VOLUME 12

NCHRP

NATIONAL
COOPERATIVE
HIGHWAY
RESEARCH
PROGRAM

REPORT 500

Guidance for Implementation of the
AASHTO Strategic Highway Safety Plan

Volume 12: A Guide for Reducing Collisions at Signalized Intersections

TRANSPORTATION RESEARCH BOARD
OF THE NATIONAL ACADEMIES

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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Guidance for Implementation of the AASHTO Strategic Highway Safety Plan

Volume 12: A Guide for Reducing Collisions at Signalized Intersections

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The members of the technical committee selected to monitor this project and to review this report were chosen for recognized scholarly competence and with due consideration for the balance of disciplines appropriate to the project. The opinions and conclusions expressed or implied are those of the research agency that performed the research, and, while they have been accepted as appropriate by the technical committee, they are not necessarily those of the Transportation Research Board, the National Research Council, the American Association of State Highway and Transportation Officials, or the Federal Highway Administration, U.S. Department of Transportation.

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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 twelfth 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 at signalized intersections. 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 twelfth 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.

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The project team was organized around the specialized technical content contained in each guide, and the overall team included nationally recognized experts from many organizations. The following team of experts, selected based on their knowledge of signalized intersections, served as lead authors for the signalized intersection guide:

- Nicholas D. Antonucci
  CH2M HILL
- Kelly K. Hardy
  CH2M HILL
- Kevin L. Slack
  CH2M HILL

Development of the volumes of *NCHRP Report 500* utilized the resources and expertise of many professionals from around the country and overseas. Through research, workshops, and actual demonstration of the guides by agencies, the resulting 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 by providing material, participating in workshops and meetings, and providing input and comments during the development of the signalized intersection guide:

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SECTION I

Summary

Introduction

One of the hallmarks of the AASHTO Strategic Highway Safety Plan (SHSP) is to approach safety problems in a comprehensive manner. The range of strategies available in the guides will ultimately cover various aspects of the road user, the highway, the vehicle, the environment, and the management system. The guides strongly encourage the user to develop a program to tackle a particular emphasis area from each of these perspectives in a coordinated manner. To facilitate this, the electronic form of the material uses hypertext linkages to enable seamless integration of various approaches to a given problem. As more guides are developed for other emphasis areas, the extent and usefulness of this form of implementation will become ever more apparent.

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

The six major areas of the AASHTO SHSP (Drivers, Vehicles, Special Users, Highways, Emergency Medical Services, and Management) are subdivided into 22 goals, or key emphasis areas, that impact highway safety. One of these goals addresses the improvement of safety at intersections. This implementation guide provides guidance to highway agencies that desire to implement safety improvements at signalized intersections and includes a variety of strategies that may be applicable to particular locations.

The crossing and turning maneuvers that occur at intersections create opportunities for vehicle-vehicle, vehicle-pedestrian, and vehicle-bicycle conflicts, which may result in traffic crashes. Thus, intersections are likely points for concentrations of traffic crashes. Intersections constitute only a small part of the overall highway system, yet intersection-related crashes constitute more than 50 percent of all crashes in urban areas and over 30 percent in rural areas (Kuciemba and Cirillo, 1992). Just under a quarter of fatal crashes occur at intersections.

Signalized intersections are generally the most heavily traveled intersection types and are therefore a major element of the highway fatality and crash problem nationally. Fatal crashes at signalized intersections are predominately multivehicle. Signalized intersections are operationally complex, with many factors contributing to the potential safety problems. The intent of a signal is to control and separate conflicts between vehicles, pedestrians, and cyclists to enable safe and efficient operations. Operation of a signal itself, however, produces conflicts (e.g., conflicts between through vehicles that could lead to rear-end crashes). In addition, varying signal operations (timing and phasing) place demands on drivers that are not always met.

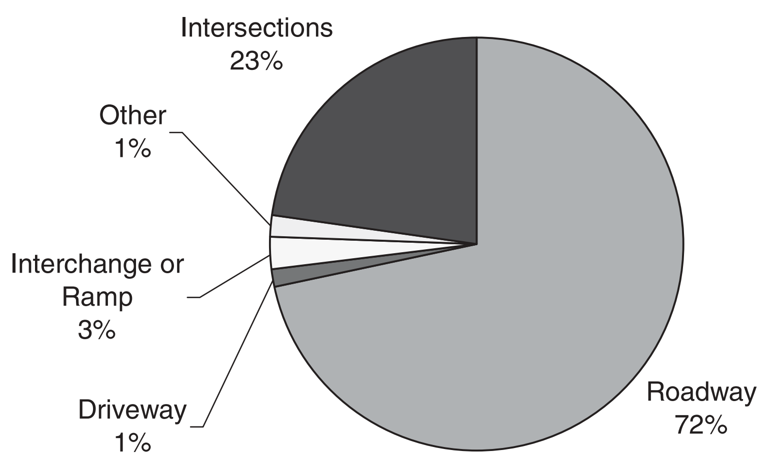
General Description of the Problem

Intersections constitute only a small part of the overall highway system, yet intersection-related crashes constitute more than 20 percent of fatal crashes. It is not unusual that crashes are concentrated at intersections, because intersections are the point on the roadway system where traffic movements most frequently conflict with one another. Good geometric design combined with good traffic control can result in an intersection that operates efficiently and safely.

Exhibit I-1 shows the breakdown of fatal crashes by facility type, which is referred to as "relation to junction" in the Fatality Analysis Reporting System (FARS) database. Just under a quarter of fatal crashes occur at intersections.

Exhibit I-2 shows the distribution of fatal crashes at signalized intersections by manner of collision. The high percentage of crashes that do not include a collision with another moving vehicle can be attributed to pedestrian and bicycle crashes. FARS data show that 75 percent of the fatal single-vehicle crashes at signalized intersections involve pedestrians or bicyclists (55 percent of fatal single-vehicle crashes at all intersections involve pedestrians or bicyclists).

EXHIBIT I-1
Fatal Crashes by Relationship to Junction
Source: 2002 FARS data. Other relationships to junctions include crashes categorized in FARS as related to railroad grade crossings, crossovers, and unknown.

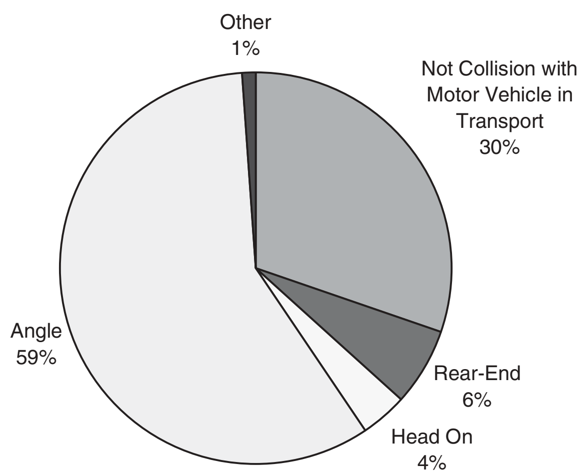


A brief analysis of FARS data for 2002 shows the following:

- 23 percent of all fatal crashes occurred at intersections,
- 6 percent of all fatal crashes occurred at signalized intersections,

- 29 percent of fatal crashes at intersections occurred at signalized intersections,
- 84 percent of fatal crashes at signalized intersections occurred in urban areas, and
- 59 percent of fatal crashes at signalized intersections involve angle collisions with other vehicles.

EXHIBIT I-2
Manner of Collision for Fatal Crashes at Signalized Intersections
Source: 2002 FARS data. "Other" includes crashes categorized in FARS as sideswipe same direction, sideswipe opposite direction, other, and unknown.



Objectives of the Emphasis Area

The objectives for improving safety at signalized intersections are explained below. Exhibit I-3 lists the objectives and the related strategies for improving safety at signalized intersections. The strategies considered go across the full range of engineering, enforcement, and education. Physical improvements include both geometric design modifications and changes to traffic control devices:

- Reduce frequency and severity of intersection conflicts through traffic control and operational improvements—Improvements to the method of assigning right-of-way at signalized intersections can reduce the potential for conflicts. This can be accomplished by modifying signal phasing, providing additional traffic control devices and pavement markings, and restricting turn movements. Improvements to traffic control can also benefit traffic operations and reduce emergency response time.

- Reduce frequency and severity of intersection conflicts through geometric improvements—Reducing the frequency and severity of vehicle-vehicle conflicts at intersections can reduce the frequency and severity of intersection crashes. This can be accomplished by incorporating geometric design solutions that separate through and turning movements at the intersection, restrict or eliminate turning maneuvers, and close or relocate intersections.

- Improve sight distance at signalized intersections—Provision of clear sight triangles in each quadrant of an intersection can minimize the possibility of crashes related to sight obstructions.
- Improve driver awareness of intersections and signal control—Some intersection-related collisions occur because one or more drivers approaching an intersection are unaware of the intersection until it is too late to avoid a collision. Improved signing and delineation and installation of lighting can help warn drivers of the presence of the intersection. In some situations, where other measures have not been effective, rumble strips may be used to get the driver's attention.
- Improve driver compliance with traffic control devices—Many accidents are caused or aggravated by drivers' noncompliance with traffic control devices or traffic laws at intersections. Both public education and enforcement have been shown to be effective in reducing traffic-law violations and consequently improving safety at intersections. Automated enforcement of traffic signals and speed limits is an increasingly common and cost-effective approach to improving driver compliance with traffic laws. At certain high-speed intersection approaches, implementing speed-reduction measures may provide an approaching driver with additional time to make safer intersection-related decisions.
- Improve access management near signalized intersections—Navigation, braking, and decision-making on intersection approaches creates additional workload on the driver. The presence of driveway access at or near a signalized intersection may confuse drivers using the intersection and create additional vehicle-vehicle conflicts. Measures to restrict driveways and to preclude cross-median turning movements in close proximity to signalized intersections can effectively reduce or eliminate serious multivehicle conflicts.
- Improve safety through other infrastructure treatments—Other improvements can be made to the intersection to decrease frequency and severity of crashes at signalized intersections. These include improving pavement conditions, coordinating operation of signals near railroad crossings, and moving signal hardware out of the clear zone.

EXHIBIT I-3
Emphasis Area Objectives and Strategies

Objectives	Strategies
17.2 A Reduce frequency and severity of intersection conflicts through traffic control and operational improvements	17.2 A1 Employ multiphase signal operation (P, T)
	17.2 A2 Optimize clearance intervals (P)
	17.2 A3 Restrict or eliminate turning maneuvers (including right turns on red) (T)
	17.2 A4 Employ signal coordination (P)
	17.2 A5 Employ emergency vehicle preemption (P)

EXHIBIT I-3 (Continued)
Emphasis Area Objectives and Strategies

Objectives	Strategies
	17.2 A6 Improve operation of pedestrian and bicycle facilities at signalized intersections (P, T) 17.2 A7 Remove unwarranted signal (P)
17.2 B Reduce frequency and severity of intersection conflicts through geometric improvements	17.2 B1 Provide/improve left-turn channelization (P) 17.2 B2 Provide/improve right-turn channelization (P) 17.2 B3 Improve geometry of pedestrian and bicycle facilities (P, T) 17.2 B4 Revise geometry of complex intersections (P, T) 17.2 B5 Construct special solutions (T)
17.2 C Improve sight distance at signalized intersections	17.2 C1 Clear sight triangles (T) 17.2 C2 Redesign intersection approaches (P)
17.2 D Improve driver awareness of intersections and signal control	17.2 D1 Improve visibility of intersections on approach(es) (T) 17.2 D2 Improve visibility of signals and signs at intersections (T)
17.2 E Improve driver compliance with traffic control devices	17.2 E1 Provide public information and education (T) 17.2 E2 Provide targeted conventional enforcement of traffic laws (T) 17.2 E3 Implement automated enforcement of red-light running (cameras) (P) 17.2 E4 Implement automated enforcement of approach speeds (cameras) (T) 17.2 E5 Control speed on approaches (E)
17.2 F Improve access management near signalized intersections	17.2 F1 Restrict access to properties using driveway closures or turn restrictions (T) 17.2 F2 Restrict cross-median access near intersections (T)
17.2 G Improve safety through other infrastructure treatments	17.2 G1 Improve drainage in intersection and on approaches (T) 17.2 G2 Provide skid resistance in intersection and on approaches (T) 17.2 G3 Coordinate closely spaced signals near at-grade railroad crossings (T) 17.2 G4 Relocate signal hardware out of clear zone (T) 17.2 G5 Restrict or eliminate parking on intersection approaches (P)

P = proven; T = tried; E= experimental. A fuller explanation of P, T, and E appears in Section V. Several strategies have substrategies with differing ratings.

SECTION II

Introduction

One of the hallmarks of the AASHTO SHSP is to approach safety problems in a comprehensive manner. The range of strategies available in the guides will ultimately cover various aspects of the road user, the highway, the vehicle, the environment, and the management system. The guides strongly encourage the user to develop a program to tackle a particular emphasis area from each of these perspectives in a coordinated manner. To facilitate this, the electronic form of the material uses hypertext linkages to enable seamless integration of various approaches to a given problem.

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

The six major areas of the AASHTO SHSP (Drivers, Vehicles, Special Users, Highways, Emergency Medical Services, and Management) are subdivided into 22 goals, or key emphasis areas, that impact highway safety. One of these goals addresses the improvement of safety at intersections. Two guides in the NCHRP Report 500 series discuss intersections: this volume covers signalized intersections, and Volume 5 discusses unsignalized intersections. This implementation guide provides guidance to highway agencies that desire to implement safety improvements at signalized intersections and includes a variety of strategies that may be applicable to particular locations.

Intersections are locations where two or more roads join or cross, and it is the crossing and turning maneuvers occurring at intersections that create opportunities for vehicle-vehicle, vehicle-pedestrian, and vehicle-bicycle conflicts. Thus, intersections are likely points for concentrations of traffic crashes. Although intersections constitute a very small portion of the highway system, crashes at intersections account for as much as half of all crashes in urban areas and about one quarter of crashes in rural areas.

Signalized intersections are generally the most heavily traveled intersection types and are therefore a major element of the highway fatality and crash problem nationally. Fatal crashes at signalized intersections are predominately multivehicle.

Signalized intersections are operationally complex, with many factors contributing to the potential safety problems. The intent of a signal is to control and separate conflicts between vehicles, pedestrians, and cyclists to enable safe and efficient operations. Operation of a signal itself, however, produces conflicts (e.g., conflicts between through vehicles that could lead to rear-end crashes). In addition, varying signal operations (timing and phasing) place demands on drivers that are not always met. While the focus of the strategies discussed in this guide is on reducing fatalities at signalized intersections, the implementation of many of these strategies will likely lead to an overall reduction in intersection crashes.

Section III

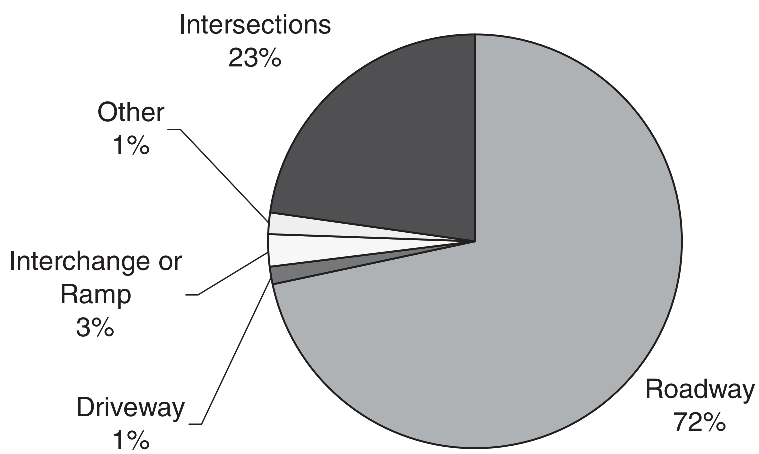
Type of Problem Being Addressed

General Description of the Problem

Intersections constitute only a small part of the overall highway system, yet intersection-related crashes constitute more than 20 percent of fatal crashes. It is not unusual that crashes are concentrated at intersections, because intersections are the point on the roadway system where traffic movements most frequently conflict with one another. Good geometric design combined with good traffic control can result in an intersection that operates efficiently and safely.

Exhibit III-1 shows the breakdown of fatal crashes by facility type, which is referred to as "relation to junction" in the Fatality Analysis Reporting System (FARS) database. Just under a quarter of fatal crashes occur at intersections.

EXHIBIT III-1
Fatal Crashes by Relationship to Junction
Source: 2002 FARS data. "Other" includes crashes categorized in FARS as related to railroad grade crossings, crossovers, and unknown.



A brief analysis of FARS data for 2002 shows the following:

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- 59 percent of fatal crashes at signalized intersections involve angle collisions with other vehicles.

Exhibit III-2 shows the distribution of fatal crashes at signalized intersections by manner of collision. The high percentage of crashes that do not include a collision with another moving vehicle can be attributed to pedestrian and bicycle crashes. FARS data show that 75 percent of the fatal single-vehicle crashes at signalized intersections involve pedestrians or bicyclists (55 percent of fatal single-vehicle crashes at all intersections involve pedestrians or bicyclists).

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Manner of Collision for Fatal Crashes at Signalized Intersections
Source: 2002 FARS data. "Other" includes crashes categorized in FARS as sideswipe same direction, sideswipe opposite direction, other, and unknown.

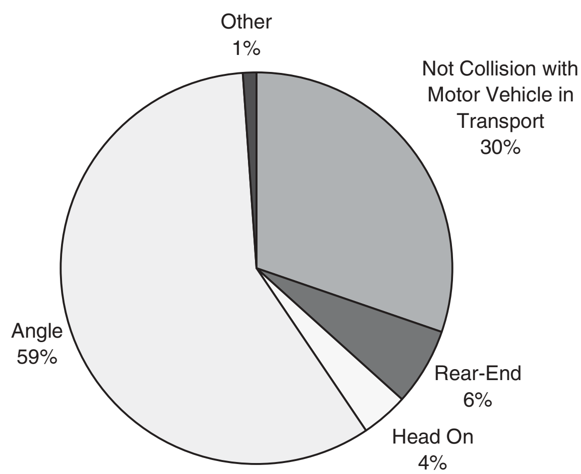
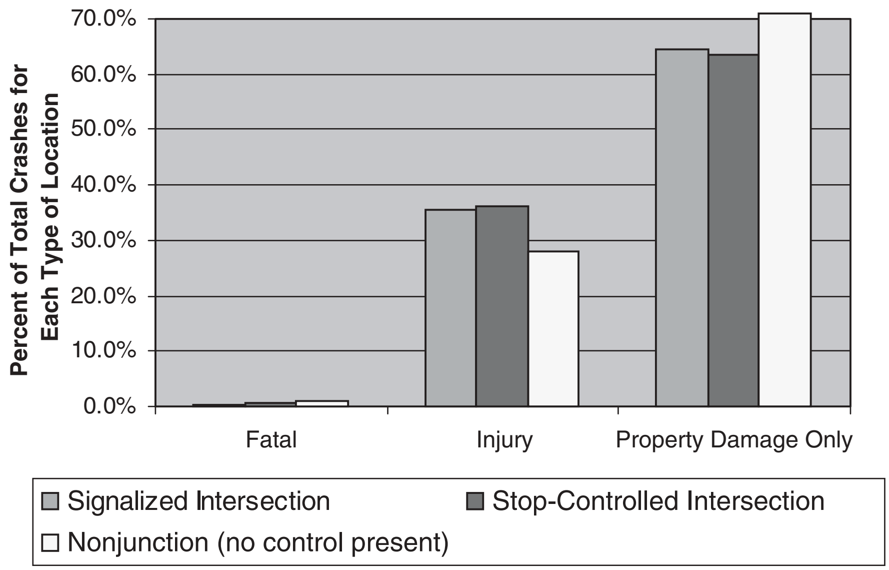


Exhibit III-3 shows the distribution of severity of crashes at signalized intersections in the United States, compared to stop-controlled intersections and nonjunctions along which there is no signal control. While nonjunctions proportionately experience slightly more fatal crashes, proportionately fewer injury crashes are associated with them than intersection crashes. There is little difference between the distributions for the two types of intersection control.

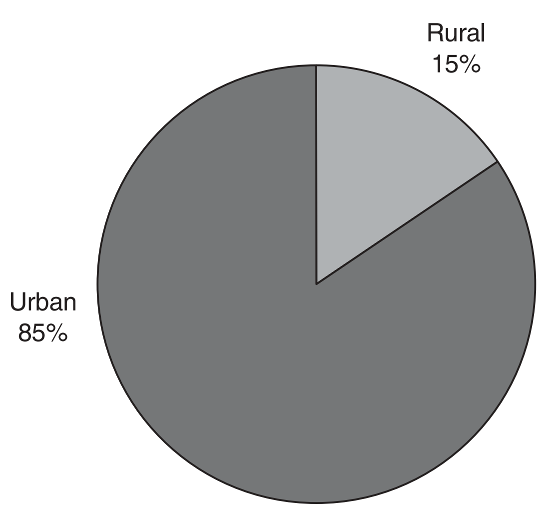
Analysis of the crash types at a signalized intersection helps focus the efforts for implementing improvements. The descriptions of strategies in this guide discuss the crash types affected by the strategies. The focus of this guide is on reducing fatalities at signalized intersections through low-cost, short-term improvements. The approach is to provide comprehensive strategies that include intersection design features (e.g., sight distance, left- and right-turn lane presence and design, skew angle, number of legs), as well as traffic operational factors (e.g., number of phases, type of signal phasing, timing, and signal progression), enforcement factors such as red-light running, and improved emergency response measures such as signal preemption.

