to begin rotating the pavement along the tangent section before the curve and not attain full rotation until into the curve. A portion of the superelevation runoff is typically located on the tangent, in advance of the point of curvature, to minimize peak lateral accelerations and side friction demand. The proportion of the runoff length placed on the tangent varies from 60 to 80 percent, with many agencies using the 2/3–1/3 rule (placing 2/3, or 67 percent, of the runoff length on the tangent). Bonneson (2000) re-evaluated the approach to horizontal curve superelevation/transition design and determined that placing 70 percent of the superelevation runoff on the tangent and 30 percent on the curve was optimal.

Finally, care should be given to provide proper drainage when improving or restoring the superelevation along a curve. The combination of the control line longitudinal profile and superelevation can produce unintended flat spots along the roadway if care is not taken during design of the transition.

Strategy 15.2 A13: Modify Horizontal Alignment (P)

General Description

This strategy is the longest-term, highest-cost alternative considered for improving the safety of a horizontal curve because it usually involves total reconstruction of the roadway. It may also require acquisition of additional right-of-way and an environmental review.

There are several ways in which the horizontal alignment of a roadway may be modified to improve safety, including

- Increasing the radius of a horizontal curve,
- Providing spiral transition curves, and
- Eliminating compound curves.

These modification approaches are addressed below.

Safety Effectiveness of Increasing the Radius of a Horizontal Curve

Increasing the radius of a horizontal curve can be very effective in improving the safety performance of the curve. This strategy is also covered under Strategy 15.1 A5 (improved highway geometry for horizontal curves) in the ROR guide. The ROR crash guide presents a table on the percent reduction of total crashes on a two-lane rural highway that would be expected after flattening a curve. The table is based on research conducted by Zegeer et al. (1992) and shows that increasing the radius of curvature can reduce total curve-related crashes by up to 80 percent. An expert panel used the work of Zegeer et al. to develop an accident modification factor for horizontal curvature on rural two-lane highways (see Equation 4). The accident modification factor is a function of the length of the curve, the radius of the curve, and the presence or absence of a spiral.

$$AMF = \frac{1.55L_c + \frac{80.2}{R} - 0.012S}{1.55L_c} \qquad (4)$$

where

L_c = length of horizontal curve (mi),
R = radius of curvature (ft), and
S = 1 if spiral transition curve is present and
0 if spiral transition curve is not present.

Safety Effectiveness of Providing Spiral Transition Curves

A spiral transition curve is a horizontal curve with a continuously changing radius that connects a tangent and a circular curve or two circular curves of different radii. A spiral provides a smooth transition between a tangent section and an adjacent circular curve. The smoother transition from tangent to curve and curve to tangent results in the lateral force increasing and decreasing gradually as a vehicle enters and departs the curve. This is intended to minimize encroachment on adjacent traffic lanes and to promote uniformity in speed (AASHTO, 2001).

Research has shown that drivers on unspiraled curves track a path radius substantially sharper than the designed radius. This is primarily because it is not possible for drivers to instantaneously change their path radius from tangent to curve, and, once on the curve, they must "overcorrect" to stay on the roadway. Providing spirals affords the driver the means of tracking a curve that fits the designed alignment.

Council (1998) and Zegeer et al. (1992) reported that spiral transition curves are effective in reducing crashes. The findings are based on studies of spiraled versus unspiraled curves in one state.

An expert panel that developed the accident modification factor for horizontal curvature on rural two-lane highways (Equation 4) judged that there is sufficient evidence to conclude that the presence of spiral transitions on horizontal curves improves safety. The negative sign associated with the spiral variable effectively reduces the value of the accident modification factor, indicating that the presence of a spiral transition at a horizontal curve improves the safety of the curve. An example is presented below that reveals in more detail the effects of curve length, curve radius, and spiral transitions on safety performance.

EXHIBIT V-15
Example Values for AMFs for Horizontal Curves with and without Spiral Transitions

Degree of Curve	Radius of Curve ft	Central Angle degrees	Length of Curve mi	AMFs	
				w/spiral	w/o spiral
38	150	150	0.07	5.5	5.6
11	500	20	0.03	3.9	4.1
6	1000	20	0.07	1.7	1.8
3	2000	20	0.13	1.1	1.2
2	3000	20	0.20	1.0	1.1

Safety Effectiveness of Eliminating Compound Curves

Compound circular curves are sometimes advantageous in providing desirable shapes of curves. However, although no quantitative comparisons have been made between the safety at simple circular curves and the safety at compound curves, agencies should be cautious of using compound curves, particularly if the radius of the first curve is significantly greater than the radius of the following curve. An abrupt change in alignment requires considerable steering effort by motorists to travel safely through the successive curves.