EXHIBIT III-3
Comparison of Severity Distribution of Crashes
Source: NHTSA, FARS , General Estimates System (GES) 2002.



Fifty percent of all crashes in urban areas and over 30 percent in rural areas (Kuciemba and Cirillo, 1992) are intersection related. For signalized intersections, 85 percent of fatal crashes occur in urban areas (see Exhibit III-4). Since most traffic signals are located in urban areas, this breakdown by area type makes sense. Many of the strategies discussed in this guide are more feasible in urban situations than in rural ones; this is appropriate due to the prevalence of fatal crashes at urban signalized intersections.

EXHIBIT III-4
Fatal Signalized Intersection Crashes by Rural and Urban Areas
Source: 2002 FARS data.



SECTION IV

Index of Strategies by Implementation Timeframe and Relative Cost

Exhibit IV-1 provides a classification of strategies according to the expected timeframe and relative cost for this emphasis area. In several cases, the implementation time will be dependent upon such factors as the agency's procedures, the need for additional right-of-way (ROW), the number of stakeholders involved, and the presence of any controversial situations. The range of costs may also be somewhat variable for some of these strategies, due to many of the same factors. Placement in the table below is meant to reflect costs relative to the other strategies listed for this emphasis area only. The estimated level of cost is for the commonly expected application of the strategy, especially one that does not involve additional ROW or major construction, unless it is an inherent part of the strategy.

EXHIBIT IV-1
Classification of Strategies

Timeframe for Implementation	Relative Cost to Implement and Operate			
	Low	Moderate	Moderate to High	High
Short (less than a year)	17.2 A1 Employ multiphase signal operation 17.2 A2 Optimize clearance intervals 17.2 A3 Restrict or eliminate turning maneuvers (including right turns on red) 17.2 A6 Improve operation of pedestrian and bicycle facilities at signalized intersections 17.2 A7 Remove unwarranted signal 17.2 B3 Improve geometry of pedestrian and bicycle facilities 17.2 C1 Clear sight triangles 17.2 D1 Improve visibility of intersections on approach(es) 17.2 D2 Improve visibility of signals and signs at intersections	17.2 E2 Provide targeted conventional enforcement of traffic laws 17.2 G4 Relocate signal hardware out of clear zone	—	—

(continued on next page)

EXHIBIT IV-1 (Continued)
Classification of Strategies

Timeframe for Implementation	Relative Cost to Implement and Operate			
	Low	Moderate	Moderate to High	High
	17.2 E1 Provide public information and education 17.2 F1 Restrict access to properties using driveway closures or turn restrictions 17.2 F2 Restrict cross-median access near intersections 17.2 G5 Restrict or eliminate parking on intersection approaches			
Medium (1–2 Years)	—	17.2 A4 Employ signal coordination 17.2 A5 Employ emergency vehicle preemption 17.2 B1 Provide/improve left-turn channelization 17.2 B2 Provide/improve right-turn channelization 17.2 E3 Implement automated enforcement of red-light running (cameras) 17.2 E4 Implement automated enforcement of approach speeds (cameras) 17.2 E5 Control speed on approaches 17.2 G1 Improve drainage in intersection and on approaches 17.2 G2 Provide skid resistance in intersection and on approaches	—	—

EXHIBIT IV-1 (Continued)
Classification of Strategies

Timeframe for Implementation	Relative Cost to Implement and Operate			
	Low	Moderate	Moderate to High	High
		17.2 G3 Coordinate closely spaced signals near at-grade railroad crossings		
Long (More than 2 Years)	—	—	—	17.2 B4 Revise geometry of complex intersections 17.2 B5 Construct special solutions 17.2 C2 Redesign approaches

SECTION V

Description of Strategies

Objectives

The main goal of the objectives in this guide is the improvement in the safety of signalized intersections and their approaches. Safety improvement measures include geometric design modifications, changes to traffic control devices, enforcement, and education. Exhibit V-1 lists the objectives and the related strategies for improving safety at signalized intersections.

- *Reduce frequency and severity of intersection conflicts through traffic control and operational improvements*—Improvements to the method of assigning ROW at signalized intersections can reduce the potential for conflicts. This can be accomplished by modifying signal phasing, providing additional traffic control devices and pavement markings, and restricting turn movements. Improvements to traffic control can also benefit traffic operations and reduce emergency response time.
- *Reduce frequency and severity of intersection conflicts through geometric improvements*—Reducing the frequency and severity of vehicle-vehicle conflicts at intersections can reduce the frequency and severity of intersection crashes. This can be accomplished by incorporating geometric design solutions that separate through and turning movements at the intersection, restrict or eliminate turning maneuvers, and close or relocate intersections.
- *Improve sight distance at signalized intersections*—Provision of clear sight triangles in each quadrant of an intersection can minimize the possibility of crashes related to sight obstructions.
- *Improve driver awareness of intersections and signal control*—Some intersection-related collisions occur because one or more drivers approaching an intersection are unaware of the intersection until it is too late to avoid a collision. Improved signing and delineation and installation of lighting can help warn drivers of the presence of the intersection. In some situations, where other measures have not been effective, rumble strips may be used to get the driver's attention.
- *Improve driver compliance with traffic control devices*—Many accidents are caused or aggravated by drivers' noncompliance with traffic control devices or traffic laws at intersections. Both public education and enforcement have been shown to be effective in reducing traffic-law violations and consequently improving safety at intersections. Automated enforcement of traffic signals and speed limits is an increasingly common and cost-effective approach to improving driver compliance with traffic laws. At certain high-speed intersection approaches, implementing speed-reduction measures may provide an approaching driver with additional time to make safer intersection-related decisions.

- *Improve access management near signalized intersections*—Navigation, braking, and decision-making on intersection approaches creates additional workload on the driver. The presence of driveway access at or near a signalized intersection may confuse drivers using the intersection and create additional vehicle-vehicle conflicts. Measures to restrict driveways and to preclude cross median turning movements in close proximity to signalized intersections can effectively reduce or eliminate serious multivehicle conflicts.
- *Improve safety through other infrastructure treatments*—Other improvements can be made to the intersection to decrease frequency and severity of crashes at signalized intersections. These include improving pavement conditions, coordinating operation of signals near railroad crossings, and moving signal hardware out of the clear zone.

Ultimately, the driver is the target of all objectives, but specifically of those objectives relating to public education and traffic law-enforcement.

This section discusses each of the strategies listed in Exhibit V-1. The order in which the strategies are listed does not imply a priority with which they should be considered.

Most of the strategies are low-cost, short-term treatments to improve safety at signalized intersections, consistent with the focus of the entire AASHTO SHSP. For each of these, a detailed discussion of the attributes, effectiveness, and other key factors describing the strategy is presented below. Several higher-cost, longer-term strategies that have been proven to be effective in improving safety at signalized intersections are also presented in this section, but in less detail. While application of these is outside the implementation framework envisioned by the SHSP, their inclusion in this guide serves to complete the picture of proven, tried, and experimental strategies to improve safety at signalized intersections.

EXHIBIT V-1
Emphasis Area Objectives and Strategies

Objectives	Strategies
17.2 A Reduce frequency and severity of intersection conflicts through traffic control and operational improvements	17.2 A1 Employ multiphase signal operation (P, T)
	17.2 A2 Optimize clearance intervals (P)
	17.2 A3 Restrict or eliminate turning maneuvers (including right turns on red) (T)
	17.2 A4 Employ signal coordination along a corridor or route (P)
	17.2 A5 Employ emergency vehicle preemption (P)
	17.2 A6 Improve operation of pedestrian and bicycle facilities at signalized intersections (P, T)
	17.2 A7 Remove unwarranted signal (P)
17.2 B Reduce frequency and severity of intersection conflicts through geometric improvements	17.2 B1 Provide/improve left-turn channelization (P)
	17.2 B2 Provide/improve right-turn channelization (P)
	17.2 B3 Improve geometry of pedestrian and bicycle facilities (P, T)
	17.2 B4 Revise geometry of complex intersections (P, T)
	17.2 B5 Construct special solutions (T)

EXHIBIT V-1 (Continued)
Emphasis Area Objectives and Strategies

Objectives	Strategies
17.2 C Improve sight distance at signalized intersections	17.2 C1 Clear sight triangles (T)
	17.2 C2 Redesign intersection approaches (P)
17.2 D Improve driver awareness of intersections and signal control	17.2 D1 Improve visibility of intersections on approach(es) (T)
	17.2 D2 Improve visibility of signals and signs at intersections (T)
17.2 E Improve driver compliance with traffic control devices	17.2 E1 Provide Public Information and Education (PI&E) (T)
	17.2 E2 Provide targeted conventional enforcement of traffic laws (T)
	17.2 E3 Implement automated enforcement of red-light running (cameras) (P)
	17.2 E4 Implement automated enforcement of approach speeds (cameras) (T)
	17.2 E5 Control speed on approaches (E)
17.2 F Improve access management near signalized intersections	17.2 F1 Restrict access to properties using driveway closures or turn restrictions (T)
	17.2 F2 Restrict cross-median access near intersections (T)
17.2 G Improve safety through other infrastructure treatments	17.2 G1 Improve drainage in intersection and on approaches (T)
	17.2 G2 Provide skid resistance in intersection and on approaches (T)
	17.2 G3 Coordinate closely spaced signals near at-grade railroad crossings (T)
	17.2 G4 Relocate signal hardware out of clear zone (T)
	17.2 G5 Restrict or eliminate parking on intersection approaches (P)

P= proven; T = tried; E = experimental. Several strategies have substrategies with differing ratings.

Types of Strategies

The strategies in this guide were identified from a number of sources, including recent 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 local level in limited areas. Some have been subjected to well-designed evaluations to prove their effectiveness. On the other hand, 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 have been classified into three types, each identified by letter symbol throughout the guide:

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

Related Strategies for Creating a Truly Comprehensive Approach

The strategies listed above in Exhibit V-1 and described in detail in the remainder of Section V are considered unique to this emphasis area. However, to create a truly comprehensive approach to the highway safety problems associated with signalized intersections, it is recommended that additional strategies be included as candidates in any program planning process. These additional strategies are of five types:

- **Public Information and Education Programs (PI&E):** Many highway safety programs can be effectively enhanced with a properly designed PI&E campaign. The primary experience 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, such as an individual intersection or corridor with a history of severe crashes related to red-light running. While this is a relatively untried approach compared with areawide campaigns, use of roadside signs and other experimental methods may be tried on a pilot basis.

Within this guide, PI&E campaigns, where application is deemed appropriate, are usually used in support of some other strategy. In such a case, the description for that strategy will suggest this possibility (in the exhibits, 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 well-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 jurisdiction-wide programs that enforce an effective law against driving under the influence of alcohol (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 seat belts, and reduced impaired driving) may occur at or near the specific location where the enforcement is applied. This effect can often be enhanced by coordinating the effort with an appropriate PI&E program. However, in many cases (e.g., speeding and seatbelt usage) the impact is areawide or jurisdiction-wide. 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, it is often in support of some other strategy. Many of those strategies may be targeted at either a whole system or a specific location. In such cases, the description for that strategy will suggest this possibility (in the exhibits, 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.

- **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 later treatment and length of time in which an individual undergoes treatment. This is especially true when it comes to timely and appropriate treatment of severely injured persons. Thus, a basic part of a highway safety infrastructure is a well-based and comprehensive emergency care program. While the types of strategies 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 in how emergency medical services interact with signalized intersections, especially for programs that are focused upon 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:** 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 jurisdiction over the majority of the road system and are responsible for its related safety problems. They know better than others do what the problems are. As additional guides are completed for the AASHTO plan, the guides may address the details regarding the design and implementation of strategies for improving safety management systems.
- **Strategies Detailed in Other Emphasis Area Guides:** Several of these objectives and many of the corresponding strategies are applicable to unsignalized intersections as well as signalized ones. The discussion in this guide of these overlapping strategies is based upon the Unsignalized Intersection guide. Strategies that overlap between these two guides are discussed briefly in this section, and the Unsignalized Intersection guide should be consulted for more details. In addition, there are many treatments for signalized intersections that would improve safety for pedestrians, bicyclists, and older drivers. The pedestrian and older driver guides should be consulted for additional information. Any program targeted at the safety problem covered in this guide on signalized intersections should be created with consideration given to potentially appropriate strategies in these other guides.

Objective 17.2 A—Reduce Frequency and Severity of Intersection Conflicts through Traffic Control and Operational Improvements

Virtually all traffic signal timing and phasing schemes are established with the primary objective being the efficient movement of traffic. Certain timing, phasing, and control strategies can produce safety benefits with only marginal adverse effects on delay or capacity. Low-cost improvements to signalized intersections that can be implemented in a short time period include revising the signal phasing and/or operational controls at the intersection to explicitly address safety concerns. Signalization improvements may include adding phases, lengthening clearance intervals, eliminating or restricting higher-risk movements, and coordinating signals. A review of crash history at a specific signalized intersection can provide insight into the most appropriate strategy for improving safety at the intersection. See the presentation and discussion of the Model Implementation Process, Step 1, for further details. In particular, guidelines linking crash types to candidate improvement strategies are useful (See Appendix 10).

Strategy 17.2 A1: Employ Multiphase Signal Operation (Combination of Tried and Proven Strategies)

General Description

This strategy includes using protected left-turn phases and split phases.

A two-phase signal is the simplest method for operating a traffic signal, but multiple phases may be employed to improve intersection safety. Left turns are widely recognized as the highest-risk movements at signalized intersections. Protected left-turn phases (i.e., the provision for a specific phase for a turning movement) significantly improve the safety for left-turn maneuvers by removing conflicts with the left turn.

Split phases, which provide individual phases for opposing approaches may also increase the overall delay experienced at an intersection. However, this strategy may improve intersection safety, as it allows conflicting movements to proceed through the intersection independently, on separate phases.

Implementation of improvements to signal phasing may necessitate the replacement of older electromechanical signal controllers. Even if not necessary, replacing the controller should be considered as it may be more cost-effective to implement the changes at the same time as replacing the controller.

Use Protected Left Turns

The safety problems that left-turning vehicles encounter arise from three sources of conflict:

- Opposing through traffic,
- Through traffic in the same direction, and
- Crossing vehicular and pedestrian traffic.

These conflict types often produce angle, sideswipe same direction, and rear-end crashes. There are several treatments that could alleviate operational and safety impacts of—and on—left-turn traffic. Protected left-turn phases are warranted based on such factors as turning volumes, delay, visibility, opposing vehicle speed, distance to travel through the intersection, and safety experience of the intersections. Agency policies on the specific thresholds of each of these factors vary in the United States. There are several geometric and operational characteristics of intersections that should be analyzed when considering which type of left-turn signal phasing to use to accommodate left turns (turning volumes, opposing through volumes, pedestrian crossing volumes, approach speeds, sight distance, number of lanes, delay, type and nature of channelization, and crash experience).

There are various options available for controlling left turns with signals: permitted, protected only, and protected/permitted (including both lead-protected/permitted and lag-protected/permitted). Several Web sites are available that provide additional information on signal phasing:

- http://www.webs1.uidaho.edu/niattproject/
- http://www.dot.state.mn.us/metro/trafficeng/dsg_crse/chap21.html#_Toc429824696

The use of “protected/permitted” phasing represents a compromise between fully protected phasing and permitted-only phasing. This operational strategy has several advantages, the most important being the reduction in delay for left-turning vehicles achieved by permitting left turns while the opposing through movement has a green indication. Other benefits include less green time needed for protected left turns (and hence more time for other high-priority movements) and the potential for improved arterial progression. The safety performance of protected/permitted left-turn phases is not as good as that of protected-only phases, due to the increased exposure of left-turning and opposing through vehicles to conflicts with each other during the permitted phase. Dual or triple left-turn lanes should only operate with protected turn phases.

In terms of explicit concern for safety, protected-only phasing may be the best option. A study by Shebeeb (1995) showed that the left-turn signal phases that provide the greatest operational benefit to left-turning vehicles, with respect to stopped delay, increase the crash risk for left-turning vehicles the most. Additional guidance on choosing a type of left-turn phasing is summarized in *NCHRP Synthesis 225: Left-Turn Treatments at Intersections* (Pline, 1996).

The choice of lead versus lag phasing for protected left-turn phases depends on intersection capacity and the presence of, or desire for, coordinated system timing. Providing the left-turn arrow before the conflicting through movement receives a green indication ("lead" left turn) minimizes the conflicts between left-turning and through vehicles. With a "lag" left-turn phase, however, left-turning vehicles are given the opportunity to turn during the permissive portion of the cycle, which may allow clearing all or part of the left-turn queue, resulting in a shorter lag phase or eliminating the need for it during that specific cycle. A study of intersections in Kentucky found a higher average number of crashes per approach for protected/permitted phasing schemes having lag left turns (2.07 crashes per 1,000 left-turning and opposing vehicles) than for those having lead left turns (1.27 crashes). (Stamatiadis et al., 1997). On the other hand, a study of intersections in Arizona concluded that the potential for left-turn head-on crashes is not high enough to be a main factor in determining whether to use lead or lag left-turn phasing (Box and Basha, 2003).

EXHIBIT V-2
Strategy Attributes for Use of a Protected Left-Turn Signal Phase (P)

Attribute	Description
Technical Attributes	
Target	The strategy is targeted at reducing the frequency of angle collisions resulting from conflicts associated with left-turn maneuvers at signalized intersections involving left-turning vehicles and opposing through vehicles. A properly timed protected left-turn phase can also help reduce rear-end and sideswipe crashes between left-turning vehicles and the through vehicles behind them.
Expected Effectiveness	Various studies have proven that installing protected left-turn phases improves left-turn safety due to the decrease in potential conflicts between left-turning and opposing through vehicles. The isolation of left-turning traffic usually reduces rear-end, angle, and sideswipe crashes, as well as improves the flow of through traffic. A protected/permitted left-turn phase has not been shown to provide the higher degree of safety of a protected-only phase, but it is safer than permitted-only phasing. Given the wide range of conditions at intersections used for studying the effectiveness of left-turn phases, a consensus on the extent of this effectiveness has not been reached. Consideration may be given to adding a protected left-turn phase when left-turn lanes are constructed. FHWA's *Signalized Intersections: Informational Guide* (to be published in 2004) provides a summary of studies of the effectiveness of adding left-turn lanes and protected left-turn phases and concludes that providing both a left-turn phase and left-turn lane appears to provide the most safety benefit. California reported a 35-percent average reduction in total crashes when left-turn lanes were constructed

EXHIBIT V-2 (Continued)
Strategy Attributes for Use of a Protected Left-Turn Signal Phase (P)

Attribute	Description
	and left-turn phases were implemented, as opposed to a 15-percent reduction when left-turn lanes were installed without a separate left-turn phase (Neuman, 1985). Overlapping the adjacent right-turn phase with the protected left-turn phase will allow for improved operation of the right-turn movements at the intersection.
Keys to Success	This strategy applies only where a separate left-turn lane exists (see below for discussion of split phasing, which may apply where separate left-turn lanes are not present.) The overall length of the turn lane is a key element in the design of the lane. A lane that does not provide enough deceleration length and storage space for left-turning traffic may cause the turn queue to back up into the adjacent through lane. This can contribute to rear-end and sideswipe crashes, as well as adversely affect delay for through vehicles. *NCHRP Synthesis 225: Left-Turn Treatments at Intersections* (Pline, 1996) summarizes recent guidance on determining left-turn phasing (protected, protected/permitted, leading, lagging, etc). This information is based on both traffic volume data and crash histories. Appropriate protected left-turn signal indications should be used to communicate the signal phasing to drivers. Several experimental signal displays are being used across the country (see Appendix 1).
Potential Difficulties	A separate phase for the left-turn movement may reduce delay for the vehicles turning left but could result in more overall intersection delay, because other movements will lose green time or gain more red time and because the total signal cycle length may increase. The length of signal phase and cycle length should be compatible with the length of the left-turn lane. Turn lanes that are too short may be blocked by through-vehicle queues, making the lane inaccessible and also negating the effectiveness of a lead left-turn phase. Provision of a left-turn lane on an intersection approach may involve restricting left turns in and out of driveways on the intersection approach. The strategies in this guide in the access management objective should be consulted (see Objective 17.2 F).
Appropriate Measures and Data	Key process measures include the number of intersections for which protected left-turn phases are implemented and the number of conflicts eliminated by the improvements. Crash frequency and severity by type of crash are key safety effectiveness measures. It is especially important to identify crashes related to left turns (angle, rear-ends). Crash frequency and severity data are needed to evaluate such improvements. Traffic volume data are needed to represent exposure, especially the volumes of left-turn movements of interest and the opposing through volumes. Delay data are needed to determine the operational impacts of a change.
Associated Needs	There is no need for special public information and education programs, as most drivers understand the operation of a protected left turn. However, signs may be temporarily erected on the approach to an intersection for which a phasing plan has been significantly altered to help frequent users of the intersection be aware of the change and not violate expectancy of the familiar driver.

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EXHIBIT V-2 (Continued)
Strategy Attributes for Use of a Protected Left-Turn Signal Phase (P)

Attribute	Description
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	The signalization policies of many agencies are primarily driven by traffic operational and delay/capacity concerns. Highway agencies should review their traffic engineering and design policies regarding the use of, or warrants for, protected left-turn phases to ensure that appropriate safety-based action is being taken on routine projects. Highway agencies and other agencies should ensure that their policies for new or reconstructed intersections incorporate provisions for protected left-turn lanes and signal phases, where applicable. Nearly any highway agency can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas. Where alternatives may involve restricting access, it will be important to involve those potentially affected in the early stages of planning.
Issues Affecting Implementation Time	Implementing this strategy may range from a few months to 3 or 4 years. Protected-only phasing can be implemented only where separate left-turn channelization exists. Where the intersection geometry already exists, the cost can be very small (engineering and technician time to install the phasing scheme). In some cases, upgrading of the existing signal equipment, including the controller, may be necessary. Even where no such channelization exists, it may be possible to re-stripe an approach to provide it. At other locations, lengthening the left-turn lane, widening the roadway, acquiring additional ROW, or redesigning the horizontal and vertical alignment may be needed in conjunction with changes in signal operation policies. The latter types of projects require time for design and construction.
Costs Involved	Costs may be highly variable and may depend on the condition and flexibility of the existing traffic signals and controller. If the existing traffic signal only requires a minor modification to allow for a protected left-turn phase, then the cost would be low. If a completely new traffic signal is needed to accommodate the protected left-turn phase, then the cost could be higher. In addition to the costs of the equipment needed for the signal, expenditures are needed for advance warning signing and signs and markings needed at the intersection (such as a “Stop Here On Red” sign). Similarly, costs would be higher if additional dedicated left-turn lanes are required; these costs may include right-of-way, pavement, pavement markings, and lane use signs.
Training and Other Personnel Needs	None identified.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with other strategies for improving safety at signalized and unsignalized intersections. Most notably, strategies concerning addition of left-turn lanes would be compatible
Other Key Attributes to a Particular Strategy	None identified.

Use Split Phases

Certain geometric configurations, such as left-turn travel paths that overlap with the opposing left-turn path, may require the use of split phasing at an intersection. Split phasing allows opposing movements on the same roadway to proceed through the intersection at different times and is a way to address several geometric situations that pose safety problems for vehicles on opposite approaches (see Exhibit V-3). These include the following:

- Skewed intersections,
- Intersections with a large deflection angle for the through movement,
- Wide medians,
- Intersections too small to allow simultaneous left turns (limited ROW),
- Intersections with lanes shared by left-turn and through movements (i.e., without separate left-turn lanes),
- Intersections with significantly unbalanced opposing left-turn volumes, and
- Intersections on a divided highway with different profiles.

EXHIBIT V-3
Split Phasing on One Intersection Approach
Source: Federal Highway Administration, in press.

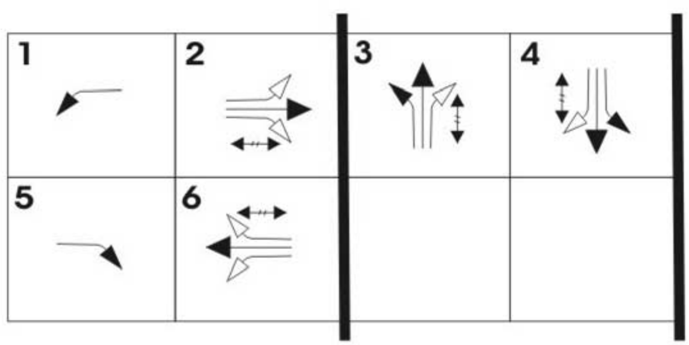

EXHIBIT V-4
Strategy Attributes for Using Split Phases (T)

Attribute	Description
Technical Attributes	
Target	This strategy targets crashes that occur related to opposing movements proceeding on the same phase through an intersection with complex geometry or lane assignment. Crash types related to this situation include sideswipe between opposing left turns, rear end, head on, and angle.
Expected Effectiveness	Though studies have not conclusively proven that implementation of split phases reduces fatalities and severe injuries at signalized intersections, the elimination of conflicts can logically be expected to reduce crashes. Using split phases to separate opposing traffic can be expected to greatly reduce the sideswipe, rear-end, and angle conflicts and the collisions associated with the geometric situation that contributes to

(*continued on next page*)

EXHIBIT V-4 (Continued)
Strategy Attributes for Using Split Phases (T)

Attribute	Description
	the conflicts between the opposing vehicles. The effectiveness in reducing crashes involving left-turning vehicles should be similar to that of adding a protected-only left-turn phase. With no movements conflicting with vehicles on a given approach, angle, head-on and sideswipe-opposite-direction crashes should be eliminated. Rear-end and sideswipe-same-direction crashes may not be completely eliminated, but some of these crashes may be related to congestion or other factors rather than conflicts with vehicles moving in opposing directions.
Keys to Success	A key to success is balancing the safety benefits of split phases with the operational disadvantages, such as increased lost time and intersection delay. Care should be taken to examine other potential strategies that could provide the same safety benefit, but with less operational cost. Such strategies might include restricting turning maneuvers (Strategy 17. 2 A3), improving left-turn channelization (Strategy 17.B1), and revising geometry of complex intersections (Strategy 17.2 B4).
Potential Difficulties	The use of split phasing will generally result in less efficient intersection operations, depending on the intersection characteristics. Increasing the number of phases usually requires a longer signal cycle and increases lost time, resulting in a longer overall intersection delay. The delay on an approach could be increased to a point where queues will exceed available storage lengths. This should be a factor to consider in any change of phasing and timing. Adverse effects on arterial progression may also result from implementation of this strategy. (See Strategy 17.2 A4). Driver error is a potential problem associated with this strategy, specifically when first implemented. Changes in signal phasing may violate the expectancy of drivers familiar with the intersection. Since drivers understand the operation of traffic signals in general, this should not be a significant problem.
Appropriate Measures and Data	Process measures include the number of intersections for which a split signal phase is implemented and the number of conflicts affected by the improvement. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to targeted movements at the intersection should be analyzed separately. Traffic volume data are needed to represent exposure. Delay data are needed to estimate the operational impacts of a change.
Associated Needs	Except for temporary warning of significant phasing changes, public information should not be needed when implementing this strategy. Drivers are familiar with the operation of traffic signals, and the effect of split phasing on driver expectancy is not anticipated to be a serious issue.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should review their traffic engineering and design policies regarding signal phasing to ensure that appropriate action is being taken when split phases may provide a safety benefit. Any highway agency with jurisdiction over signalized intersections can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas.
Issues Affecting Implementation Time	Implementation of split signal phasing could vary from a few days to a few months, depending upon the condition and flexibility of the existing traffic signal. Should anticipated queuing exceed available storage lengths, much longer time would be required for reconstruction of the approach(es) in need of additional storage space.

EXHIBIT V-4 (Continued)
Strategy Attributes for Using Split Phases (T)

Attribute	Description
Costs Involved	Costs are variable and may depend upon the condition and flexibility of the existing traffic signal. If the existing traffic signal only requires a minor modification to allow for split phasing, then the cost would be low. If a completely new traffic signal is needed, the cost would of course be higher, due to signal design, timing, and equipment costs. Reconstruction of storage lanes may also result in major costs.
Training and Other Personnel Needs	The safety benefits of split phasing should be addressed in agency training on intersection safety and traffic signals.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with other approaches for improving safety at signalized intersections.
Other Key Attributes to a Particular Strategy	None identified.

Strategy 17.2 A2: Optimize Clearance Intervals (P)

General Description

The clearance interval is the portion of a signal cycle between the end of a green phase and the beginning of the next green phase for a conflicting movement. Clearance times provide safe, orderly transitions in ROW assignment between conflicting streams of traffic. The clearance interval can include both yellow and all-red time between conflicting green phases.

There is no standardized method for determining clearance intervals. Clearance intervals are a function of operating speed, the width of the intersection area, lengths of vehicles, and driver operational parameters such as reaction, braking, and decision-making time. ITE has developed an equation for determining the length of the yellow change interval. Many agencies use rule-of-thumb methods as well. See Appendix 2 for more information on establishing clearance intervals.

Clearance intervals that are too short in duration can contribute to rear-end crashes related to drivers stopping abruptly and right-angle crashes resulting from signal violations. One study showed clearance intervals shorter than those calculated using the ITE equation have higher rear-end and right-angle crash rates than intersections with timings that exceed the ITE value (Zador et al., 1985). In the extreme, a too-short interval can result in drivers operating at the legal speed limit being forced to violate the red phase. A study by Retting et al. (2000) noted that signal intervals that are considered too short are associated with vehicle conflicts and red-light running.

Increasing clearance intervals may improve safety at signalized intersections where the existing yellow (or yellow plus red) change intervals do not allow drivers adequate time to react to the reassignment of ROW. Longer clearance intervals may also be effective at intersections with significant physical size, to allow drivers to clear the intersection before the opposing traffic enters. See Appendix 2 for more information on establishing clearance intervals. A detailed discussion on yellow and all-red intervals is provided in *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running* (McGee, 2003; available online at http://www.ite.org/library/redlight/MakingInt_Safer.pdf).

Lengthening clearance intervals will often require a commensurate lengthening of the total cycle length. Clearance intervals represent time that is lost to movement of traffic. Lengthening the cycle reduces the percentage of time that is "lost" for clearance. Unfortunately, widespread use of longer clearance times and cycle lengths has led in many areas of the country to a growing problem of red-light violations. Drivers are with greater frequency learning that the clearance time is long and that if they stop for the signal the delay they incur will be long. Establishment of a policy for determining clearance interval duration is necessary to provide consistency throughout a jurisdiction's system. Also, consideration should be given to other enforcement actions associated with potential red-light running (see strategies enumerated in Objective 17.2 E, Improve Driver Compliance with Traffic Control Devices).

EXHIBIT V-5
Strategy Attributes for Optimizing Clearance Intervals (P)

Attribute	Description
Technical Attributes	
Target	The target of this strategy is crashes related to clearance interval lengths that are too short for a particular intersection. These crashes include angle crashes between vehicles continuing through the intersection after one phase has ended (possibly due to being in the dilemma zone as the clearance interval started) and the vehicles entering the intersection on the following phase. Rear-end crashes may also be a symptom of short clearance intervals. A vehicle stopping at a signal may be rear-ended by a vehicle following it when the following driver expected to be able to proceed through the intersection during a longer clearance interval.
Expected Effectiveness	This strategy is proven effective in reducing multivehicle crashes at signalized intersections. A study of signalized intersections in one city in New York found a 9-percent reduction in multivehicle and a 12-percent reduction in injury crashes at intersections where the duration of the change intervals was lengthened to meet ITE recommendations. The crash risk for rear-end and angle crashes did not change significantly. The same study showed a 37-percent reduction in crashes involving pedestrians or bicyclists. The authors explained that pedestrian- and bicycle-related crashes may be more affected by changes in clearance interval timing because many pedestrians and bicyclists will enter the intersection during the change interval before they are given a walk signal. (Retting et al., 2000).
Keys to Success	A clearance interval should not be so long as to encourage disrespect in drivers for the interval, thereby contributing to red-light running and even more severe crashes, nor so short as to violate driver expectancy regarding the length of the interval, resulting in abrupt stops and possible rear-end crashes.
Potential Difficulties	The Retting et al. (2000) study cited above suggests that drivers do not generally assume that longer change intervals at one or more locations will mean that they will

EXHIBIT V-5 (Continued)
Strategy Attributes for Optimizing Clearance Intervals (P)

Attribute	Description
	be used at all signalized intersections. Therefore expectancy problems related to this are not likely to be experienced at intersections having shorter change intervals. Further research may be needed, however, to provide more evidence that the effect of lengthening a change interval does not create general expectancies among drivers. As clearance intervals are increased, there will usually be an attendant increase in the cycle length and delay. Thus, an intersection may become safer, but the resulting level of delay increases, which may raise objections from the traveling public. Moreover, increased cycle lengths and delay may have adverse operational effects on one or more approaches (e.g., left-turn-lane overflow or blockage, loss of progression, queue collision with adjacent intersections). Longer cycle lengths may also lessen the effectiveness of a signal progression scheme for a route or corridor. Any of the above difficulties may create a degradation in safety away from the intersection, thus potentially negating some of the benefits of improved clearance times.
Appropriate Measures and Data	A key measure of the implementation process is the number of signalized intersections for which clearance intervals are optimized. Crash frequency and severity by type of crash are also key safety effectiveness measures. It is especially useful to separately analyze crashes by movement or type. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to a clearance interval (right angle and rear end) should be analyzed. Traffic volume data are needed to represent exposure. Delay data are needed to assess operational impacts.
Associated Needs	Except for temporary warning of timing changes, there is no need for special public information and education programs relating to signal clearance intervals. Public information and education campaigns for red-light running should encompass this issue.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway and other agencies should ensure that their signal design policies provide guidance and allow some flexibility in clearance interval length. Tort liability is an issue to be considered when selecting change intervals. Agencies responsible for traffic signals have paid large settlements in cases where clearance intervals did not meet recommended values. Examples of this are discussed in the ITE *Traffic Safety Toolbox* (Institute of Transportation Engineers, 1999b). Highway agencies should review their traffic engineering policies regarding clearance intervals to ensure that appropriate action is being taken on projects. Nearly any highway agency can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas. Very long clearance intervals may be required in rural areas or at intersections with very high-speed traffic.
Issues Affecting Implementation Time	Implementation time is low for changing the length of a clearance interval. Engineering studies, development of retiming plans, and field implementation are required.
Costs Involved	Costs for changing the length of a clearance interval will be low. The design of the new signal timing and the reprogramming of the signal should be the only costs.

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EXHIBIT V-5 (Continued)
Strategy Attributes for Optimizing Clearance Intervals (P)

Attribute	Description
Training and Other Personnel Needs	Effective use of clearance intervals, including the length of the red clearance interval, should be addressed in highway agency training concerning intersection design and operation. Agency engineering staff should be aware of the legal implications of dilemma zones and clearance intervals in their jurisdiction.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	Optimizing the length of the clearance interval is compatible with other strategies to improve signalized intersection safety. Note that some strategies to improve safety may increase required clearance intervals. One such strategy is widening an approach to add left-turn lanes. An alternative to optimization of clearance interval is implementation of measures to reduce speeds on one or more approaches.
Other Key Attributes to a Particular Strategy	None identified.

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

Agencies are utilizing technology to automatically extend signal intervals in order to aid drivers approaching a signalized intersection in determining whether to stop or proceed through the intersection. The "dilemma zone" for an intersection is a specific road segment, prior to the intersection, in which the driver will be able neither to stop safely before entering the intersection nor to proceed through the intersection without violating the red indication. The ITE *Traffic Engineering Handbook* (Pline, 1999) contains a more detailed description of the dilemma zone, including zone boundaries based on approach speed. Agencies are implementing systems to protect drivers in the dilemma zone by extending the green or red interval. Refer to Appendix 3 for additional details. European countries have also implemented treatments for protecting drivers in the dilemma zone (see Appendix 4).

Strategy 17.2 A3—Restrict or Eliminate Turning Maneuvers (Including Right Turns on Red) (T)

General Description

This strategy includes restricting or eliminating left- or right-turning maneuvers using channelization or signing and prohibiting right turns on red (RTOR).

Safety at some signalized intersections can be enhanced by restricting or prohibiting turning maneuvers, particularly left turns. This strategy can be applied during certain periods of the day (such as peak traffic periods) or by prohibiting particular turning movements altogether. This strategy may be appropriate where a turning movement is considered to be "high risk" and other strategies (such as left-turn channelization or retiming of signals) are impractical or not possible to implement.

Crashes related to turning maneuvers include angle, rear-end, pedestrian, and sideswipe (involving opposing left turns) type crashes. If any of these crash types are an issue at an intersection, restriction or elimination of the turning maneuver may be the best way to improve the safety of the turn.

Restrict or Eliminate Turning Maneuvers Using Channelization or Signing. Turn restrictions and prohibitions can be implemented by channelization or signing. Raised concrete channelization or flexible delineators can be used to physically prevent drivers from making restricted maneuvers. Turning prohibitions or restrictions implemented with signing alone will most likely require some periodic enforcement. The cost of enforcement should be considered when discussing methods for restricting or prohibiting turns.

Prohibit Right Turns on Red. Prohibition of RTOR can help reduce crashes related to limited sight distance and pedestrians that involve right-turning vehicles. This strategy can also help reduce the frequency and severity of crashes between vehicles turning right on red and vehicles approaching from the left on the cross street or turning left from the opposing approach. Prohibition of RTOR may also be a safety-effective strategy where weaving or other conflicts are evident downstream of the right turn. This strategy can be implemented with signing, although enforcement is often needed to realize the potential benefits of the new regulation. Prohibition of RTOR at specific intersections can be implemented during certain times of the day (such as when pedestrians are more likely to be present). Also, supplemental sign plaques prohibiting RTOR, when pedestrians are present, have been used to help protect pedestrians.

EXHIBIT V-6
Strategy Attributes for Prohibiting or Eliminating Turning Movements (Including RTOR) (T)

Attribute	Description
Technical Attributes	
Target	The target of this strategy is crashes related to turning maneuvers including angle, rear-end, pedestrian, and sideswipe (involving opposing left turns) type crashes. For RTOR, the target of this strategy is right-turning vehicles that are involved in rear-end or angle crashes with cross-street vehicles approaching from the left or vehicles turning left from the opposing approach, as well as crashes involving pedestrians. See the pedestrian guide for additional discussion on strategies for improving pedestrian safety.
Expected Effectiveness	Though there are no studies proving that prohibition of turning movements reduces fatal and severe crashes at signalized intersections, prohibition of left-turning movements—if enforced—would be expected to eliminate crashes involving left turns over the time period of the prohibition based on the assumption that no drivers will violate the restriction. Note, however, that a complete assessment of the effect of a turn restriction or prohibition on safety requires consideration of the impacts on alternative routes to which the traffic that desires to make the affected turn is diverted. Also, the benefit of restricting turn movements may be reduced by an increase in accidents related to formation of queues (such as rear-end collisions) at alternative turn locations. No data on the effectiveness of prohibiting RTOR are available, but it is expected that prohibition of RTOR will eliminate crashes related to vehicles making that turn during the time period the restriction is in effect, assuming that no drivers violate the restriction. Crashes related to right turns that occur on green would not be affected by prohibiting RTOR.

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EXHIBIT V-6 (Continued)
Strategy Attributes for Prohibiting or Eliminating Turning Movements (Including RTOR) (T)

Attribute	Description
	Fleck and Lee (2002) report in an *ITE Journal* article that RTOR collisions are not always reported as such; rather, they are often coded as violation of pedestrian ROW, driving under the influence, or other types of violations. Therefore, it is important to carefully analyze crash histories, especially those involving pedestrians, to determine the problem's nature. Retting et al. (2002) report that prohibition of RTOR during certain hours of the day is effective in reducing RTOR without stops. However, prohibition of RTOR when pedestrians are present is a much less effective strategy. These results are based on a study of intersections in Arlington, Virginia, but it could be expected that similar urbanized areas would experience the same results. A reduction in drivers turning right on red without stopping could lead to a lower number of pedestrian crashes.
Keys to Success	A key to success of the prohibition of left turns is the provision for safe and adequate alternative locations to make the left turn in close proximity to the intersection where the prohibition is placed. As noted above, a careful traffic engineering study should be made to ensure that the safety and operational problems calling for the prohibition are not merely relocated elsewhere. It will be important to include stakeholders in the planning and implementation of this strategy. Law enforcement agencies in the jurisdiction should be partners in the effort. If access to properties may be negatively affected, representatives of those involved should be included in the process. Affected transit agencies should also be involved. With respect to RTOR prohibition, a key to success is to establish that prohibition of RTOR is justified due to an existing pattern of right-turn collisions. RTOR prohibitions should be provided only in areas where the restriction could be beneficial, such as urbanized areas with high pedestrian volumes, at intersections with concentrations of children (e.g., enroute and adjacent to schools, parks, playgrounds), or where experience has shown a high number of crashes involving vehicles attempting to turn right on red. Otherwise, installation of a RTOR prohibition is unlikely to provide substantial safety benefits, while possibly contributing to driver disrespect for the prohibition. Enforcement of the prohibition is also important to the success of the strategy.
Potential Difficulties	Prohibition of left turns at a major intersection may be difficult to justify, unless the left-turn volumes are very low. Refer to Strategy 17.2 F2 for discussion on restricting median left turns. If at all possible, it is generally preferred to more safely accommodate the turning movement at the point where the driver desires to turn than to displace the turn activity to an alternative location. Restriction and prohibition of turning maneuvers are discussed in more detail in the unsignalized intersection guide. However, issues in implementing turn prohibitions become more complex in higher-volume suburban and urban signalized intersections. Drivers familiar with the intersection might fail to notice the prohibition of RTOR when the restriction is first put into place. This is expected to be a common occurrence where other intersections within the jurisdiction permit RTOR operation. Additional signing or public information and educational materials may help alleviate this.
Appropriate Measures and Data	Process measures include the number of intersections for which a prohibition has been implemented, the percentage of intersections at which there is a turn problem for which a prohibition has been implemented, and the number of conflicts affected by the improvements. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to targeted turning movements at the

EXHIBIT V-6 (Continued)
Strategy Attributes for Prohibiting or Eliminating Turning Movements (Including RTOR) (T)

Attribute	Description
	intersection should be analyzed separately. Traffic volume data are needed to represent exposure. It will be important that the analysis include all intersections potentially affected by the restriction, including those to which turning traffic will be diverted.
Associated Needs	There is a need to inform the public about the change in regulations at the intersection and about the safety benefits of the prohibition. Informing the public of a RTOR prohibition takes on added significance when other intersections within the jurisdiction permit RTOR operation.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should review their traffic engineering and design policies regarding RTOR and policies for restricting turns and prohibiting RTOR. When planning turn restrictions, it is important to include public transport agencies, due to the potential effects on bus transit. Either rerouting a bus route or allowing buses to make the turns that other vehicles are prohibiting from making are options, should this be an issue.
Issues Affecting Implementation Time	Implementation of the turn restriction or prohibition could vary from a few days to a few months, depending upon the extent of public information and education provided.
Costs Involved	Costs may be variable—turn restrictions can be implemented with low-cost signing, but enforcement of the regulation and PI&E campaigns regarding the new regulation will increase costs.
Training and Other Personnel Needs	Turn restrictions, including RTOR, should be incorporated into agency training on intersection operations and safety.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with other strategies for improving safety at signalized and unsignalized intersections. Refer in particular to the pedestrian guide for a range of strategies aimed at pedestrian safety, many of which can work in concert with implementation of turn restriction, specifically with a RTOR prohibition.
Other Key Attributes to a Particular Strategy	RTOR reduces delay for right-turning vehicles and, in fact, was encouraged by the federal government in the 1970s as an energy conservation measure. Previous research has shown that RTOR movements result in a 5-percent reduction in fuel consumption on urban streets. RTOR from an auxiliary lane has a negligible impact on delays if the average gap-acceptance is less than 15 sec per vehicle. If the cross flow does not exist or is light, then multiple RTOR can be performed at a rate of one vehicle per 4.7 seconds. This could result in a significant reduction in delays. If 10 percent of the approaching flow turns right, then the RTOR has little influence on right turn delay. If 40 percent of the approaching flow turns right, then the RTOR movements may reduce delays significantly. However, RTOR is not likely to reduce delays significantly if the saturation ratio of the cross flow is greater than 0.6 sec and the delays without RTOR are less than 30 sec per vehicle.