If an agency permits the use of compound curves, the designs should meet AASHTO (2001) guidelines. AASHTO recommends that for compound curves on open highways, the ratio of the flatter radius to the sharper radius should not exceed 1.5:1, and on ramps the ratio may be greater, possibly as great at 2:1. Wherever practical, however, smaller differences in radii should be used.

Strategy Attributes

In general, whether the curve is isolated between two long tangents or is located along a stretch of curvilinear roadway, the horizontal alignment should be designed to meet a driver's expectation. When an alignment fails to meet a driver's expectation, the alignment should be modified accordingly. Speed profile models may be used to evaluate the conformance of a highway's geometry with driver expectancy. Fitzpatrick et al. (2000b) have developed a speed profile model that may be used to evaluate the design consistency of two-lane rural roads. This model was developed for use in the Interactive Highway Safety Design Model (IHSDM) (http://www.fhwa.dot.gov/ihsdm/index.htm).

Strategy 15.2 A14: Install Automated Anti-Icing Systems (T)

General Description

Automated anti-icing systems are a potentially effective tool for keeping roadway surfaces clear of ice and safe for travel in areas of the country with severe winter climates. Anti-icing involves pretreatment of the roadway surface with chemicals before a winter storm arrives, as opposed to deicing, which involves treatment of the roadway surface during or after the storm, when ice may already have formed. The most common automated anti-icing system now in use is one that uses a series of spray-nozzles connected to a chemical storage tank. Using a pump system, a liquid anti-icing agent is distributed along a roadway segment using the nozzles that can be embedded into the pavement or placed along the edges of the road. The system can either be fully automated, relying wholly on sensors in the area to determine the need of an application of anti-icing chemicals, or semi-automated, where the system can be engaged by someone from a remote location in response to a sensor indication. A potential advantage is that automated anti-icing system can be engaged immediately when appropriate conditions are detected. Existing approaches for anti-icing involve a delay until staff can be called out and equipment deployed. Furthermore, truck-based systems treat locations in sequence according to a routing or priority scheme; automated systems can be activated at all appropriate locations simultaneously.

While not yet in widespread use, automated anti-icing systems are beginning to be used in place of exiting anti-icing systems that involved motorized vehicles traveling along roadway lanes while distributing anti-icing agents. Seventeen states have installed anti-icing systems at selected locations. The most prevalent locations for current automated anti-icing systems are on bridges and overpasses where deck surfaces are prone to ice formations sooner than adjoining road sections. One system in California is currently being planned at a location on a horizontal curve. (See Appendix 4 for more detailed information on this system in California.) Horizontal curves are logical locations for anti-icing treatment because tire-pavement friction is critical to vehicle control at horizontal curves.

Many crashes each year result from the vehicle loss of control while traveling on icy roads. Anti-icing systems that have been installed have shown benefit/cost ratios in the range from 1.8 to 3.4 and reductions in the frequency of wintertime accidents from 25 to 100 percent (Friar and Decker, 1999; Barrett and Pigman, 2001; Khattak and Pesti, 2003). However, despite the positive safety evaluations, this strategy is listed as “tried” primarily because this technology has not been in use for a long period of time, nor have the studies specifically addressed installations along horizontal curves.

EXHIBIT V-16
Strategy Attributes for Installing Automated Anti-Icing Systems at Horizontal Curves (T)

Technical Attributes	
Target	Accidents involving skidding on horizontal curves because of icy road surface conditions.
Expected Effectiveness	Recent evaluations have reported benefit/cost ratios in the range of 1.8 to 3.4 and reductions in accident frequency in the range of 25 to 100 percent. However, experience with these systems is limited, and the systems evaluated have not been deployed on horizontal curves. Further research to quantify the safety benefits of these systems on roadways in general, and specifically on horizontal curves, is desirable.
Key to Success	A key to success in the use of automated anti-icing systems is their use at locations with the greatest need. Appropriate locations for their application include sites with high traffic volumes, high wintertime accident rates, and/or isolated locations that are difficult to reach in bad weather (Khattak and Pesti, 2003).