Strategy 17.2 A4: Employ Signal Coordination (P)

General Description

Signal coordination has long been recognized as having beneficial effects on the quality of traffic flow along a street or arterial. Good signal coordination can also generate measurable safety benefits, primarily in two ways.

Coordinated signals produce platoons of vehicles that can proceed without stopping at multiple signalized intersections. Reducing the number and frequency of required stops and maintaining constant speeds for all vehicles reduce rear-end conflicts. In addition, signal coordination can improve the operation of turning movements. Drivers may have difficulty making permitted turning maneuvers at signalized intersections (e.g., permitted left turns, RTOR after stop) because of lack of gaps in through traffic. Crashes may occur when drivers become impatient and accept a gap that is smaller than needed to complete a safe maneuver. Such crashes could be reduced if longer gaps were made available. Increased platooning can create more gaps of increased length for permitted vehicle movements at intersections and result in improved intersection operation. Also, platooning will contribute to consistent vehicle speeds along a corridor, which will help decrease rear-end type crashes.

Corridors with coordinated signals that experience a higher level of rear-end and angle crashes should be reviewed to determine if the timing should be revised or if the signals should be optimized again.

EXHIBIT V-7
Strategy Attributes for Signal Coordination (P)

Attribute	Description
Technical Attributes	
Target	The target of this strategy is crashes involving major-street left-turning and minor-street right-turning vehicles where adequate safe gaps in opposing traffic are not available. These crash types are generally angle and rear-end crashes. Major road rear-end crashes associated with speed changes can also be reduced by retiming signals to promote platooning.
Expected Effectiveness	Studies have proven the effectiveness of signal coordination in improving safety. The ITE *Traffic Safety Toolbox* (Institute of Transportation Engineers, 1999b) cites two studies of coordinated signals with intersection crash frequencies that dropped by 25 and 38 percent. One of the studies showed an improvement in crash rates for midblock sections as well. Signal coordination can also contribute to a decrease in red-light running. A study on the effectiveness of traffic signal coordination (Rakha et al., 2000) concluded that there is a small but significant improvement in crash rates on intersection approaches after signal coordination. Crashes along the study corridor in Arizona decreased 6.7 percent.
Keys to Success	A key to success is the appropriate spacing of the signals. Signals within a half mile of each other should be coordinated, but signal systems that operate on different cycle lengths do not need to be coordinated. The grouping of the signals to be coordinated is a very important aspect of design of a progressive system. Factors that should be

EXHIBIT V-7 (Continued)
Strategy Attributes for Signal Coordination (P)

Attribute	Description
	considered include geographic boundaries (see discussion below), volume/capacity ratios, and characteristics of traffic flow (random vs. platoon arrivals).
Potential Difficulties	Spacing of traffic signals is an important factor. As with all signals, coordinated signals too close together can present problems related to drivers focusing on a downstream signal and not noticing the signal they are approaching or proceeding through a green signal and not being able to stop for a queue at an immediate downstream signal. Dispersion of platoons can occur if signals are spaced too far apart, resulting in inefficient use of the signal coordination and loss of any operational benefit. Operations on cross streets may be negatively impacted. Achieving a coordinated system along a corridor may be complicated by signal requirements associated with crossing facilities, any of which may also require signal coordination. Need for long signal cycles associated with multiphase operation and long clearance intervals will dictate the cycle length on which progression will be based. Such a cycle length may produce additional delays on crossing facilities. Furthermore, if there are unsignalized access points that serve substantial entering and exiting traffic volumes along the segments between intersections, this may disrupt the platoon effect of signal coordination. Care should be taken to address effects on gaps produced at unsignalized intersections once coordination is implemented. Site-specific measures may be necessary if adverse operational effects occur or are expected (see the guide on crashes at unsignalized intersections). Coordinating signals for an extended length of highway can involve multiple governmental jurisdictions. There is often disagreement over the benefits or desirability of signal progression, as well as practical issues of developing and maintaining a coordinated signal system. Agreement among the many governmental stakeholders must be achieved in such cases. Along corridors heavily used by fire, ambulance, and other emergency services, implementation of signal preemption for emergency vehicles may be considered (see Strategy 17.2 A5). On some corridors heavily served by bus transit, transit operators are provided in-vehicle traffic signal override capability to enable bus operators to maintain schedule and enhance service. Other corridors may include at-grade rail crossings. In such situations, preemption by emergency vehicles, transit operators, or arrival of trains will break up a platoon and negate the effectiveness of a coordination scheme.
Appropriate Measures and Data	Key process measures include the number of conventional signalized intersections, or length of corridor, for which coordination is implemented. Crash frequency and severity by type of crash are key safety effectiveness measures. It is especially useful to separately analyze crashes by movement or type. Traffic conflicts may be used as a surrogate measure. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to gap acceptance (right-angle crashes involving a vehicle turning left off the main road or permitted RTOR from minor street) and to driver unawareness of signals or signal indications (rear-end crashes) should be analyzed. Traffic volume data are needed to represent exposure. Operational measures are also needed to assess the impact on the subject street and cross streets. Number or percent of vehicles stopped, average speed of progression,

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EXHIBIT V-7 (Continued)
Strategy Attributes for Signal Coordination (P)

Attribute	Description
	and other measures can be derived from use of operational analyses using CORSIM or other traffic operational models. Operational improvement along a corridor may attract vehicles from parallel corridors, potentially offsetting the benefits of coordination in the corridor. However, if the effect on operations in parallel corridors is also evaluated, a more complete understanding of the system benefits would result.
Associated Needs	None identified. However, informing the public that signals are coordinated for safety and operational benefits can be a positive. Some jurisdictions post the speed at which the progression is established, thereby encouraging drivers to maintain that speed.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should review their traffic engineering policies regarding signal coordination to ensure that appropriate action is being taken on projects. Nearly any highway agency can participate in implementing this strategy, which is applicable mainly to urban and suburban areas where signals are typically more closely spaced. Agreement among jurisdictions as to the need for coordination, appropriate operational parameters, and responsibility for signal system upgrades and maintenance need to be addressed.
Issues Affecting Implementation Time	Implementation time for signal coordination is short to moderate. Installation of signals that may otherwise be unwarranted will increase implementation time, due to additional approvals required. The type of signal system to be installed or upgraded will also affect implementation time.
Costs Involved	Costs involved will be low to medium. If a new system is required to control the coordination, costs will be higher and will include design of the system and purchase and installation of new equipment. If existing signals in a coordinated system are spaced far enough apart that platoons begin to disperse, additional intervening signals may prove beneficial in keeping platoons together (refer to MUTCD Signal Warrant 6). This will also increase costs.
Training and Other Personnel Needs	Traffic signal coordination should be addressed in highway agency training concerning intersection operation.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	Traffic signal coordination is compatible with most other strategies to improve signalized intersection safety. Strategy 17.2 A7 discusses removing a signal that is no longer warranted. Consideration may be given to retaining an unwarranted signal to use in a coordinated system.
Other Key Attributes to a Particular Strategy	Traffic signal coordination is generally implemented to improve traffic operations along a major route or in a network and not solely for safety reasons. Other factors to consider include distance between intersections, volume/capacity ratio, and other traffic characteristics.

Strategy 17.2 A5: Employ Emergency Vehicle Preemption (P)

General Description

Signal preemption allows emergency vehicles to disrupt a normal signal cycle in order to proceed through the intersection more quickly and under safer conditions. The preemption systems can extend the green on an emergency vehicle's approach or replace the phases and timing for the whole cycle. The *Manual on Uniform Traffic Control Devices* [MUTCD (Federal Highway Administration, 2000, 2003)] discusses signal preemption, standards for the phases during preemption, and priorities for different vehicle types that might have preemption capabilities.

Providing for emergency vehicle preemption capability at a signal or along a corridor can be a highly effective strategy in two ways. Any type of crash could occur as emergency vehicles try to navigate through intersections and as other vehicles try to maneuver out of the path of the emergency vehicles. In addition, a signal preemption system can decrease emergency vehicle response times therefore decreasing the wait to receive emergency medical attention. Preemption is especially useful where emergency vehicles are likely to have to travel some distance along a corridor. Also, preemption can provide both a safety and operational benefit at signalized intersections on high-speed roadways where emergency vehicles need to enter the intersection from the minor road.

Technologies for detecting emergency vehicles are described briefly in Appendix 5. Many of these systems have applications in transit-vehicle priority as well as signal preemption for emergency vehicles. Some jurisdictions use confirmation lights to inform drivers that emergency vehicles are preempting the signal or signs that inform drivers that a police pursuit is in progress.

EXHIBIT V-8
Strategy Attributes for Employing Emergency Vehicle Signal Preemption (P)

Attribute	Description
Technical Attributes	
Target	The target of this strategy is signalized intersections where normal traffic operations impede emergency vehicles and where traffic conditions create a potential for conflicts between emergency and nonemergency vehicles. These conflicts could lead to almost any type of crash, due to the potential for erratic maneuvers of vehicles moving out of the paths of emergency vehicles.
Expected Effectiveness	Installation of signal preemption systems for emergency vehicles has been shown to decrease response times. A review of signal preemption system deployments in the United States shows decreases in response times between 14 and 50 percent for systems in several cities (Collura et al, 2001). In addition, the study reports a 70-percent decrease in crashes with emergency vehicles in St. Paul, Minnesota, after the system was deployed (though the extent to which emergency vehicle priority was implemented in the city is unclear).
Keys to Success	A key to success is ensuring that the preemption system works when needed by providing clear sight lines between emergency vehicles and detectors. Also, it is important to ensure that vehicles from a variety of jurisdictions will be able to participate in the signal preemption program. The focus of the treatment should be on fire and EMS. Some police agencies have found that since officers respond to incidents from many directions, the preemption system is not as effective for their needs.

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EXHIBIT V-8 (Continued)
Strategy Attributes for Employing Emergency Vehicle Signal Preemption (P)

Attribute	Description
	Another key to success is the coordination of implementation across jurisdictions, including compatibility of equipment and technology, as well as operational policies.
Potential Difficulties	Preempted signals that stop vehicles for too long may encourage disrespect in drivers for the red signal, and they may decide to proceed even though the signal is red.
	Preemption of signals by emergency vehicles will temporarily disrupt traffic flow. Congestion may occur, or worsen, before traffic returns to normal operation. One study of signal preemption systems in the Washington, DC, metropolitan area demonstrated that once a signal was preempted, coordinated systems took anywhere from half a minute to 7 minutes to recover to base-time coordination. During these peak periods in more congested areas, vehicles experienced significant delays. Agency traffic personnel indicated that signal preemption impacts increase as the length of the peak period increases (Collura et al., 2001).
	Light-based detectors need a clear line of sight to the emitter on the vehicles; this line could become blocked by roadway geometry, vehicles, foliage, or precipitation.
	Systems from different vendors may not interact well together. Also, other alarms, such as from nearby buildings, may be erroneously activated by a sound-based system.
Appropriate Measures and Data	Key process measures include the number of intersection approaches for which signal preemption systems are implemented and the number and percent of emergency response vehicles that are equipped.
	A key operational measure of effectiveness is response time of emergency vehicles proceeding through the intersections where signal preemption is implemented. Other operational measures include delay, conflicts en route, and time to return to normal operation along affected streets.
	Frequency and severity of crashes involving emergency vehicles by type of crash are also key safety effectiveness measures. Traffic volume data are needed to represent exposure. These data should be collected before and after installation of the system.
Associated Needs	It is extremely important to coordinate with all surrounding jurisdictions to maximize use of the preemption system chosen.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway and other agencies should ensure that their policies for traffic signals include use of signal preemption systems. A successful program requires the coordinated and cooperative involvement of agencies from engineering, enforcement, emergency medical services, etc. throughout the area. Implementation of a preemption system should be considered as part of programs to upgrade corridor or jurisdictional traffic signal and control systems.
	Highway agencies should review their traffic engineering policies regarding use of emergency vehicle signal preemption to ensure that appropriate action is being taken on individual projects.
	Nearly any agency can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas. In some cases, multijurisdictional programs will be desirable to create an effective system.
Issues Affecting Implementation Time	Implementation time will vary from short to medium based upon the number of intersections and number of agencies involved in the preemption system.

EXHIBIT V-8 (Continued)
Strategy Attributes for Employing Emergency Vehicle Signal Preemption (P)

Attribute	Description
Costs Involved	Costs for installation of a signal preemption system will vary from medium to high, based upon the number of signalized intersections at which preemption will be installed and the number of emergency vehicles to be outfitted with the technology. The number of detectors and the intricacy of the preemption system could increase costs.
Training and Other Personnel Needs	Appropriate signal phasing and timing for periods of preemption control should be addressed in highway agency training concerning traffic signal operations and signal preemption.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	Signal preemption is compatible with most other strategies to improve signalized intersection safety.
Other Key Attributes to a Particular Strategy	None identified.

Information on Agencies or Organizations Currently Implementing This Strategy

The Oregon DOT uses an on-line explanation and form for localities desiring to install signal preemption devices along state highways; see http://www.odot.state.or.us/traffic/signalpre.htm.

Strategy 17.2 A6: Improve Operation of Pedestrian and Bicycle Facilities at Signalized Intersections (Combination of Tried and Proven Strategies)

Nearly one-third of all pedestrian-related crashes occurs at or within 50 feet of an intersection. Of these, 30 percent involve a turning vehicle, whereas another 22 percent involve a pedestrian either running across the intersection or darting in front of a vehicle whose view was blocked just prior to the impact. Another 16 percent of these intersection-related crashes occur because of driver violation (e.g., failure to yield the ROW).

The companion guide for crashes involving pedestrians comprehensively addresses pedestrian safety. The following discussion summarizes key issues relative to pedestrian safety at signalized intersections.

Traffic control improvements that can be made to an intersection to increase pedestrian safety include the following:

- Pedestrian signs, signals, and markings,
- Crossing guards for school children,
- Lights in crosswalks in school zones,
- Pedestrian-only phase or pedestrian-lead phase during signal operation,
- Prohibition of RTOR,

- Public information or signs that educate pedestrians regarding use of push buttons (specifically, that they will not receive the walk signal immediately), and
- Technology to show a push button is working (such as a button that lights up, similar to an elevator).

Providing pedestrian push buttons may facilitate safe pedestrian roadway crossings at signalized intersections (vs. midblock crossings), where pedestrian conflicts with motor vehicles can be managed through use of pedestrian crossing signals and/or exclusive pedestrian-only phases during the signal operation. However, pedestrian push buttons at an intersection are often obscured by roadside furniture or other items. Providing visible signs alerting pedestrians to the presence of push buttons and anticipated wait time for the crossing signal may increase the use of existing pedestrian push buttons.

Several strategies employed in Europe to improve pedestrian safety at signalized intersections are described in Appendix 4.

The AASHTO *Guide for the Development of Bicycle Facilities* (American Association of State Highway and Transportation Officials, 1999) should be consulted for information on bicycle safety. Traffic control improvements that can be made to an intersection to increase safety for bicyclists include the following:

- “Bicyclist Dismount” signs at intersections, and
- Stop and “Bicyclist Dismount” signs at intersections with bike trails.

Additional details are provided in the guides for crashes at unsignalized intersections and for pedestrian crashes.

Strategy 17.1 A7: Remove Unwarranted Signal (P)

General Description

Traffic signals can remedy many safety and operational problems at intersections. However, signals often can adversely affect intersections. It is possible that a signal may no longer be warranted due to changes in traffic conditions. Problems created by an unwarranted signal, such as excessive delay, increased rerouting of traffic to less-appropriate roads and intersections, higher crash rates, and disobedience of the traffic signal can be addressed by removing the signal if doing so would not create worse problems.

Signalized intersections generally experience crashes of different types than unsignalized intersections but not necessarily a lower total crash rate. Converting the intersection to unsignalized may not improve the total crash rate, but it may improve crash severity for some crash types.

Studies should be performed when considering removing a signal, just as installation of a signal is studied. This study should identify the appropriate replacement traffic control devices and any sight distance restrictions that may not have been an issue while under signalized control.

Once the new traffic control has been installed, the signal heads should be set to flash or should be covered for a minimum of 90 days to draw driver, pedestrian, and bicyclist attention to the change in control. After this period, the signal can be removed if the data collected during the study period support removal of the signal. The poles and cables may remain in place, however, for up to a year while additional analysis continues.

EXHIBIT V-9
Strategy Attributes for Removing Unwarranted Traffic Signals (P)

Attribute	Description
Technical Attributes	
Target	This strategy is targeted at signalized intersections where traffic volumes and safety record do not warrant a traffic signal. Signalized intersections tend to have higher rear-end crash rates than unsignalized intersections, and conversion to two-way stop-control or all-way stop-control may reduce the rear-end crash rate.
Expected Effectiveness	Removal of an unwarranted signal will eliminate excessive delay and disobedience of the signal indicators at the targeted intersections if these conditions exist because the signal is no longer needed. Signal removal should also decrease the use of inappropriate routes (e.g., residential streets) used by drivers in an attempt to avoid the traffic control signals and decrease the frequency of collisions (especially rear-end collisions). Two studies have examined the effectiveness of removing traffic signals. Kay et al. (1975) found a decrease in annual average crash frequency of greater than one crash per year when intersections are converted to all-way stop control. Where signals were replaced by two-way stop control intersections, right-angle crashes increased, but rear-end crashes decreased by approximately the same amount. The ITE *Traffic Engineering Handbook* (Pline, 1999) cites two studies that present conflicting results of safety analyses of removed signals: Kay et al. (1975) found that frequency for all crash types did not change after signals were removed and that rates for right-angle crashes increased and rates for rear-end crashes decreased. Another study showed that rates of right-angle and rear-end crashes both decreased. Since there is conflicting evidence on the safety benefits of signal removal, each intersection for which signal removal is considered should be analyzed separately, and other conditions at the intersections (specifically, geometry, sight distance and traffic conditions) should be carefully considered as well.
Keys to Success	Keys to success include determining the appropriate traffic control to be used after the removal of the signal and removing any sight-distance restrictions through the intersection. Pedestrian and bicycle movements through the intersections should be considered when determining traffic control, geometric changes, and signing improvements that will be made when the signal is removed. Intersection sight distance may not be required where signals are present. If a signal is to be removed, care should be taken to ensure that adequate intersection sight distance is provided and that necessary improvements to sight distance, such as clearing sight triangles, should accompany the signal removal. Keeping the public informed about the traffic control removal study will also lead to the success of this strategy.
Potential Difficulties	Right-angle crashes may increase after the signal is removed. Removal of the traffic signals could delay the flow of pedestrians and bicyclists through the intersection. Confusion to drivers regarding ROW and disorderly movement through the intersection may also result if sufficient PI&E is not provided regarding the change in traffic control.

(*continued on next page*)

EXHIBIT V-9 (Continued)
Strategy Attributes for Removing Unwarranted Traffic Signals (P)

Attribute	Description
Appropriate Measures and Data	A key measure of the implementation process is the number of intersections where signals are removed. Another measure is the volume of conflicting flows that are affected by removal. Crash frequency and severity by type of crash are also key safety effectiveness measures. It is especially useful to separately analyze crashes by movement or type. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes that may be related to the traffic control (right angle, rear end) should be analyzed. Traffic volume data are needed to represent exposure.
Associated Needs	The public should be informed when a study is underway for the removal of a traffic signal at each intersection. PI&E is a key element of a project to remove a signal, to help ensure that driver expectancy is not violated.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should review their traffic engineering and design policies regarding the removal of traffic signals to ensure that appropriate action is being taken. Policy guidance regarding the removal of traffic signals is discussed in the MUTCD. The MUTCD should be consulted if agency policy has not incorporated the information from the MUTCD. Nearly any highway agency can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas.
Issues Affecting Implementation Time	Implementation time can vary, depending upon the extent and nature of the public involvement.
Cost Involved	Since implementation of this strategy requires the removal of traffic signals and replacing them with signs, its cost would be low. Costs would be attributed to the equipment needed for signal removal and temporary traffic control while implementing the new traffic control method (usually signs).
Training and Other Personnel Needs	Traffic signal warrants should be addressed in highway agency training regarding traffic control devices, along with guidelines for recognizing the appropriateness of removing a signal.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	Removal of traffic signals is typically done when studies show that traffic patterns have changed significantly. This strategy is not usually associated with any other strategies.
Other Key Attributes to a Particular Strategy	None identified.

Objective 17.2 B—Reduce Frequency and Severity of Intersection Conflicts through Geometric Improvements

Geometric improvements can provide both operational and safety benefits at signalized intersections. Improvements to turning movements, through channelization or even physically preventing turns, can result in reductions in certain types of crashes. Geometric changes can also improve safety for pedestrians and bicyclists. Higher-cost, longer-term improvements, such as redesign of the intersection, can also improve safety and are briefly discussed in this section.

Strategy 17.2 B1: Provide or Improve Left-Turn Channelization (Combination of Tried and Proven Strategies)

General Description

This strategy includes the following:

- Providing left-turn lanes,
- Lengthening left-turn lanes,
- Providing positive offset for left-turn lanes,
- Providing positive guidance with channelization, and
- Delineating turn path.

Many intersection safety problems can be traced to difficulties in accommodating left-turning vehicles. A key strategy for minimizing collisions related to left-turning vehicles (angle, rear-end, sideswipe) is to provide exclusive left-turn lanes, particularly on high-volume and high-speed major-road approaches. Left-turn lanes allow separation of left-turn and through-traffic streams, thus reducing the potential for rear-end collisions. Because they provide a sheltered location for drivers to wait for a gap in opposing traffic, left-turn lanes may encourage drivers to be more selective in choosing a gap to complete the left-turn maneuver. This may reduce the potential for collisions between left-turn and opposing through vehicles. Provision of a left-turn lane also provides additional flexibility in designing a phasing plan.

Installation, lengthening, and offsetting of left-turn lanes are discussed in further detail in the guide for crashes at unsignalized intersections.

Install Left-Turn Lane. Left-turn lanes are a proven treatment for addressing safety problems associated with left-turning vehicles. By removing left-turning vehicles from the through-traffic stream, conflicts with through vehicles traveling in the same direction can be reduced (and even eliminated, depending on the signal timing and phasing scheme [see Strategy 17.2 A1]). Drivers wait in the turn lane until there is a gap in opposing traffic through which they can turn, which helps reduce the conflicts with the opposing through traffic.

The design of the left-turn lane is crucial to its effectiveness as either a safety or operational improvement strategy. In providing left-turn lanes, vehicles in opposing left-turn lanes may block the respective driver’s view of approaching vehicles in the through lanes. This potential problem can be resolved by offsetting the left-turn lanes (see below).

See Appendix 6 for further considerations for installing left-turn lanes.

Improve Left-Turn Lane Geometry. Safety improvements can also be made to approaches that already incorporate separate left-turn lanes. Three treatments are discussed below: lengthening of the left-turn lane, redesigning to provide positive visual offset, and delineating the turning path.

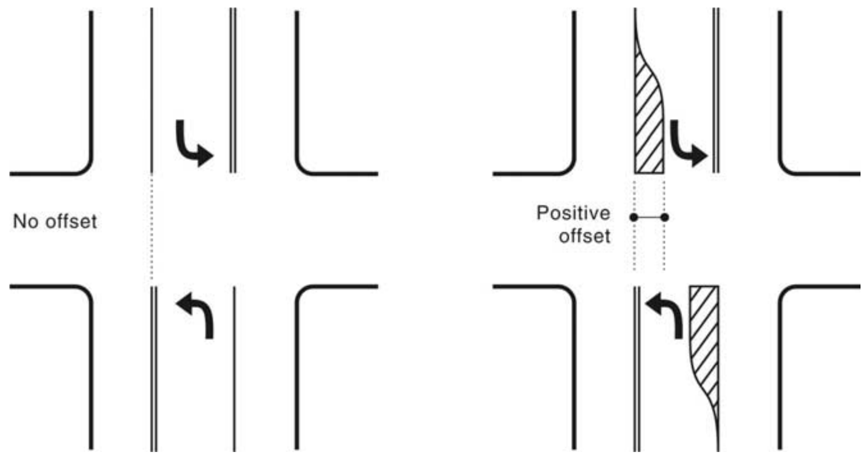
Lengthen Left-Turn Lane. The length of a left-turn lane consists of three components: entering taper, deceleration length, and storage length. The left-turn lane length should allow for the removal of slow or decelerating vehicles from through traffic, thus reducing the potential for rear-end collisions. A turn lane long enough to accommodate deceleration can have safety benefits for higher-speed intersections such as are typically found in rural highways. The turn lane should be of adequate length to store vehicles waiting to turn left without the queue overflowing into the adjacent through lane. If a left-turn queue extends into the adjacent through lane, through vehicles will be forced to stop or, if there are multiple through lanes, change lanes. These maneuvers can lead to rear-end and sideswipe crashes. Also, if access to a left-turn lane is blocked by a queue of through vehicles at a signal, the left-turners may drive into the opposing lane to reach the left-turn lane. This could lead to head-on crashes.

Design criteria for selecting an appropriate left-turn lane length are presented in the AASHTO *Policy on Geometric Design for Highways and Streets* (American Association of State Highway and Transportation Officials, 2001), the TRB *Highway Capacity Manual* (2000), *NCHRP Report 279* (Neuman, 1985), and the policies of individual highway agencies. *NCHRP Report 457* (Bonneson and Fontaine, 2001) also includes guidance on determining left-turn length depending on volume and traffic control. A detailed analysis of traffic conditions should be performed to ensure that a left-turn lane is of a length appropriate for the given traffic.

Provide Positive Offset for Left-Turn Lanes. A potential for conflict exists when vehicles in opposing turn lanes on the major road block the drivers' views of approaching traffic. A left-turning driver's view of opposing through traffic may be blocked by left-turning vehicles on the opposite approach. When left-turning traffic has a permissive green signal phase, this can lead to collisions between vehicles turning left from the major road and through vehicles on the opposing major-road approach. To reduce the potential for crashes of this type, the left-turn lanes can be offset by moving them laterally, so that vehicles in opposing lanes no longer obstruct the opposing driver (See Exhibit V-10). This helps improve safety and operations of the left-turn movement by improving driver acceptance of gaps in opposing through traffic. This is especially true for older drivers who have difficulty judging gaps in front of oncoming vehicles. Note that the effectiveness of this strategy is greatest where signal operations include permissive signal phasing or permissive/protected phasing for left-turning movements. (See Strategy 17.2 A1).

AASHTO's *Policy* recommends that medians wider than 18 feet should have offset left-turn lanes. One method for laterally shifting left-turning vehicles is to narrow the turn lane width using pavement markings. This is accomplished by painting a wider stripe at the right side of the left-turn lane, which causes left-turning vehicles to position themselves closer to the median. Wider lane lines were implemented at six intersections in Nebraska with good results. The width of these lines ranged from 0.5 feet to 3 feet. The wider the left-turn lane line used to offset vehicles, the greater the effect on improving sight distance. (McCoy et al., 1999).

EXHIBIT V-10
Positive Offset of Left-Turn Lanes
Source: Federal Highway Administration, in press.



Delineate Turn Path. Even at signalized intersections, where the traffic signals help to eliminate confusion about ROW, driver confusion can exist in regard to choosing the proper turn path. This is especially relevant at intersections where multiple left-turn lanes are provided, the overall pavement area of the intersection is large, or other unfamiliar elements are presented to the driver. Delineation of turn paths (see Exhibit V-11) is especially useful to drivers making simultaneous opposing left turns, as well as some cases involving drivers

EXHIBIT V-11
Delineation of Turn Paths for Double Left-Turn Lanes
Source: Federal Highway Administration, in press.

turning right for which a clear path is not readily apparent. This strategy is also appropriate for application where the roadway alignment may be confusing or unusual, such as a deviation in the path for through vehicles. Providing positive guidance to the driver in the form of pavement markings can help eliminate driver confusion and eliminate vehicle conflict by "channeling" vehicles in their proper path.

EXHIBIT V-12
Strategy Attributes for Providing or Improving Left-Turn Channelization (P, T)

Attribute	Description
Technical Attributes	
Target	This strategy targets intersections where crashes related to left-turn movements are an issue. Crash types that could be reduced by providing or improving left-turn channelization include angle, sideswipe (both same and opposite direction), rear-end, and head-on crashes.
Expected Effectiveness	Recent research has demonstrated the substantive safety effect of providing left-turn lanes. The safety effectiveness varies with the location (rural vs. urban), number of legs, type of traffic control, and number of approaches for which the lane is installed. Exhibit V-12A (rural) and Exhibit V-12B (urban) below provide the best estimates of the relative effectiveness of left-turn lanes (Harwood et al., 2002). The full report should be consulted, since the accident modification factors (AMFs) are to be applied to a base model that is provided therein. Also, there are a variety of effectiveness estimates made for varying types of crashes and left-turn lane treatments.

EXHIBIT V-12A
Recommended Accident Modification Factors for Installation of Left-Turn Lanes on the Major-Road Approaches to Rural Intersections

Intersection Type	Intersection Traffic Control	Number of Major-Road Approaches on Which Left-Turn Lanes Are Installed	
		One Approach	Both Approaches
Three-leg	Stop sign[a]	0.56	—
	Traffic signal	0.85	—
Four-leg	Stop sign[a]	0.72	0.52
	Traffic signal	0.82	0.67

[a] On minor-road approach(es).

EXHIBIT V-12B
Recommended Accident Modification Factors for Installation of Left-Turn Lanes on the Major-Road Approaches to Urban Intersections

Intersection Type	Intersection Traffic Control	Number of Major-Road Approaches on Which Left-Turn Lanes Are Installed	
		One Approach	Both Approaches
Three-leg	Stop sign[a]	0.67	—
	Traffic signal	0.93	—
Four-leg	Stop sign[a]	0.73	0.53
	Traffic signal	0.90	0.81

[a] On minor-road approach(es).

EXHIBIT V-12 (Continued)
Strategy Attributes for Providing or Improving Left-Turn Channelization (P, T)

Attribute	Description
	The safety effectiveness of providing a positive offset between opposing left-turn lanes has not been quantitatively demonstrated. The positive offset increases visibility of the sight lines, enabling drivers to perceive safe gaps when operating as permissive movements at signalized intersections. Harwood et al. (2002) report some findings related to the use of painted vs. curbed channelization of left-turn lanes. Delineation of turn paths is expected to improve intersection safety, though the quantitative effectiveness of this treatment has not been proven. The additional guidance in the intersection will help separate vehicles making opposing left turns, as well as vehicles turning in adjacent turn lanes.
Keys to Success	Keys to success in implementing left-turn lanes include the appropriate design of all elements (length, width of lane, tapers). Re-striping of available width, including use of all or part of a shoulder or parking lane, can be an effective low-cost way to implement this strategy. The operational effects, on adjacent approaches, of re-striping or redesign should be addressed. Another key to success with left-turn lanes is to incorporate other safety-effective strategies, such as protected-only signal phasing. The key to success in using pavement delineators is to make sure that the pavement markings are visible to, and understandable by, the driver. Delineators should be used as guidance devices, rather than warning devices. It is important to maintain the markings so that they retain their value. Placement of pavement delineators should be based on prevailing speeds, block lengths, distance from intersections, and other factors influencing communication with the driver.
Potential Difficulties	Potential difficulties in providing left-turn lanes where they currently do not exist are the cost and acquisition of space required for the additional lane and the need to relocate the signal heads and hardware. As noted above, use of shoulders and/or parking lanes may be considered, but potential adverse safety concerns, such as lack of a shoulder for emergency stops, should be addressed. In addition, it will be important to address concerns from business owners or other stakeholders concerned about loss of parking. Difficulties may arise due to the need to coordinate design changes with adjacent intersections, as well as accounting for possible operational effects on adjacent intersections. The addition of left-turn lanes may have other adverse effects that should be addressed. Most notably, the greater pavement width and exposure to traffic for pedestrians (including potentially the loss of median protection for pedestrians) represents a risk. Decreased visibility of required pavement delineators can be caused by degraded retroreflectivity during night and/or adverse weather conditions. Rain during the daytime reduces the driver's ability to see the surrounding area. At night, headlight glare from oncoming vehicles, movement of the windshield wiper, slippery pavement surface, and degraded retroreflectivity all add to the decreased visibility of pavement markings. Snow covers pavement markings, and the use of snowplows and chemical and deicing agents affect the durability of the pavement markings.
Appropriate Measures and Data	Key process measures include the number of intersections at which left-turn lanes are implemented and/or improved, the total number and type of left-turn lanes installed, and the number of potential conflicts affected by the improvement.

(*continued on next page*)

EXHIBIT V-12 (Continued)
Strategy Attributes for Providing or Improving Left-Turn Channelization (P, T)

Attribute	Description
	Crash frequency and severity by type of crash are key safety-effectiveness measures. It is important to identify crashes related to the targeted movement and to analyze them separately. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to the targeted maneuvers at the intersection should be analyzed separately. Traffic volume data are needed to represent exposure. It is especially desirable to obtain data on the volume of vehicles using the intersection, turning volumes, and the conflicting volumes. Driver behavior measures may be used as surrogates (e.g., vehicle paths, actual vehicle conflicts, erratic maneuvers).
Associated Needs	Many highway agencies have shifted their focus from constructing new roadways to improvement of existing facilities. The challenge for highway, traffic, and safety engineers is to develop techniques that will result in the decrease of accidents, delays, and other inconveniences on existing facilities. Maintenance of pavement markings is one aspect of this. Development of a roadway delineation management system is a way to track conditions of pavement markings.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway and other agencies should ensure that their design polices for new or reconstructed intersections incorporate consideration of all aspects of left-turn lane design and operation delineation. Highway agencies should review their policies for left-turn warrants and design to consider explicit safety considerations as well as capacity and traffic operational considerations. Highway agencies may also wish to revise their standard intersection design details to accommodate offset left-turn lane treatments as their standard approach. Highway agencies should also review the MUTCD, in addition to their traffic engineering and design policies, regarding use of delineators on routine projects.
Issues Affecting Implementation Time	Improving or implementing left-turn lane treatments can range widely in time. Where no changes to existing pavement or no new construction is needed, implementation can take only weeks or months (including engineering studies). Where redesign or re-striping of approaches is performed, time may be longer (6 months or more) depending on the need to reposition or change the location of traffic signal heads or other hardware. Also, gaining acceptance from stakeholders for removal of parking or other actions may require time. Implementation time of applying pavement delineators is relatively quick (1 to 2 days).
Costs Involved	Costs of implementing or improving the design of left-turn lanes can vary. Where reallocation of available width by re-striping is all that is needed, the cost can be relatively low. Where redesign and widening or other construction is necessary, costs will be moderate. Costs may include upgrading and/or relocation of traffic signals and other hardware. Left-turn lane improvements that require ROW acquisition or major reconstruction can be high-cost projects. The cost of delineators is variable and determined largely by the material used for pavement markings (paint, thermoplastic, epoxy, etc.). When using delineators, an issue of concern is the cost-to-service-life of the material. Predicting how long pavement delineators will last is difficult due to the variable factors influencing service life (weather and amount and type of traffic). Materials with a short service life are not

EXHIBIT V-12 (Continued)
Strategy Attributes for Providing or Improving Left-Turn Channelization (P, T)

Attribute	Description
	desirable, due to the frequent disruption of traffic and threat to worker safety needed to re-mark the pavement.
Training and Other Personnel Needs	Revisions to standard intersection designs such as offset left-turn lanes may require some training of agency engineering personnel.
	Instituting and following a roadway delineation management system will require training. Personnel will require training to apply, inspect, and maintain pavement delineators.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with the other strategies for improving safety at signalized and unsignalized intersections. In particular, optimum results from improving or adding left-turn lanes may result by combining it with signalization strategies such as protected phasing and improved clearance intervals.
Other Key Attributes to a Particular Strategy	None identified.

Strategy 17.2 B2: Provide or Improve Right-Turn Channelization (P)

This strategy includes providing right-turn lanes and lengthening right-turn lanes.

General Description

Many collisions at signalized intersections are related to right-turn maneuvers. A key strategy for minimizing such collisions is to provide exclusive right-turn lanes. It is also important to ensure that the right-turn lanes are of sufficient length to allow vehicles to decelerate before turning, ideally without affecting the flow of through traffic. Right-turn lanes remove slow vehicles that are decelerating to turn right from the through-traffic stream, thus reducing the potential for rear-end collisions.

Provide Right-Turn Lanes. The provision of right-turn lanes can minimize collisions between vehicles turning right and following vehicles, particularly on high-volume and high-speed major roads. A right-turn lane may be appropriate in situations where there are an unusually high number of rear-end collisions on a particular approach. Installation of a right-turn lane on one major road approach at a signalized intersection is expected to reduce total crashes according to the AMFs in Exhibit V-13 (Harwood et al., 2002).

The benefits of a right-turn lane are not provided just by the presence of the lane but also by the specific design. Key design issues addressed in design guides include entering taper, deceleration length, and storage length. Design criteria for selecting an appropriate right-turn lane length are presented in both the AASHTO *Policy on Geometric Design for Highways and Streets* and the FHWA'S 2003 MUTCD, as well as in the policies of individual highway agencies. Through drivers may enter an excessively long right-turn lane by mistake, without realizing it is a turn lane. Upstream signing and marking of the turn lane may address this.

EXHIBIT V-13
Recommended Accident Modification Factors for Installation of Right-Turn Lanes on the Major-Road Approaches to Rural and Urban Intersections

	Number of Major-Road Approaches on Which Left-Turn Lanes Are Installed	
Intersection Traffic Control	**One Approach**	**Both Approaches**
Stop sign[a]	0.86	0.74
Traffic signal	0.96	0.92

[a] On minor-road approach(es).

It is possible that installation of a right-turn lane could create other safety or operational problems at the intersection. For example, vehicles in the right-turn lane may block the cross street right-turning drivers' view of through traffic; this would be a significant issue where RTOR are permitted on the cross street. If a right shoulder is re-striped to provide a turn lane, there may be an adverse effect on safety due to the decrease in distance to roadside objects. Delineation of the turn lane also should be carefully considered, so that adequate guidance is provided through the intersection. A channelized right-turn roadway may be desirable in some locations. Channelization of the right turn with a raised or painted island can provide larger turning radii and also an area for pedestrian refuge. Details on the design of channelizing islands for turning roadways can be found in the AASHTO *Policy on Geometric Design for Highways and Streets.*

Channelizing islands can be raised or flush with the pavement. A Georgia study evaluated the effects of right-turn channelization in the form of painted islands, small raised islands, and large raised islands. Results from the study show that traffic islands appear to reduce the number of right-turn angle crashes and that the addition of an exclusive turn lane appears to correspond to an increased number of sideswipe crashes given the introduction of a lane change (Dixon et al., 1999). Harwood et al. (2002) report some potentially significant differences in the safety performance of painted versus curbed channelization.

Visibility of channelizing islands is very important. Islands can be difficult for drivers to see, especially at night and in inclement weather. This is particularly true for older drivers. Raised islands have been found to be more effective than flush painted islands at reducing nighttime collisions, since they are more easily seen.

Older drivers in particular benefit from channelization as it provides a better indication of the proper use of travel lanes at intersections. However, older drivers find that making a right turn without the benefit of an acceleration lane on the crossing street is particularly difficult (Staplin et al., 1998).

Right-turn roadways can reduce the safety of pedestrian crossings. Crossing distances are increased, as is pedestrian exposure to traffic. Elderly and mobility-impaired pedestrians may have difficulty crossing intersections with large corner radii. Right-turn channelization also makes it more difficult for pedestrians to cross the intersection safely, adequately see oncoming traffic that is turning right, and know where to cross. Proper delineation of the turning roadway may help, particularly at night.

Where curbed islands are provided, they offer a refuge for pedestrians. Where it is known that channelization islands are being used by pedestrians, crossing paths should be clearly delineated, and the island itself should be made as visible as possible to passing motorists.

Removal of small right-turn triangular channelizing islands may be an appropriate method for improving right-turn channelization. Often, these islands were installed in urban areas as a location to place a signal pole. Right-turning drivers may not see this island when approaching the intersection and may stop suddenly, increasing the potential for rear-end collisions. Removal of this island may be appropriate, especially if the road becomes less urban in nature. The city of Winston-Salem, North Carolina, has removed such triangular islands in an attempt to reduce rear-end collisions related to right turns. To provide positive guidance through the turn, the city installed flexible delineators along the gore stripe. The "after" study has not been completed, but it does appear right-turn rear-end crashes are becoming less common.

Other issues to consider when designing a right-turn lane include provision of clear sight triangles, increased crossing distance for pedestrians, potential conflicts between turning vehicles and cyclists proceeding through the intersection, and the potential need to move the stop bar on the cross street. Transit stops may also need to be moved from the near side to the far side of an intersection due to possible conflicts between through buses and right-turning vehicles.

Lengthen Right-Turn Lanes. Lengthening a right-turn lane can help improve operations and safety by providing additional sheltered space for vehicles to decelerate or wait to turn. If the length of a right-turn lane is inadequate, vehicles waiting to turn may be doing so from the through-traffic stream, thus increasing the potential for rear-end collisions. Providing longer entering tapers and deceleration lengths can reduce the potential for rear-enders. Also, if access to a right-turn lane is blocked by a queue of through vehicles at a signal, the right-turners may block the movement of through traffic, if the two movements operate on separate or split phases. This could lead to unsafe lane changes and added delay.

The length of a right-turn lane consists of three components: entering taper, deceleration length, and storage length. Design criteria for selecting an appropriate right-turn lane length are presented in both the AASHTO *Policy on Geometric Design for Highways and Streets* and the TRB *Highway Capacity Manual*, as well as in the policies of individual highway agencies. A detailed analysis of traffic conditions should be performed to ensure that a right-turn lane is of proper length.