EXHIBIT V-16 (Continued)
Strategy Attributes for Installing Automated Anti-Icing Systems at Horizontal Curves (T)

Potential Difficulties	In a report by Barrett and Pigman (2001), certain difficulties were listed from an automated anti-icing system installed on a Kentucky Interstate bridge in October 1997. For the first couple of seasons of use, a certain amount of system debugging had to take place. However, when the logistics had been corrected, the system was found to be quite self-sufficient. There were other states that observed their systems operating more efficiently in non-snow events or light snow storms. Some systems were also found to work better in semi-automatic mode. In this case, the system can be turned on from a remote location as personnel see fit as opposed to relying wholly upon the field sensors to detect a need for anti-icing measures. A potential difficulty can also be found in retrofitting existing roads with automated anti-icing systems. The most common system being used is one that distributes a liquid anti-icing agent onto the roadway. This is set up with spouts distributed along the length of a roadway segment, either slightly elevated on the roadside or embedded into the road's surface. While not impracticable, the difficulties and expense of this installation should be taken into account. Another potential difficulty was noted by Stowe (2001). Automated systems must be constantly monitored because the system could malfunction due to a number of circumstances, such as external debris or solids in the chemical spray that plug the nozzles of the system. If system malfunction were to occur, ice could begin to form on the roadway. System malfunction must be detectable so that appropriate maintenance can restore system operation.
Appropriate Measures and Data	The process measures of program effectiveness would include the length of roadway and number of horizontal curves where automated anti-icing systems were successfully installed. The impact measures would require a study of the site's wintertime crash statistics before and after the installation of the automated anti-icing system. A concomitant measure of effectiveness would be the cost savings to highway agencies by not having to deploy personnel, equipment, and materials.
Associated Needs	Because automated anti-icing systems have not been extensively used on horizontal curves, more information is needed as to whether it is actually feasible to use current systems in that environment. It may also be necessary to evaluate the effect that the dispensed chemicals will have on the surrounding environment.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	The implementation of this strategy will be done at the discretion of the state and local transportation agencies. It does not appear that there will be any issues arising between organizations or institutions. As this is a maintenance function that is administrative in nature, care should be taken regarding the selection and documentation of sites to be treated. The agency will want to prepare for potential tort claims for curves in which such treatment is not provided. It will be important to upgrade maintenance protocols to ensure that the performance of the systems is maintained during inclement weather, both for the safety of the traveling public and to avoid exposure to liability. There is a definite need for a full evaluation of current winter maintenance strategies before an agency decides on an appropriate role for automated anti-icing systems.

(*continued on next page*)

EXHIBIT V-16 (Continued)
Strategy Attributes for Installing Automated Anti-Icing Systems at Horizontal Curves (T)

Issues Affecting Implementation Time	The major issues affecting the time required to implement automated anti-icing systems are the time required to prioritize roadway segments for installation of the systems and the time required for installation. Selection of locations for automated anti-icing systems should be based on consideration of wintertime accident rates, traffic volumes, horizontal alignments, and distances from maintenance yards to determine which areas are in the greatest need for such systems. After priorities have been set, then the actual system design and installation can take place. The time needed for installation is influenced by the length of road to be treated by the automated system and the type of system chosen.
Costs Involved	For an automated anti-icing system installed in Kentucky (Barrett & Pigman, 2001), the approximate cost was $65,000. This included roadway coverage 183 m (600 ft) long and 3 lanes wide. This cost estimate does not include the cost of the road weather information system (RWIS), which is needed to determine when anti-icing becomes necessary. A detailed discussion of RWIS, including a cost-benefit comparison, may be found at http://www.its.dot.gov/JPODOCS/REPTS_TE/13660.html#_Toc535648483. For information about a Vermont DOT installation of an RWIS, see http://www.aot.state.vt.us/matres/Documents/ACROBAT.pdf/web953.pdf. Another source (Stowe, 2001) has estimated installation cost for a 1,320-m (4,330-ft), two-lane road segment at $599,500. However, this estimate is more inclusive in that it covers the automated anti-icing system, the RWIS, and the design engineering fees involved. In addition to this amount, it is estimated that the annual operations and maintenance costs will be roughly $32,800. This figure includes materials, power, communications, maintenance, weather forecasting, and training.
Training and Other Personnel Needs	There does not appear to be any need for specialized personnel to implement this strategy, but staff need to be trained on the operation and maintenance of the system.
Legislative Needs	None identified.
Other Key Attributes	
	There has been only limited use of anti-icing systems by highway agencies. Therefore, it is not possible to identify problems or benefits associated with a larger network of such systems operating in a given area. A better understanding of the application of anti-icing systems at horizontal curves is also needed.