Improvements to right-turn lanes are discussed in greater detail in the Unsignalized Intersection guide.

Strategy 17.2 B3: Improve Geometry of Pedestrian and Bicycle Facilities (Combination of Tried and Proven Strategies)

The mix of travel modes at intersections, along with the vehicle-vehicle conflicts possible, can create safety and operational concerns for nonmotorists. A variety of relatively low-cost treatments can be implemented to help pedestrians and bicyclists proceed through the intersection more safely and more efficiently. Multivehicle crashes (specifically rear-ends) can be reduced if pedestrians are more visible and more drivers expect to encounter them.

Geometric or physical improvements that can be made to an intersection to increase pedestrian safety include the provision of the following:

- Continuous sidewalks,
- Signed and marked crosswalks,
- Sidewalk set-backs,
- Median refuge areas,
- Pedestrian overpasses,
- Intersection lighting,
- Physical barriers to restrict pedestrian crossing maneuvers at higher-risk locations,
- Relocation of transit stops from the near side to the far side of the intersection, and
- Other traffic calming applications to reduce vehicle speeds or traffic volumes on intersection approaches.

Improvements to pedestrian facilities are discussed in greater detail in the guide for crashes involving pedestrians. Several strategies used by European countries to improve pedestrian safety at signalized intersections are described in Appendix 4.

Some of the problems facing bicyclists at intersections include high traffic volumes and speeds as well as the lack of space for bikes. Possible improvement projects include the following:

- Widening outside through lanes (or adding bike lanes),
- Providing median refuge areas,
- Providing independent crossing structures,
- Upgrading storm drain grates with bicycle-safe designs, and
- Implementing lighting.

Additional improvements for bicyclists are listed in the guide for crashes occurring at unsignalized intersections.

Strategy 17.2 B4: Revise Geometry of Complex Intersections (Combination of Tried and Proven Strategies)

This strategy includes a series of mostly higher-cost solutions:

- Converting a four-leg intersection to two T intersections,
- Converting two T intersections to one four-leg intersection,
- Improving intersection skew angle, and
- Improving deflection in the through-vehicle travel path.

A fifth solution, closing an intersection leg, is one commonly tried when addressing the problem of complex intersections. This can be a low-cost solution because it does not typically require major reconstruction. A detailed description of this strategy follows.

General Description

Some geometric problems with signalized intersections will not be remedied using signing, channelization, or signal phasing. Physical modifications to all or part of an intersection may be needed to reduce severe crash rates. There may be multiple problems associated with one or more movements at the intersection that can be best addressed with significant improvements to intersection design. Because of the extensive reconstruction required to implement these strategies, they will not be appropriate for agency programs designed for quick low-cost action.

Convert a Four-Leg Intersection to Two T Intersections. (T) For some signalized four-leg intersections with very low through volumes on the cross street, the best method of improving safety may be to convert the intersection to two T intersections. This strategy should help reduce crashes related to the intersection layout, such as angle crashes involving left-turning vehicles in which drivers are not expecting to encounter one of the infrequent through-vehicles. This conversion to two T intersections can be accomplished by realigning the two cross-street approaches an appreciable distance along the major road, thus creating separate intersections that operate relatively independently of one another. The intersections should be separated enough to ensure the provision of adequate turn-lane channelization on the major road.

If through volumes are high, the intersection may be safer if left as a conventional four-leg intersection. Converting it to two T intersections would only create excessive turning movements at each of the T intersections.

In a study conducted by Hanna et al., (1976) offset intersections had accident rates that were approximately 43 percent of the accident rate at comparable four-leg intersections. Thus, it is expected that this strategy would reduce the accident experience of targeted four-leg intersections.

Convert Two T Intersections to One Four-Leg Intersection. (T) For some signalized offset T intersections with very high through volumes on the cross street, the best method for improving safety may be to convert the intersection to a single four-leg intersection. This can be accomplished by realigning the two cross-street approaches to meet at a single point along the major road. It is expected that this strategy would reduce accidents involving left-turning traffic from the major road onto the cross street at each of the two T intersections.

Improve Intersection Skew Angle. (P) Roads that intersect with each other at angles less than 90 degrees can present sight distance and operational problems for drivers. A high incidence of right-angle accidents, particularly involving vehicles approaching from the acute angle, may be the result of a problem associated with skew. Vehicles have a longer distance to travel through the intersection (increasing their exposure to conflicts), and drivers may find it difficult to turn their head and neck to view an approach on an acute angle. Furthermore, vehicles turning right at an acute angle may encroach on the lane for vehicles approaching from the opposite direction. When RTOR are permitted, drivers may have more difficulty judging gaps when turning. Also, crossing distances for pedestrians are increased.

Skewed intersections (with the angle of intersection less than 75 degrees) pose particular problems for older drivers, as many older drivers experience a decline in head and neck mobility. A restricted range of motion reduces the older driver's ability to effectively scan to the rear and sides of their vehicle to observe blind spots. They may also have trouble identifying gaps in traffic when making a left turn or safely merging with traffic when making a right turn. More information on converting a four-leg intersection to two T intersections, or vice versa, and eliminating intersection skew is contained in the guide for crashes occurring at unsignalized intersections.

Remove Deflection in Through-Vehicle Travel Path. (T) Intersections with substantial deflections between approach alignments can produce operational and safety problems for through-vehicles as they navigate through an intersection (see Exhibit V-14). Forced path changes for through-vehicles violate driver expectations and may be difficult for unfamiliar drivers to navigate. Violation of driver expectancy can result in reduced speed of the vehicle through the intersection. Crashes influenced by a deflection in travel path are likely to include rear-end, sideswipe, head-on, and angle. Acceptable deflection angles through intersections vary by individual agency, but are typically related to the design and/or posted speed on an intersection approach. Typical maximum deflection angles are 3 to 5 degrees.

Pavement markings can be a low-cost solution to guide through vehicles through the intersection. Dashed lines similar to those used to delineate left-turn paths are appropriate for delineation of the through path.

Redesign of an intersection approach is a relatively high-cost solution. Proper design of an intersection involves providing traffic lanes that are clearly visible to drivers at all times, clearly understandable for any desired direction of travel, free from the potential for conflicts to appear suddenly, and consistent in design with the portions of the highway approaching the intersection. The sight distance should be equal to, or greater than, minimum values for interchange conditions.

EXHIBIT V-14
Deflection in through-Vehicle Travel Path through Intersection
Source: Federal Highway Administration, in press.

Close Intersection Leg. (T) For some signalized intersections with crash histories, the best method for improving safety may be to close access to a leg of the intersection. This is a radical approach to safety improvement that should generally be considered only when less restrictive measures have been tried and have failed. Closure of access to an intersection leg can be accomplished by closing and abandoning a minor approach using channelizing devices or by reconstructing the minor approach so that it dead-ends before reaching the intersection with the major street. An alternative to closing the entire intersection leg is to convert the leg to a one-way street that departs the intersection. Though it is a significant modification to an intersection, it can be a low-cost treatment. A major consideration in deciding to implement this strategy is the impact closure will have on traffic patterns and volumes at other locations. This treatment may be most applicable to those intersections with more than four legs.

EXHIBIT V-15
Strategy Attributes for Revising Geometry of Complex Intersections—Closing Access to an Intersection Leg (T)

Attribute	Description
Technical Attributes	
Target	The target of this strategy should be signalized intersections with high levels of crashes on a leg where other strategies have not been successful or are not considered appropriate. Any crash type could be targeted by this strategy, since reasons for closing an intersection leg can vary.
Expected Effectiveness	Closure of an intersection leg would be expected to eliminate crashes related to that leg. Determination of the effectiveness is site specific, due to the varying conditions at intersections where leg closure might be considered. In addition, consideration must be given to the adjacent intersections, to alternative routes onto which traffic would be diverted, and to the potential impact to safety on those routes. Where properly applied, a net safety benefit can be expected.
Keys to Success	The key to success for a project of this type is conducting an adequate system traffic study to ensure that the safety and other operational problems are not merely transferred from the intersection being treated to other locations. Such a study should involve representatives from the affected neighborhood, businesses, and road. Their input should be sought early in the decision-making process and maintained through implementation of the agreed-upon plan.
Potential Difficulties	Diverted traffic may contribute to safety or operational problems at adjacent intersections or on alternative routes, resulting in no net benefit. Owners of properties where access would be reduced, especially commercial operations, may oppose this strategy. Care should be taken during the transition period, both before and after the intersection leg is closed, to alert drivers to the changes as they approach the section involved. Another potential difficulty is in loss of local access for emergency vehicles on the approach being closed. Design solutions may need to be considered, including

(*continued on next page*)

EXHIBIT V-15 (Continued)
Strategy Attributes for Revising Geometry of Complex Intersections—Closing Access to an Intersection Leg (T)

Attribute	Description
	mountable curbs as well as vegetation or other barriers that can be driven through or over in an emergency.
Appropriate Measures and Data	Key process measures include the number of intersections with legs closed and the change in the number of conflicts due to closure. The latter may also be used as a surrogate safety measure. Crash frequency and severity by type are key safety effectiveness measures. Separate analysis of crashes targeted by such intersection relocations is desirable. Where issues of potential effect on commercial operations exist, economic impact measures may be needed that reflect the change in sales or other measures of economic activity. Crash frequency and severity data are needed for the existing intersection and the intersection with the closed leg. Traffic volume data are needed to represent exposure. In some cases, sales and other economic data may be needed to assess impacts on commercial operations whose access is affected. Net change in conflicts may be used as a surrogate measure of safety until adequate crash data are available.
Associated Needs	PI&E is central to successful use of this strategy.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agency policies concerning geometric design of intersections should address the appropriate application and potential benefits of closure of intersection legs. Nearly any highway agency can participate in the implementation of this strategy. While the strategy is applicable to both rural and urban locations, the most likely use of this strategy will be by agencies that operate extensive systems of urban and suburban arterials. In some cases, public transit service may be affected by the closure. Therefore, care must be taken to establish communication and participation among all public agencies potentially affected.
Issues Affecting Implementation Time	This strategy will likely require an implementation time of at least 1 year to provide time to work out the details of street closure and to communicate the plan to affected businesses and residents.
Costs Involved	Costs to implement this strategy are highly variable. Where mere closure of an intersection leg is all that is needed, costs are low, especially if the closure will be implemented with barricades or other low-cost devices. In other cases, modifications to the closed street and improvements required due to diversion of traffic to a different intersection (such as signing, improved signal timing at nearby intersections, etc.) may require substantially higher expenditures.
Training and Other Personnel Needs	Use of this technique should be included in training concerning geometric design and traffic control issues.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	Closure of an intersection leg is compatible with most strategies for improving signalized intersection safety.
Other Key Attributes to a Particular Strategy	This strategy is primarily appropriate for urban and suburban intersections where reasonable alternative access or routes are readily available.

Strategy 17.2 B5: Construct Special Solutions (T)

This strategy includes the following:

- Providing indirect left turn,
- Reconstructing intersections, converting intersections to roundabouts,
- Convert two-way streets to a one-way pair, and
- Constructing interchanges.

General Description

Signalized intersections may have such a significant crash problem that the only alternative is to change the nature of the intersection itself. These types of projects will be high cost and require substantial time for implementation. As such, they will generally not be applicable for agency programs focusing on low-cost, short-term solutions. Note that implementing these strategies will also necessitate significant public involvement and stakeholder activity. Nonetheless, these strategies are outlined here to provide a complete picture of the range of solutions to signalized intersection safety.

Provide Indirect Left Turn. As traffic growth on arterial roadways continues to result in congestion and safety problems at major (high-volume) at-grade intersections, indirect left-turn designs are increasingly being considered and constructed. A few indirect left-turn designs are relatively common to some areas, while many involve rather innovative solutions. These projects may result in major reconstruction of an intersection or conversion to interchanges. ROW restrictions are commonly a determining factor when choosing an alternative. A longer-term, higher-cost design may be the best solution to severe operational and/or safety problems at an intersection.

EXHIBIT V-16
Jughandle Intersection
Source: Federal Highway Administration, in press.

Safety problems associated with left-turns at signalized intersections are magnified at high-volume intersections—or, at least, intersections with high volumes of left turns. Indirect left-turn treatments, such as jughandles before the crossroad, directional median crossovers, and loop roadways beyond the crossroad, can address both safety and operational problems related to left turns. These treatments remove the left-turning vehicles from the traffic stream without causing them to slow down or stop in a through-traffic lane, thereby reducing the potential for rear-end crashes with through vehicles. Right-angle crashes are also likely to decrease after indirect left-turn treatments are implemented, since the turning movement is relocated or changed to a different maneuver. Such treatments are effective on divided highways with medians too narrow to accommodate left-turn lanes and on approaches without enough room for a turn lane long enough to provide sufficient storage capacity. In some cases, it is possible to implement indirect left turns using appropriate signing. However for other designs, implementation costs could be quite high, and the time required to implement could be quite lengthy. If ROW must be acquired, care should be taken to ensure that safety problems are not transferred to nearby intersections if drivers choose alternative routes, such as in cases where less convenient turn arrangements result. Clear signing is a necessity for indirect left-turn designs, especially if there are not similar treatments at other intersections in an area.

This strategy should reduce rear-end collisions resulting from the conflict between vehicles waiting to turn left and following vehicles as well as right-angle collisions resulting from the conflict between vehicles turning left and oncoming through-vehicles.

Alternative left-turn designs are discussed in various publications and will be included in the forthcoming FHWA *Signalized Intersection Guide*. One option is to convert the intersection to a roundabout (see next substrategy), and various other options for alternative left-turn designs that may be considered are shown in Exhibit V-17 through Exhibit V-21.

EXHIBIT V-17
Median U-Turn Crossover
Source: Federal Highway Administration, in press.

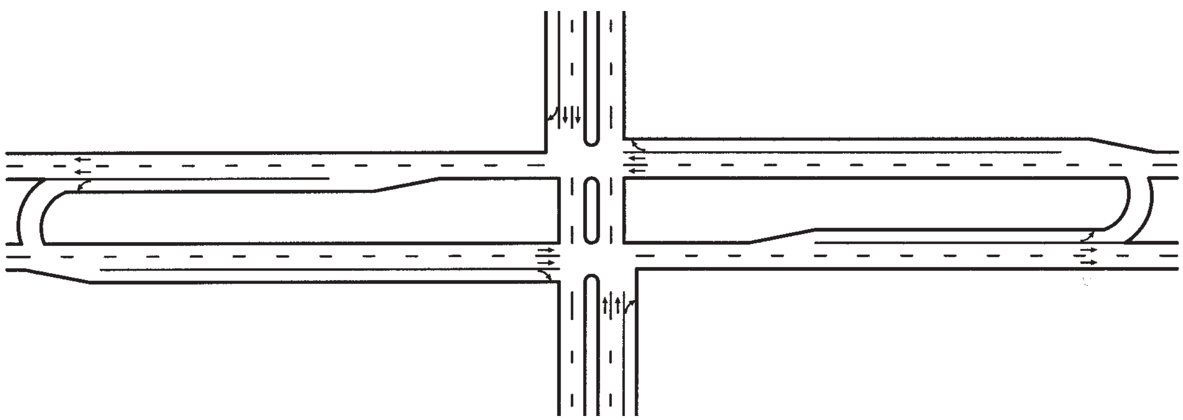


EXHIBIT V-18
Super Street Median Crossover
Source: Federal Highway Administration, in press.

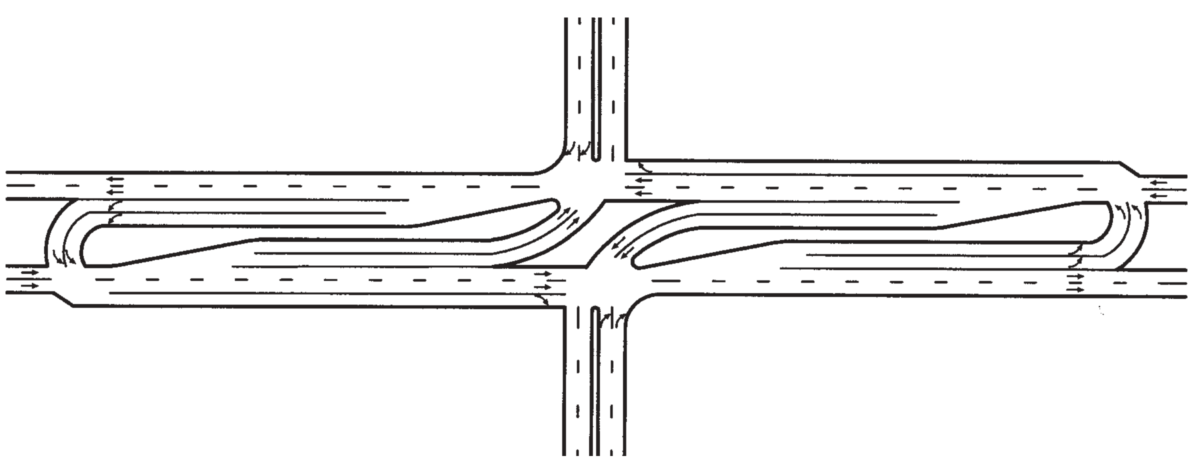


EXHIBIT V-19
Quadrant Roadway Intersection
Source: Federal Highway Administration, in press.

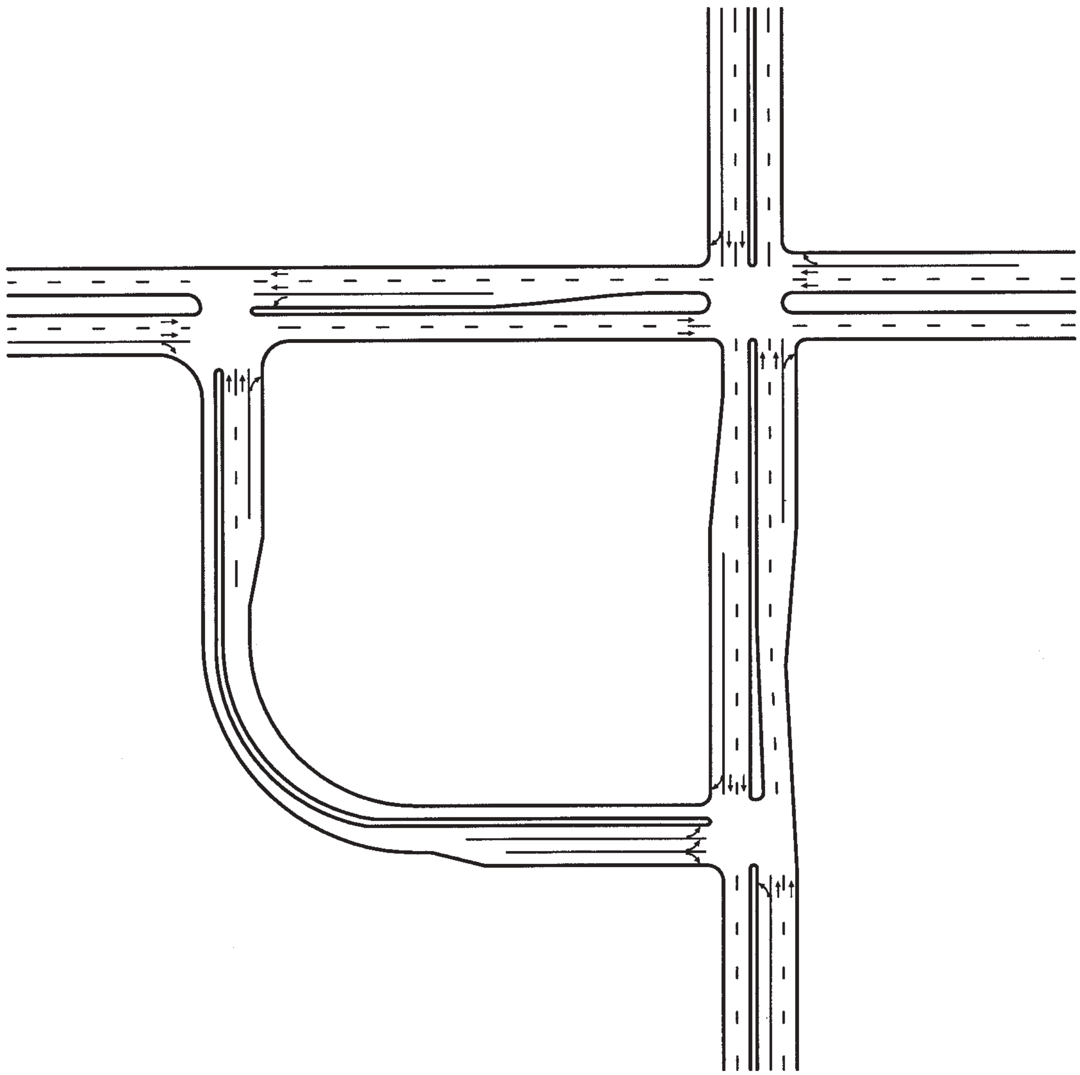


EXHIBIT V-20
Split Intersection
Source: Federal Highway Administration, in press.

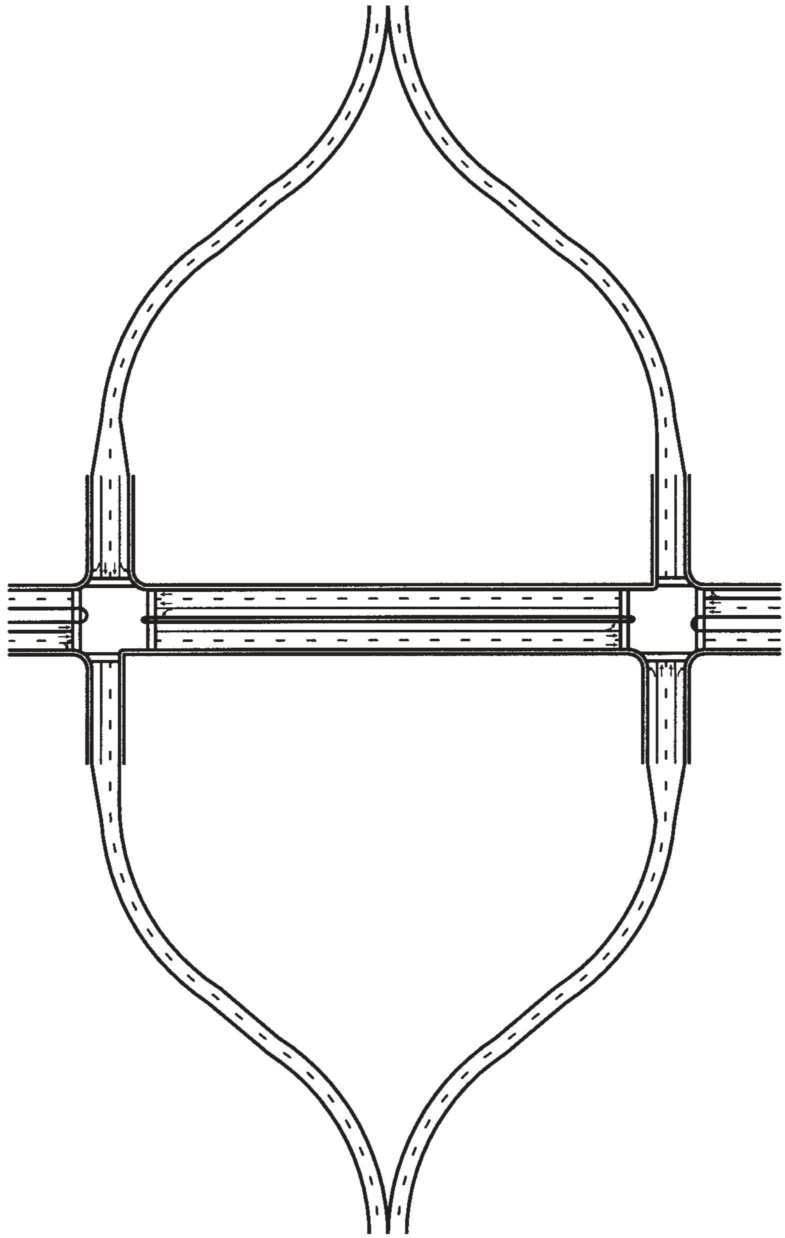
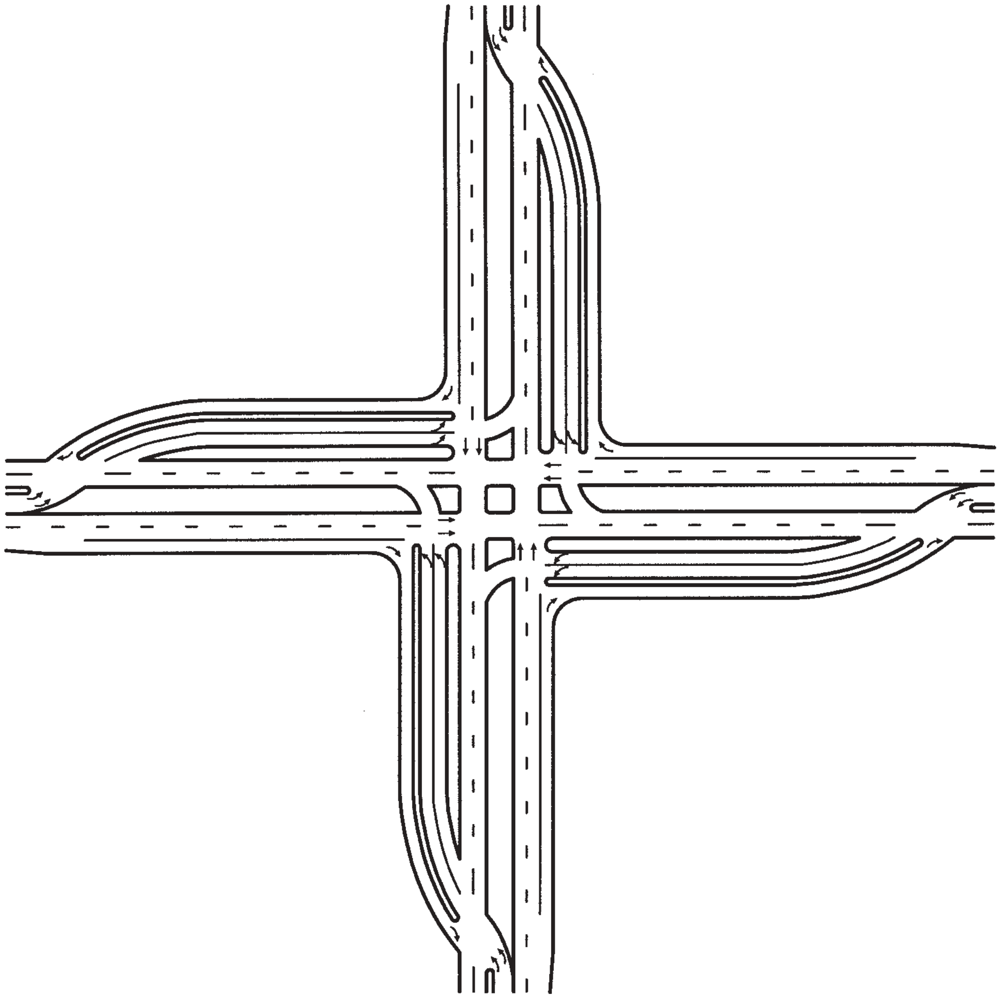


EXHIBIT V-21
Continuous Flow Intersection
Source: Federal Highway Administration, in press.



Convert to Roundabout. A roundabout can potentially have a better crash experience than a conventional signalized intersection. The FHWA publication *Roundabouts: An Informational Guide* (Robinson et al., 2000, available online at http://www.tfhrc.gov/safety/00-0671.pdf), summarizes the current state of practice and should be consulted as a source of information on the design, operation, and safety of roundabouts. The types of conflicts that occur at roundabouts are different from those occurring at conventional intersections; namely, conflicts from crossing and left-turn movements are not present in a roundabout. The geometry of a roundabout forces drivers to reduce speeds as they proceed through the intersection. This helps keep the range of vehicle speed narrow, which helps reduce the severity of crashes when they do occur. Pedestrians only have to cross one direction of traffic at a time at roundabouts, thus reducing their potential for conflicts. However, vehicles in the circulating roadway are not required to stop by virtue of the presence of a positive traffic control device.

The safety performance of roundabouts in the United States is not well documented due to the small number that have been built here. A current NCHRP study (Project 3-65) involves a comprehensive analysis of the operation and safety of roundabouts in the United States. However, recent conversion of several intersections in the United States to roundabouts showed a reduction in crash rates after construction. Data collected after intersections were converted to roundabouts in Europe and Australia show that reductions in crash rates resulted. Single-vehicle crash rates for roundabouts, however, tend to be higher than for conventional intersections (Robinson et al., 2000)

A comparison was made of crash rates for conventional intersections (using a U.S. crash-prediction model) and rates for roundabouts (using a model from the United Kingdom). For volumes entering the intersection of 20,000 vehicles/day, the crash rate was 33 percent lower for roundabouts than for signalized intersections in urban/suburban areas and 56 percent lower in rural areas. For an entering Average Daily Traffic (ADT) of 40,000 vehicles/day, approximately 15 percent fewer crashes are predicted for roundabouts. At higher volumes (50,000 or more entering vehicles per day), the safety performance of roundabouts and signalized intersections is probably comparable, and it is less likely there will be a safety benefit of conversion to a roundabout. (ITE *Traffic Safety Toolbox* [Institute of Transportation Engineers, 1999b]).

Studies do not show an improvement in rates for crashes involving bicyclists. In addition, since single-vehicle crash rates tend to increase after conversion to a roundabout, central islands, splitter islands, and the clear zone on the perimeter of the roundabout should be kept clear of obstacles.

Roundabouts are not appropriate for every intersection and will not solve all safety problems at specific intersections. Volumes of traffic entering the intersection are an important factor in the effectiveness of a roundabout, along with turning movements and other operational characteristics. All of these should be studied to ensure that a roundabout is an appropriate design for a given intersection.

Indirect left-turn treatments and roundabouts are both discussed in further detail in the guide for crashes occurring at unsignalized intersections. European uses of roundabouts are described in Appendix 4.

Convert Two-Way Streets to a One-Way Pair. When two-way streets are converted to one-way streets, it is generally for the purpose of increasing capacity, but the removal of opposing traffic flows can improve safety as well. Removal of one direction of traffic from a two-way street allows for better signal synchronization and progression of platoons. Smooth progression and reduced congestion can reduce rear-end crashes. In addition, the removal of one direction of traffic can reduce congestion and improve safety by

- Reducing the number of vehicle/vehicle conflict points at intersections,
- Allowing for unopposed turn maneuvers,
- Simplifying operations and signal phasing at multileg intersections,

- Allowing pedestrians to only have to deal with traffic from one direction, reducing conflicts with vehicles, and
- Providing more gaps for vehicles and pedestrians at unsignalized crossings.

The ITE *Traffic Safety Toolbox* (Institute of Transportation Engineers, 1999b) reports that studies have shown a 10- to 50-percent reduction in total crashes after conversion of a two-way street to one-way operation. At the same time, this strategy increases capacity significantly; a one-way street pair can handle up to 50 percent more volume than two parallel two-way streets.

Safety-related drawbacks to conversion to one-way streets may include the following:

- Pedestrians not looking in the correct direction for oncoming vehicles, and
- Minor sideswipe crashes related to weaving maneuvers as drivers attempt to park or reach a turn lane.

Supplemental and redundant signing is recommended on one-way streets converted from two-way operation.

Transit operations may be adversely affected with the introduction of one-way operation. Special care should be taken to avoid contraflow bus lanes on such streets, as these present a special hazard to crossing pedestrians. One key element of creating a one-way pair is the design of the transitions at each end. Care must be taken not to create conditions that cause driver confusion and erratic maneuvers.

Construct Interchange or Grade Separation. At some signalized intersection locations with extremely high volumes, extremely poor crash histories, or other mitigating factor(s), provision of a grade separation or interchange can be considered. This is an expensive approach to safety improvement and should generally be considered when other, less restrictive measures have been tried and have failed. Often this solution is applied for capacity and operational reasons, where the capacity of a signalized intersection is insufficient to accommodate the volume passing through it. If a grade separation alternative is considered, maintaining access to existing development is a key element to successfully implementing the improvement.

By separating the grades of intersecting roadways, volumes of crossing and turning traffic, as well as bottlenecks and spot congestion, may be reduced. This can lower the number and severity of crashes caused by these movements and intersection conditions, specifically rear-end and angle crashes.

Guidance on constructing and designing interchanges is discussed in the AASHTO *Policy on Geometric Design of Highways and Streets* (American Association of State Highway and Transportation Officials, 2001). Time required for the design and construction of an interchange could range anywhere from 4 to 10 years, depending upon location constraints and environmental factors. Costs would likely be high and variable. Simple service interchanges are less expensive than system interchanges, but construction costs may still be several million dollars.

Objective 17.2 C—Improve Sight Distance at Signalized Intersections

Adequate intersection sight distance contributes to the safety of the intersection. In general, sight distance is needed at signalized intersections for the first vehicle stopped at an approach to be able to see the first vehicles stopped at the other approaches, for drivers making permitted left turns, and for right-turning vehicles. Where RTOR are allowed, adequate sight distance should be available. Improvements in sight distance can lead to a reduction in crashes caused by drivers stopping suddenly (rear-end), drivers proceeding through the intersection when the signal has not assigned them the right-of-way (angle), and drivers turning through an inadequate gap in opposing traffic (angle).

Strategy 17.2 C1: Clear Sight Triangles (T)

General Description

Sight distance improvements can often be achieved at relatively low cost by clearing sight triangles to restore sight distance obstructed by vegetation, roadside appurtenances, buildings, bus stations, or other natural or man-made objects.

The most difficult aspect of this strategy is the removal of sight restrictions located on private property. The legal authority of highway agencies to deal with such sight obstructions varies widely, and the time (and possibly the cost) to implement sight distance improvements by clearing obstructions may be longer if those obstructions are located on private property. If the object is a mature tree or planting, then local concerns over adverse environmental consequences may arise. For a more detailed discussion of trees, see the guide for crashes involving trees in hazardous locations.

Research has established a relationship between intersection safety and sight distance at unsignalized intersections. No such research quantifies the effectiveness of improving sight distance at signalized intersections. One may expect that crashes related to inadequate sight distance (specifically, angle and turning related) would be reduced if the sight distance problems are improved. However, as the signal assigns ROW for most vehicles crossing paths at right angles and because traffic volumes affected by the other situations cited above are low, the overall impact on crashes could be relatively small.

Since sight distance is a greater issue at intersections with stop control than at signalized intersections, more research has been performed on the effectiveness of sight distance improvements at stop-controlled intersections (several of the studies are summarized in *NCHRP Report 440* [Fitzpatrick et al., 2000]). There are several movements at signalized intersections that operate similarly to stop-controlled intersections (such as RTOR and permitted left turns) for which expected effectiveness of sight distance improvements at signalized intersections may be inferred from similar studies at stop-controlled intersections. Such estimates should be performed with caution, taking into consideration the other characteristics of signalized intersection operation that would alter the effectiveness estimates.

More information on clearing roadside and median intersection sight triangles is presented in the guide for crashes at unsignalized intersections.

Strategy 17.2 C2: Redesign Intersection Approaches (P)

General Description

Signalized intersections with sight-distance-related safety problems that cannot be addressed with less expensive methods (such as clearing sight triangles, adjusting signal phasing, or prohibiting turning movements) may require horizontal or vertical (or both) realignment of approaches. Realigning both of the minor-road approaches so that they intersect the major road at a different location, or a different angle, can help address horizontal sight distance issues.

This is a high-cost, longer-term treatment for the intersection, but if completed according to applicable design policy, it should help alleviate crashes related to sight distance. The 2001 AASHTO *Policy on Geometric Design of Highways and Streets* contains updated sight distance guidelines, and these guidelines should be considered when revising intersection approach geometry. There are significant ROW and property access issues involved in this strategy, and public information campaigns are vital to the success of the intersection improvements.

An intersection leg can be closed in order to address sight distance issues related to that particular leg. This strategy is covered in the previous section of this guide.

Intersection relocation and closure, elimination of intersection skew, and offsetting of left-turn lanes are all strategies that involve improvements to approach alignment to improve sight distance. These strategies are each covered in greater detail in the unsignalized intersection guide.

Objective 17.2 D—Improve Driver Awareness of Intersections and Signal Control

Driver awareness of both downstream intersections and traffic control devices is critical to intersection safety. The inability to perceive an intersection or its control or the back of a stopped queue in time to react as necessary can result in safety problems. Drivers caught unaware could be involved in serious crashes, especially at intersections with high speeds on the approaches. This objective details strategies aimed at improving driver awareness of signalized intersections and the traffic control in place.

Strategy 17.2 D1: Improve Visibility of Intersections on Approach(es) (T)

This strategy includes the following:

- Improving signing and delineation,
- Installing larger signs,
- Providing intersection lighting,
- Installing rumble strips on approaches, and
- Installing queue detection system.

General Description

Some crashes at signalized intersections may occur because drivers are unaware of the presence of an intersection or are unable to see the traffic control device in time to comply.

These crashes are generally rear-end or angle collisions. The ability of approaching drivers to perceive signalized intersections immediately downstream can be enhanced by signing, delineation, and warning devices. Other strategies to improve the visibility of an intersection include providing lighting, improving the visibility of the signals, and using devices to call attention to the signals. All of these strategies are discussed in detail in the unsignalized intersection guide, and that guide should be consulted for additional information.

The FHWA report *Synthesis of Human Factors Research on Older Drivers and Highway Safety: Volume 2* (Staplin et al., 1997) reviews research on older drivers' visual abilities related to driving. Research shows that recognition and legibility distances as well as response speeds are lower for older drivers than for younger ones. The *Synthesis* summarizes recent research by stating that if recognition of an intersection is based on signs being legible to drivers, older drivers will take longer to recognize intersections. Therefore, consideration should be given to providing traffic control devices that contribute to improved legibility and response times for older drivers. This may include redundant signing, overhead signing, and advanced route signing. The older drivers guide should be consulted for more information.

Improve Signing and Delineation. Installing or upgrading signs and pavement markings on intersection approaches can help better prepare drivers for the intersection ahead. This may include advance guide signs, advance street name signs (Exhibit V-22), warning signs, pavement markings, overhead street signing, and post-mounted delineators. Advance warning signs, such as the standard intersection warning sign or the standard sign with flashers, can also alert drivers to the presence of an intersection. Installing advance warning signs on both sides of the roadway to provide redundancy in signing may be appropriate in some situations, such as when the intersection approach in on a curve. Street name and lane assignment signs in advance of the intersection prepare drivers for choosing and moving into the lane they will need to use for their desired maneuver. Signs and flashers warning drivers they are approaching a red signal might improve both awareness of the intersection and a red signal (see Exhibit V-23).

EXHIBIT V-22
Advance Street Name Sign
Source: Federal Highway Administration, in press.

EXHIBIT V-23
Advanced Warning Sign for Red Signal
Source: Federal Highway Administration, in press.

Providing a break in pavement markings at intersections also helps to alert drivers to their presence. This includes centerlines, lane lines, and edge lines. Close spacing of progressive signals can lead to drivers focusing on a downstream signal and not noticing an intermediate signal. Signing, pavement markings, lighting, or alteration of the appearance of a signal to make it more noticeable should be considered in this situation.

Maintenance of signs and pavement markings is also important to the success of this strategy. Retroreflectivity of older pavement markings and signs should be checked periodically to determine whether replacement is needed.

Install Larger Signs. The visibility of intersections with existing regulatory and warning signs and the ability of drivers to perceive the signs can be enhanced by installing signs with larger letters. Such improvements may include advance guide signs, warning signs, pavement markings, and post-mounted delineators. The FHWA *Older Driver Highway Design Handbook* (Staplin et al., 1998; available at http://www.fhwa.dot.gov/tfhrc/safety/pubs/older/intro/) encourages installation of larger signs to contribute to a better driving environment for older drivers. The older driver guide contains additional information about engineering improvements to aid older drivers.

Provide Intersection Lighting. Providing lighting at the intersection itself or at both the intersection and on its approaches can make drivers aware of the presence of the intersection and reduce nighttime crashes. Crash data should be studied to ensure that safety at the intersection could be improved by providing lighting (this strategy would be supported by a significant number of crashes that occur at night). The costs involved with intersection lighting may be moderately expensive, especially since maintenance is needed to keep the equipment in working order.

Intersection lighting is of particular benefit to police officers. Lighting not only helps them perform their duties, such as traffic stops, but also helps drivers see them better, especially when out of the vehicle.

Install Rumble Strips on Approaches. Rumble strips can be installed in the roadway on intersection approaches transverse to the direction of travel to call attention to the presence of the intersection and the traffic control used. Rumble strips are particularly appropriate on intersections where a pattern of crashes related to lack of driver recognition of the presence of the signal is evident, often on high-speed approaches. This strategy should be used sparingly, as the effectiveness of rumble strips is dependent on their being unusual. Rumble strips are normally applied when less intrusive measures, such as “signal ahead” signs or flashers, have been tried and have failed to correct the crash pattern, and they are typically used in combination with the advance warning signs. For example, a rumble strip can be located in the roadway so that when the driver crosses it, a key traffic control device such as a “signal ahead” sign is directly in view. Rumble strips in the traveled way can also be used on a temporary basis to call attention to changes in traffic control devices, such as installation of a signal where none was present before. Care must be taken to avoid use of rumble strips where the noise generated will be disturbing to adjacent properties. *NCHRP Synthesis of Highway Practice 191* (Harwood, 1993) reviews the state of the art of rumble strip usage.

Install Queue Detection System. Queue detection systems are standard tools for operation of traffic signals. In normal practice, queue detection is used for actuated signal systems to “call-up” a phase given the presence of a vehicle in a specific lane or movement.

The application of queue detection systems as safety devices is a new and potentially effective device. One such system has been implemented in Oregon on an approach to a signalized intersection in a rural setting that regularly experiences significant queues, especially during the summer when seasonal traffic increases. Two loop detectors in each lane on the intersection approach detect when a vehicle is stopped at that location. The detectors are connected to an overhead sign with beacons located a half mile upstream. The sign contains the message “Prepare to stop when lights flash.” When a vehicle is continuously present at a detector, beacons on the overhead sign flash to warn drivers of the stopped vehicle ahead. A preliminary evaluation indicates a reduction in crashes after installation of this system, but additional data are needed to determine if other factors contributed to this decrease. For additional information on this system, refer to the FHWA report *Safety Applications of ITS in Rural Areas*, (Federal Highway Administration, 2002), available online at http://www.itsdocs.fhwa.dot.gov/JPODOCS/REPTS_TE/5_1_1.htm.