Strategy 15.2 A15: Prohibit/Restrict Trucks with Very Long Semitrailers on Roads with Horizontal Curves that Cannot Accommodate Truck Offtracking (T)

General Description

Longer trucks, particularly single-trailer combination trucks with longer semitrailers, may have difficulty negotiating sharp horizontal curves because they may encroach on an adjacent lane or shoulder because of vehicle offtracking. Vehicle offtracking is the phenomenon in which the rear axles of a truck do not follow the same path as the front axle; at lower speeds, the rear axles of the truck typically track to the inside of the front axle path.

The magnitude of vehicle offtracking is the amount of radial distance displaced from the center of the first axle to the center of the rear axle as a vehicle is making a turn (see Exhibit V-17). Offtracking is a primary determinant of the amount of space a truck or other large vehicle occupies when executing a turning movement; this space, known as the swept path width, is the maximum width of the envelope defined by the front outside corner and the rear inside corner of the truck as it turns (Exhibit V-18). The maximum offtracking and swept path width generally occurs when a vehicle is turning at a low speed. Increasing vehicle speed gradually brings the rear of the truck back toward the path defined by the front axles of the truck. At very high speeds, the rear of the truck can actually offtrack toward the outside of the turn. However, low-speed offtracking is a consideration in the design of any roadway or intersection because traffic or environmental conditions will normally require low-speed travel sometimes on any roadway. For a more complete discussion of vehicle offtracking considerations in roadway design, see *NCHRP Report 505* (Harwood et al., 2003).

The greatest concern in vehicle offtracking relevant to horizontal curves is the operation of tractor-semitrailer combination trucks with long semitrailers on roadways with sharp horizontal curvature. The distance from the point of connection of the trailer with the tractor (kingpin) to its rear axle is a critical criterion. A number of states restrict the kingpin-to-rear-axle distance for tractor-semitrailer combinations with semitrailers over 14.6 m (48 ft) in length; on many semitrailers, the rear axles of the trailer can be moved forward to comply with kingpin-to-rear-axle distance limitations. In states where longer kingpin-to-rear-axle distances

EXHIBIT V-17
Illustration of Truck Offtracking
(Harwood et al., 2003)

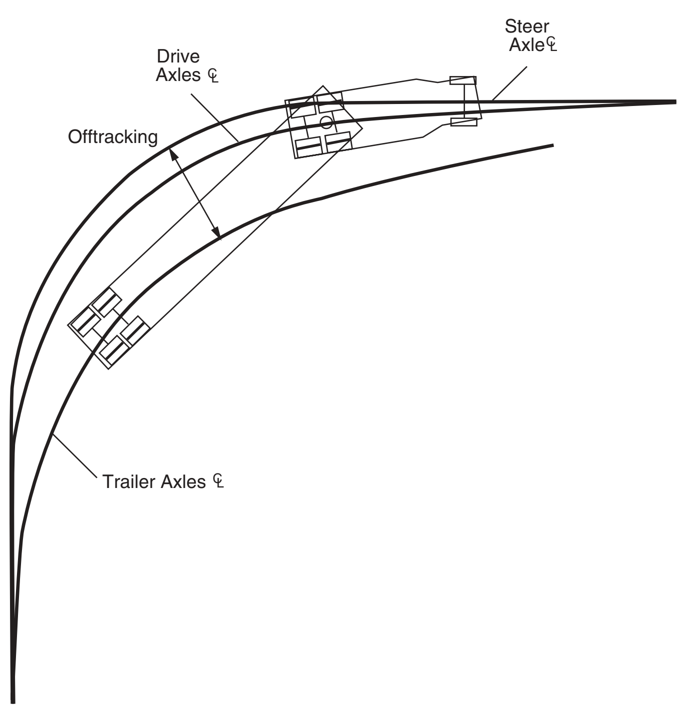
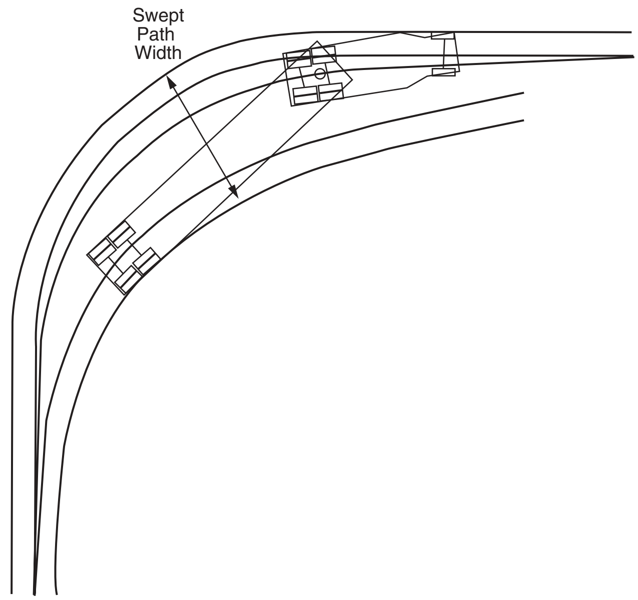


EXHIBIT V-18
Illustration of Swept Path Width
(Harwood et al., 2003)



for trucks are permitted, it may be desirable to prohibit or restrict trucks with kingpin-to-rear-axle distances that exceed a specified threshold from operating on specific facilities.

California has an active program of identifying roadways with horizontal curves that cannot accommodate trucks with longer kingpin-to-rear-axle distances and establishing appropriate truck advisory restrictions on particular roads (Caltrans, 1989). This program has been in place for nearly 20 years. California establishes these restrictions based on the distance from the kingpin to the center of the rearmost axle of the trailer, known as the kingpin-to-center-of-rear-axle (KCRA) distance. Most other states base their restrictions on the distance from the kingpin to the center of the rear tandem axle set, known as the kingpin-to-rear-tandem (KCRT) distance. The KCRT distance is generally approximately 0.6 m (2 ft) shorter than the KCRA distance.

Along 5,414 km (3,364 mi) or 22 percent of California's 24,400-km (15,166-mi) state highway system, the California Department of Transportation has established advisory restrictions for trucks with KCRA distances that exceed 12 m (40 ft). This portion of the highway system was selected for restriction based on an analysis of vehicle offtracking on the horizontal curves' geometrics actually present on those roadways. These restrictions were not based on established accident patterns on the roadways in question, but rather on the potential for collisions when large trucks encroach on adjacent lanes or shoulders.

In California, advisory restrictions on truck use of particular facilities are implemented by signing on the roads in question and maps for truckers published by the California Department of Transportation. An example of a sign used to inform truckers of the restriction is illustrated in Exhibit V-19.

Similar restrictions have been established for motorcoach operators in California, and system maps intended specifically for motorcoach operators are also published.

EXHIBIT V-19
California Truck Advisory Sign
(http://www.dot.ca.gov/hq/traffops/trucks/trucksize/fs-trkrouts.htm)

EXHIBIT V-20
Strategy Attributes for Prohibiting/Restricting Trucks and/or Other Large Vehicles on Roadways with Horizontal Curve Geometrics that Cannot Accommodate Vehicle Offtracking (T)

Technical Attributes	
Target	Accidents related to vehicle encroachments on adjacent lanes or shoulders. The resulting restrictions are targeted at drivers of trucks with long semitrailers, or other large vehicles, on roadways with horizontal curve geometrics that may not accommodate their vehicles within the travel lane.
Expected Effectiveness	There are no studies available on the effectiveness of this strategy, such as estimated accident reductions. The strategy has been implemented in one state not because of an existing accident pattern, but as a proactive measure to prevent such an accident pattern from developing were trucks with longer semitrailers permitted to operate on such facilities with restrictive horizontal geometrics.
Keys to Success	The keys to success for this strategy are (1) an effective process to determine whether the geometrics of particular roadways can accommodate vehicles with particular offtracking characteristics; (2) an effective rulemaking process that allows truckers, motorcoach operators, and affected communities an opportunity for input into the decision-making process; (3) the availability of appropriate alternative routes for truck or motorcoach operation; and (4) the use of both signing and published maps to inform truck and motorcoach operators of the restrictions.
Potential Difficulties	See legislative needs.
Appropriate Measures and Data	Process measures of program effectiveness would include the number of miles of road, or number of curves, where trucks and/or other large vehicles were prohibited because of unsafe geometrical properties. Impact measures include the number of crashes because of trucks or other large vehicles encroaching upon other lanes or running off the road because there is not enough space to accommodate vehicle offtracking. Such impact measures are difficult to determine because restrictions are normally established proactively to keep such accident patterns from developing.
Associated Needs	Analysis of appropriate restrictions requires accurate data on the actual horizontal curve geometrics on the roadway system.

(*continued on next page*)

EXHIBIT V-20 (Continued)
Strategy Attributes for Prohibiting/Restricting Trucks and/or Other Large Vehicles on Roadways with Horizontal Curve Geometrics that Cannot Accommodate Vehicle Offtracking (T)

Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	State and local highway agencies would have to adopt policies that would include criteria and methods to be used to determine where restrictions of usage by large trucks should be applied. In addition, funding and personnel must be committed to enforce these policies.
Issues Affecting Implementation Time	Implementation would probably require at least one year of lead time to analyze a road as a candidate for restriction and to allow an adequate period for public and industry comments on any proposed restrictions.
Costs Involved	The cost of implementing this strategy is primarily the cost of staff time needed to conduct site-specific analyses, to conduct an appropriate public involvement process, to establish appropriate signing, and to publish appropriate maps.
Training and Other Personnel Needs	Law enforcement personnel need training on the appropriate enforcement of this strategy.
Legislative Needs	Many agencies lack legal authority to restrict truck use on their facilities or must comply with specific legislative requirements in establishing truck restrictions. Implementation of this strategy in some jurisdictions would require new legislation. Another potential approach is to make the restrictions advisory, rather than regulatory, as was done in California. It may be possible to obtain voluntary compliance because the geometry of the roads in question is not generally considered desirable by truckers and because truckers may be able to comply with the restriction by moving their rear axles forward. While truck restrictions may not be possible on some or all of the National Highway System (NHS) and the designated National Network, the need for this strategy is not likely to be present on roads that are part of these systems.
Other Key Attributes	
	A public education and information program will be desirable, targeted at the trucking industry.

Objective 15.2 B—Minimize the Adverse Consequences of Leaving the Roadway at a Horizontal Curve

Combined Discussion of Strategies

Objective 15.2 A focuses on helping drivers stay within the limits of the roadway while negotiating a curve. By contrast, Objective 15.2 B focuses on reducing the severity of curve-related crashes that occur outside of the roadway (i.e., on the roadside).

Despite the countermeasures (i.e., strategies) implemented in pursuit of Objective 15.2 A, some vehicles will still leave the roadway and stray onto the roadside. The strategies for Objective 15.2 B are intended to minimize the consequences to vehicles that travel beyond the shoulder and onto the roadside at a horizontal curve.

Five strategies are designed to reduce the consequences of leaving the roadway:

- Strategy 15.2 B1: Design safer slopes and ditches to prevent rollovers (P)
- Strategy 15.2 B2: Remove/relocate objects in hazardous locations (P)
- Strategy 15.2 B3: Delineate roadside objects (E)
- Strategy 15.2 B4: Add or improve roadside hardware (T)
- Strategy 15.2 B5: Improve design and application of barrier and attenuation systems (T)

These strategies are discussed in the ROR crash guide under the section entitled "Combined Strategy: Improving Roadsides," and the reader is referred to that section for more detailed information on this set of strategies. Although these strategies are fully discussed in the ROR crash guide, it is important to at least identify them here because ROR crashes are so prevalent along horizontal curves. The reader is also referred to the *Roadside Design Guide* (AASHTO, 2002) for current information and operating practices relating to roadside safety.

Strategy Attributes

Vehicles that encroach upon the roadside while traversing a curve can face conditions different than if they were traveling along a tangent alignment. This issue was addressed under Strategy 15.2 A4 (Install Shoulder Rumble Strips) and Strategy 15.2 A5 (Install Centerline Rumble Strips). As a vehicle leaves the roadway, the departure angle is affected by the degree of road curvature. The concern is for the potentially more extreme condition that can occur when a vehicle leaves the road on the outside of the curve. If a vehicle drifts to the right at a constant angle along a tangent section, the vehicle can have a shallower departure angle than where the vehicle leaves the roadway on the outside of a horizontal curve. The larger departure angle is because of the curvature of the roadway. This is demonstrated, among other things, in Exhibit V-21.

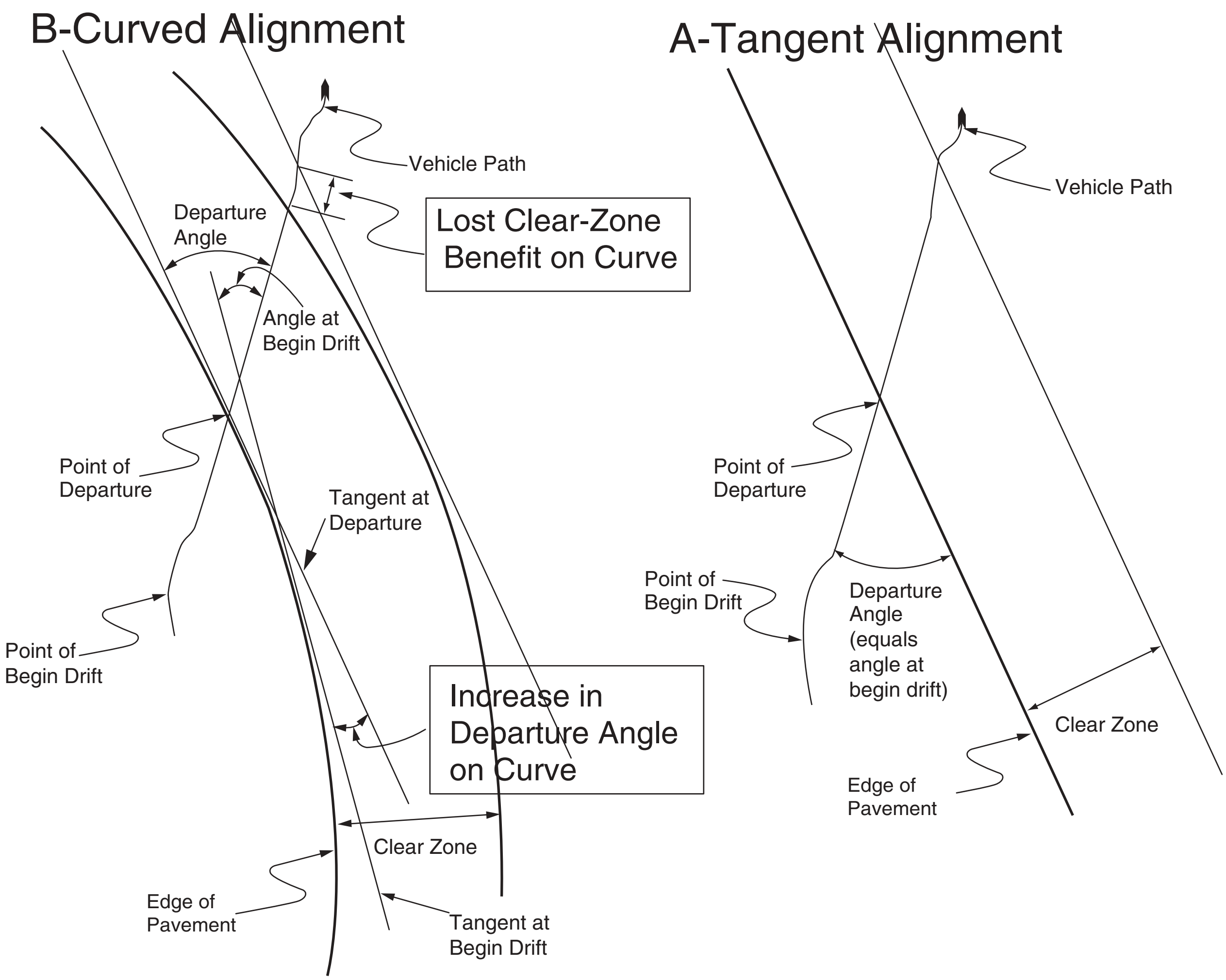
This greater departure angle at horizontal curves has implications on the travel distance and time to roadside objects. Given that an object is located a certain distance from the roadway and that the vehicle follows a certain trajectory, a driver has less distance and time to regain control of his/her vehicle before striking a roadside object located at a horizontal curve than a roadside object located on a tangent.

Another way of looking at it is in terms of the change in the effectiveness of a clear zone (on the outside of the curve) of constant width. Exhibit V-21 shows that not only because of the increased angle of departure, but also because of the curvature of the clear zone adjacent to the curved segment of the road, the distance traveled by an errant vehicle, before reaching the outer edge of the clear zone, will be smaller than if the road were on a tangent alignment. Thus, the probability of an errant vehicle going beyond a constant clear zone is greater along the outside of a curve than along a tangent segment of road. This implies that roadside objects should be further removed from the roadway along the outside of horizontal curves compared with roadside objects located along tangent sections of highway.

There are several assumptions inherent in the analysis, but these are similar to the assumptions currently used in roadside safety analyses. It should also be noted that the opposite conclusion is true for encroachments on the inside of curved roads. However, clear-zone requirements are based on more than just a vehicle that drifts off the road.

The guides for addressing collisions with trees in hazardous locations and utility poles provide supplemental information on reducing the harm done by collisions after vehicles have left the roadway. Strategy 15.2 B2 in this guide directly relates to Strategy 16.1 B1 in the tree guide. Similarly, Strategy 15.2 B3 in this guide and Strategy 16.1 B4 in the tree guide are directly related. The reader is directed to these additional sections for more specific information on the effects of collisions with trees. For Strategy 15.2 B2, if the reader is seeking specific information on utility poles, then the utility pole guide should be consulted.

EXHIBIT V-21
Depiction of the Effect of Curvature on the Conditions Resulting from a Vehicle Encroaching on the Roadside



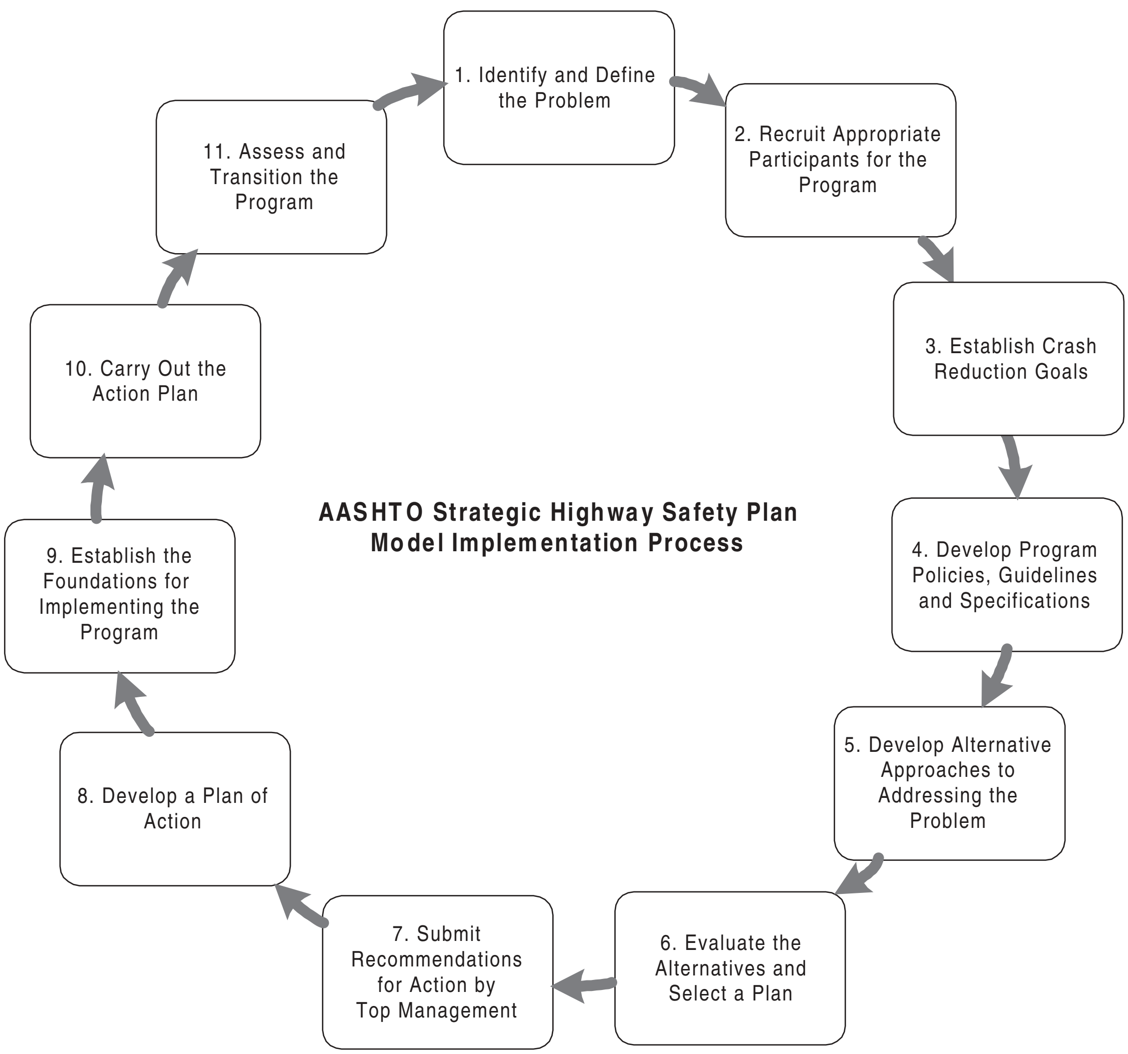
SECTION VI

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 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/practice/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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Appendixes

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

1 Rumble Strip Configurations
2 Example of a Solar-Powered Installation
3 Costs of Dynamic Curve-Warning Systems
4 Automated Anti-Icing System in California

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