Strategy 17.2 D2: Improve Visibility of Signals and Signs at Intersections (T)

General Description

Lack of visibility of traffic control devices may contribute to crash experience at signalized intersections. Visibility of traffic signals and signs at intersections may be obstructed by physical objects (such as signs or other vehicles) or may be obscured by weather conditions, such as fog or bright sunlight. Also, drivers’ attention may be focused on other objects at the intersection, such as extraneous signs. Poor visibility of signs and signals may result in vehicles not being able to stop in time for a signal change or otherwise violating the intended message of a regulatory or directional sign. Providing adequate visibility of signs and signals also aids in drivers’ advance perception of the upcoming intersection. The FHWA *Older Driver Highway Design Handbook* should be consulted to ensure that improvements to visibility of traffic control devices will be adequate for older drivers (Staplin et al., 1998; available at http://www.fhwa.dot.gov/tfhrc/safety/pubs/older/home/index.htm).

In addition to potentially restricting driver sight lines, large numbers of appurtenances and signage not associated with the driving task in the vicinity of an intersection can impose a high workload. This may ultimately distract the driver from the task at hand (i.e. safely navigating the intersection). This "visual clutter" can make it difficult for the driver to extract the information from the signs required to execute the driving task (directional information, speed information, etc.). Enforcement of existing sign restrictions, and/or the creation of new restrictions limiting the placement of signs near intersections, can reduce the amount of information provided to the driver near intersections.

Maintenance of signals and signs is important to the visibility of the devices. If visibility of traffic control devices is considered to be a potential factor in crashes, a field review should be performed to determine if part of a sign's message is covered, obliterated, or blocked, as well as to check the reflectivity of the sign.

Methods for improving visibility of traffic signals and signs include the following:

- Install additional signal head (see Exhibit V-24),
- Provide visors to shade signal lenses from sunlight,
- Provide louvers, visors, or special lenses so drivers are able to view signals only for their approach,
- Install backplates,
- Install larger (12-in.) signal lenses,
- Remove or relocate unnecessary signs, and
- Provide far-side left-turn signal.

Methods for improving visibility of traffic signals and signs are discussed further in Appendix 7. Additional information on improving signal visibility to reduce red-light running can be found in *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running* (McGee, 2003; available online at http://www.ite.org/library/redlight/MakingInt_Safer.pdf).

EXHIBIT V-24
Signal Head with Double Red Section
Source: Federal Highway Administration, in press.

EXHIBIT V-25
Strategy Attributes for Improving Visibility of Signals and Signs at Intersections

Attribute	Description
Technical Attributes	
Target	This strategy is targeted at crashes that occur because drivers are unable to see traffic signals and signs sufficiently in advance to safely negotiate the intersection being approached. Crash types would include angle and rear-end crashes.
Expected Effectiveness	Improved visibility and awareness of traffic control information are expected to reduce conflicts related to drivers not being able to see the device well or in enough time to comply with the signal indication or sign message (such as those resulting in rear-end and right-angle crashes).
Keys to Success	Visibility and clarity of the signal should be improved without creating additional confusion for drivers. Additional signing to warn drivers should not clutter the intersection and should not present confusing or conflicting messages to drivers.
Potential Difficulties	Care should be taken to ensure that new or relocated signs do not present additional sight distance, roadside, or driver distraction hazards. If rumble strips are used in an area with adjacent residences, the noise may be objectionable, creating public resistance. Bicyclists may also object to rumble strips as the treatment may force them to ride in the roadway travel lanes. If some of the devices recommended are not maintained properly, the expected benefits may be lost.
Appropriate Measures and Data	Key process measures include the number of intersection approaches for which improvements are implemented, which increase driver perception of traffic signals located immediately downstream, and the number of conflicts potentially eliminated by the improvement. Crash frequency and severity by type of crash are key safety effectiveness measures. It is especially useful to identify crashes related to unseen signals (inadvertent red light running, etc). Driver behavior measures (e.g., conflicts, erratic maneuvers, speeds, and braking) may be used as surrogate safety measures. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to the targeted improvements at the intersection should be analyzed separately. Traffic volume data are needed to represent exposure, especially the volumes of movements of interest and the opposing through volumes.
Associated Needs	Removing signs and other elements contributing to roadside clutter may require public involvement activities.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should review their traffic engineering and design policies regarding use of traffic control devices to ensure appropriate action is being taken on routine projects. Nearly any highway agency can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas.
Issues Affecting Implementation Time	Implementation time will be relatively short for procedures to install new signs, improve signals, and remove or relocate signs.

EXHIBIT V-25 (Continued)
Strategy Attributes for Improving Visibility of Signals and Signs at Intersections

Attribute	Description
Costs Involved	Costs will be low for most procedures to install or upgrade signs and signals to improve visibility and awareness of the traffic control devices. Ongoing maintenance costs should be included when considering use of these devices.
Training and Other Personnel Needs	Visibility of traffic control devices should be addressed in highway agency training concerning traffic signal installation and human factors.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	Actions taken to improve visibility of signals are compatible with most other strategies to improve signalized intersection safety but are not appropriate in conjunction with removal of a signal.
Other Key Attributes to a Particular Strategy	None identified.

Objective 17.2 E—Improve Driver Compliance with Traffic Control Devices

Safety problems at signalized intersections cannot always be solved only with engineering countermeasures. Enforcement of traffic regulations or public information campaigns may be the best way to improve intersection safety. This section details information on strategies to improve compliance with traffic control devices, focusing mainly on red-light running and speeding on approaches to signalized intersections.

Strategy 17.2 E1: Provide Public Information and Education (T)

General Description

Providing targeted public information and education (PI&E) on safety problems at intersections is a preventive measure that can help improve driver compliance with traffic control devices and traffic laws. PI&E programs generally add effectiveness to targeted enforcement programs, as well.

Another option is to develop public information campaigns aimed at specific drivers who violate regulations at intersections, even though it is often difficult to identify and focus upon a subset of the driving population using a specific intersection. Therefore, an areawide program is often the preferred approach. A key to success for this strategy is reaching as much of the targeted audience as possible, whether it is through television, radio, distribution of flyers, driver education classes, or other methods. Targeted drivers need to be defined both in terms of the location of the hazardous intersection(s) and the attributes of the drivers who may have been identified as over represented in the population involved in crashes. More information on public information that is targeted at specific drivers is provided in the guide for crashes occurring at unsignalized intersections.

EXHIBIT V-26
Strategy Attributes for Providing Public Information and Education (T)

Attribute	Description
Technical Attributes	
Target	The target for this strategy is crashes related to drivers either being unaware of, or refusing to obey, traffic laws and regulations that impact traffic safety. Crashes related to red-light running, speeding, and not yielding to pedestrians could be reduced with PI&E campaigns.
Expected Effectiveness	Data on the effectiveness of this strategy for this specific application are not known, but it is expected that providing information to drivers will help improve safety at intersections. It may not be possible to identify or reach the entire audience that would benefit from a PI&E campaign.
Keys to Success	Keys to success include identifying and reaching as much of the intended audience as possible, providing information in nontechnical terms, and providing agency personnel to answer questions and calls from the public. It is important to motivate people to drive (and bike or walk) safely. Since unsafe actions do not always result in crashes, road users may have a false sense of security and may not see the need to drive more safely or follow traffic regulations in all circumstances. Use of trained public information specialists is important for program success. Establishing good relationships with media representatives will be extremely helpful for maximizing coverage and impact.
Potential Difficulties	The primary potential difficulty associated with this strategy is relating the importance of informational/educational programs to the public. Many people may see a notice for a public meeting and think that it is a waste of time and not attend. Brochures, posters, and advertisements can be effective if they are conspicuous and readily available. Use of electronic media is expensive, unless strategies are employed for receiving donated time. Consideration should be given to people who may need materials in languages other than English or in alternative formats to accommodate disabilities. Another difficulty is maximizing the reach of a public involvement program.
Appropriate Measures and Data	Key process measures include identifying the number and frequency of different media used (radio ads, brochures, etc.) and measuring the population exposed to the message. Level of expenditure is another possible process measure and can be used to produce a productivity measure. Crash frequency and severity by type of crash should be tracked before and after implementation of the public information campaign. Traffic volume data are needed to represent exposure. Surrogate safety measures can include driver behavior (e.g., change in unsafe targeted and untargeted driving acts).
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should ensure that education and information programs are scheduled when most likely to maximize the exposure of the message to the target population. Coordination and cooperation with other parts of an organization that have established marketing skills can be useful. It will be helpful to enlist media representatives as part of the group of stakeholders involved in planning and implementing the program.

EXHIBIT V-26 (Continued)
Strategy Attributes for Providing Public Information and Education (T)

Attribute	Description
	Nearly all highway agencies can make use of this strategy, which is applicable in rural, urban, and suburban areas.
Issues Affecting Implementation Time	Implementation time for this strategy should be short to moderate. Extensive planning of the program and design of the educational materials can lengthen the implementation time.
Costs Involved	Cost will generally be low to moderate and depend upon the kinds of materials developed (brochures, posters, radio, or television advertisements), the extent of effort spent on designing the materials, and the amount of free media coverage that can be achieved. Strategies may be used to attract media attention without purchasing air time.
Training and Other Personnel Needs	Training for highway personnel in providing PI&E should be included as a part of developing and implementing the program.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with the other strategies for improving safety at signalized intersections. It may be used in conjunction with overall traffic safety public service campaigns.
Other Key Attributes to a Particular Strategy	None identified.

Strategy 17.2 E2: Provide Targeted Conventional Enforcement of Traffic Laws (T)

General Description

Enforcement is a potential countermeasure to unsafe and illegal motorist behavior at intersections. Studies report the reduction of traffic law violations when enforcement is used (*Traffic Engineering Handbook* [Pline, 1999]). Traffic law enforcement agencies will often select locations for targeted enforcement when crash, citation, or other sources of information suggest that the site is unusually hazardous due to illegal driving practices, such as speeding or red-light running. These actions can lead to rear-end, head-on, sideswipe, angle, and pedestrian or bicycle-related crashes.

Traffic law enforcement methods vary depending upon the type of program being implemented. For background on methods and approaches please refer to the publications available at the following Web sites: http://www.nhtsa.dot.gov/people/injury/enforce/DESKBK.html and http://www.nhtsa.dot.gov/people/injury/enforce/millennium/index.htm).

Targeted enforcement of traffic laws is a short-term, moderate-cost measure to address site-specific signalized intersection safety. Though this is an effective strategy, the effectiveness has often been found to be short-lived. It is difficult—if not impossible—to provide constant enforcement of traffic regulations due to funding and staffing reasons, so periodic enforcement may be necessary to sustain the effectiveness of this strategy. For European experience on the effectiveness of traffic law enforcement, including speeding laws, see Appendix 11 and Appendix 12.

It is important to correctly identify intersections that would benefit from enforcement. Care should be taken to first ensure that the existing signals are operating properly, are visible, and meet MUTCD requirements, as well as that timing plans—including clearance intervals—are appropriate. Analysis of crash statistics can help with this process, as can spot speed or conflict studies. In some cases, public input or observations by law enforcement personnel may suggest that a location should be targeted for enforcement.

Police officers providing targeted enforcement of red-light running can be aided by "tell-tale" or "tattle-tale" lights. These lights are placed at traffic signals, but facing away from on-coming traffic. Police officers are able to wait in their vehicles on the downstream side of the traffic signal` and view the tattle-tale light. This way, they are able to pursue red-light runners without also running through the red light themselves (and possibly into vehicles entering the intersection from the cross street).

Targeted enforcement at intersections is covered in more detail in the unsignalized intersection guide.

Strategy 17.2 E3: Implement Automated Enforcement of Red-Light Running (Cameras) (P)

General Description

Red-light running is a well-documented and growing traffic safety problem. Various engineering countermeasures can be used to address red-light running; refer to Strategy 17.2 A2 for a discussion of optimizing clearance times, as well as the ITE and FHWA report *Making Intersections Safer: A Toolbox of Engineering Countermeasures to Reduce Red-Light Running* (McGee, 2003; available online at http://www.ite.org/library/redlight/MakingInt_Safer.pdf). While some occurrence of this can be addressed by engineering, in many instances inappropriate driver behavior is the primary problem. Because it is not feasible to provide police officers to enforce traffic signals as often or in as many locations as an agency might need, automated enforcement is an attractive alternative (see Exhibit V-27).

Automated enforcement refers to the use of photo radar and video camera systems connected to the signal control. Such systems record vehicles proceeding through the intersection after the signal displays red. Red-light-running cameras turn on after the signal turns red. A detector senses approaching vehicles and sends a signal to the camera, which photographs the vehicles as they enter the intersection. It is possible to set a grace period (generally one second) so that the cameras do not photograph people who were caught in the dilemma zone and enter the intersection just after the signal turns red. Data on the

EXHIBIT V-27
Red-Light-Running Camera
Source: Federal Highway Administration, in press.

violation, such as date, time, speed of vehicle, and the time that had elapsed since the signal turned red, are printed on the photograph. Police officers review the photos to determine if a violation occurred, and if so, a citation is mailed to either the driver or the vehicle owner, depending on the legislation for the jurisdiction.

Automated enforcement of red-light running has been shown to significantly decrease violations, not only at intersections where cameras are installed, but also at other intersections in the area.

There are many applications of red-light-running technology throughout the world. For additional information on red-light-running cameras available on the Internet, see http://www.iihs.org/safety_facts/rlc.htm, http://safety.fhwa.dot.gov/programs/srlr.htm, and http://www.ite.org/library/redlight/index.asp.

In Canada, cameras are being used for the purpose of speed enforcement as well as red-light running. Strathcona County in Alberta was the first jurisdiction in North America to use red-light cameras to record speeding violations. A red-light-running camera installed at the intersection of Wye Road and Ordze Avenue in 1998 was used for speed enforcement beginning in 2000. This strategy has been effective in reducing speeding: a 75-percent drop in violations was experienced from 2001 to 2002. For additional information, visit the Royal

Canadian Mounted Police Web site for Strathcona County (http://www.strathconacountyrcmp.ca/redlightcam.htm).

Red-light-running camera equipment can be used not only to record violators but also to protect cross-street vehicles. There are systems capable of using a vehicle's speed to predict whether the vehicle will run the red light, and if so, the system can extend the cross-street red indication to prevent cross-street vehicles from entering the intersection while the violating vehicle is still in the intersection.

Red-light-running cameras are used in Europe as well; refer to Appendix 4 for additional information on several countries' experiences. Automated enforcement offers the opportunity to address a systemwide problem in an efficient manner, using technology as a substitute for law enforcement personnel time. While the advantages in terms of safety and cost-effectiveness are clear, there are problems and in some cases controversies associated with automated enforcement. Concerns over invasion of privacy and the ability to identify and cite the driver (most systems identify the vehicle through identification of the plates), as well as the belief by some that the systems are unfair or intended to generate fine revenue versus address safety problems are all issues that have arisen. In some jurisdictions, enabling legislation may be needed for successful prosecution of red-light-running camera violations. The National Conference of State Legislatures tracks status of legislation and provides examples of model legislation (http://www.nhtsa.dot.gov/ncsl/Index.cfm).

EXHIBIT V-28
Strategy Attributes for Providing Automated Enforcement of Red-Light-Running (Cameras) (P)

Attribute	Description
Technical Attributes	
Target	The target for this strategy is drivers who intentionally disobey red signal indications. Intersections where observations or crash histories indicate a red-light-running problem may be suitable for installation of a red-light-running camera. Crashes of this type are likely to be angle and rear-end collisions.
Expected Effectiveness	Several studies have shown the effectiveness of automated red-light enforcement in reducing red-light violations and crashes related to those violations. Fairfax, Virginia, experienced a 44-percent reduction in violations during the first year of operation. Two other sites in the city that did not have cameras experienced decreases in violations of 34 percent. Control sites in nearby counties experienced little change. (Retting et al., 1999a). Oxnard, California, experienced approximately 41 percent fewer red-light violations within a few months after beginning to use the cameras to enforce the signals (Retting et al., 1999b). FHWA has made a general estimate of a 15-percent reduction in red-light-running incidents resulting from these programs. The ITE Informational Report, *Automated Enforcement in Transportation* (Institute of Transportation Engineers,1999a), contains information on experiences with red-light-running cameras in other jurisdictions. The automated enforcement programs highlighted in this document experienced a range of reduction in violations of 23 to 83 percent. An evaluation of a program in Victoria, Australia, showed a decrease in

EXHIBIT V-28 (Continued)
Strategy Attributes for Providing Automated Enforcement of Red-Light-Running (Cameras) (P)

Attribute	Description
	violations of 35 to 60 percent, accompanied by a 35-percent reduction in right-angle crashes, 25-percent reduction in right-angle turning crashes, 31-percent reduction in rear-end crashes, and 28-percent reduction in rear-end turning crashes.
Keys to Success	Keys to success of red-light-running programs primarily relate to acceptance of local stakeholders, including both officials and the public. Acceptance by local law enforcement is another critical element necessary for the success of an automated enforcement program. Indeed, local law enforcement needs to be seen as central to such a program. So, incorporation of a public information campaign explaining the program, the need for it, how the cameras work, and what the benefits may be is a key to successful implementation. Successful red-light camera programs have generally begun as safety improvement programs. Programs that are perceived as revenue generators (i.e., through collection of fines) are generally not well-accepted. Therefore, there should be clear justification of the installations based upon documented violation levels. It is important that both the highway agency and the law enforcement agency(ies) in the jurisdiction be involved jointly in planning and operating the program. Moreover, where private contractors are used to implement parts of the program, it is important that their contract and compensation not be directly linked to revenue or tickets issued. Some programs have lost public support because it was perceived that a private company was profiting from traffic ticket revenue. Avoiding controversial contract provisions and maintaining clear control over administration of the program by the appropriate police agency are keys to success. FHWA and NHTSA developed guidelines for implementation of red-light-running cameras, which can be found online at http://safety.fhwa.dot.gov/rlcguide/index.htm. See Appendix 8 for a description of a successful red-light camera program in Howard County, Maryland. Adequate legislative authority is needed to conduct such a program (see the section below on "Legislative Needs").
Potential Difficulties	There are many opponents to red-light-running enforcement cameras. Arguments against this strategy include violation of personal privacy, violation of constitutional rights, lower effectiveness than other types of enforcement, high cost outweighing the benefits, and implementation solely to generate revenue. Recent challenges also include questioning the precision of the cameras and the proper setting of the camera. Counter-arguments to all of these issues are presented in ITE's *Automated Enforcement in Transportation.* Other potential difficulties to overcome include administration of the program through the use of contractors. The program needs to be clearly identified as a public safety program, with administrative responsibility remaining clearly in the hands of the police. Timeliness of the citation is important. Administrative systems may slow the processing and create a lengthy gap between the moment of the violation and the moment the sanction is received by the driver. Principles of effectiveness of enforcement suggest that the time between violation and punishment should be short to be effective. In addition, the technology has spawned an industry directed at defeating it. For example, see http://www.phantomplate.com.

(*continued on next page*)

EXHIBIT V-28 (Continued)
Strategy Attributes for Providing Automated Enforcement of Red-Light-Running (Cameras) (P)

Attribute	Description
Appropriate Measures and Data	A key process measure is the number of intersection approaches on which red-light-running cameras are installed. A more detailed measure is the number of citations issued from the program, as well as the number of traffic convictions resulting. Crash frequency and severity data by type are key safety effectiveness measures. Data describing these crashes and data on the frequency of violations are needed for periods both before and after installation of the cameras. Traffic volume data are needed to represent exposure. Where feasible, the effect of automated enforcement on total crashes and crash types potentially related to signal violations should be evaluated separately. Surrogate safety measures include violation frequency and the number of intersections where potential benefits may be observed even though cameras are not installed.
Associated Needs	PI&E is needed to make automated enforcement successful. Public opinion and acceptance can “make or break” an automated enforcement program. Information and awareness efforts and materials typically include the following: (1) documentation of the problem (in nontechnical terms), (2) objectives of the automated enforcement program, (3) advantages of automated enforcement or conventional enforcement, (4) general locations or areas of automated enforcement systems, (5) uses of revenue generated by automated enforcement, and (6) information on what to do when a citation is received in the mail. Signs before each approach to the intersection, informing the public that automated technology is being used, have been used to make the public aware of an automated enforcement system. Some jurisdictions have even painted the cameras in highly visible colors. Having members of local law enforcement speak on television and radio shows, or on panels at local meetings, has been helpful to some agencies installing cameras.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agency crash analysis procedures should include methods to identify the need for automated red-light enforcement. It is important that the program be handled in a coordinated manner by the highway, law enforcement, and judicial agencies.
Issues Affecting Implementation Time	The time to implement red-light-running cameras can vary depending upon the extent of public involvement and whether new legislation is needed.
Costs Involved	Costs may vary, depending upon the effort put into public information and need for additional legislation. Equipment costs can vary somewhat, due to the type of camera selected (i.e., 35-mm, video, digital). Costs also include monitoring of the videotapes, issuance of citations, collections and records maintenance, maintenance of equipment, maintaining quality control, and rotating or moving the equipment from location to location. Some agencies have established staffs or hired consultants to perform work associated with program implementation. Some cost information may be found at http://www.iihs.org/safety_facts/rlc.htm Proceeds from citations can be used to cover all or some of the costs of implementing, operating, and maintaining the system. If fines are set sufficiently high, additional monies can be put into a general fund or a special fund targeted for safety improvements. It is important, however, for the program revenue to not be the reason for the program itself.
Training and Other Personnel Needs	Training for highway engineers, safety analysts, and police officers should address automated red-light enforcement. Implementation of the program either through the

EXHIBIT V-28 (Continued)
Strategy Attributes for Providing Automated Enforcement of Red-Light-Running (Cameras) (P)

Attribute	Description
	jurisdiction or private contract requires acquisition of the necessary hardware and software, training in their use, implementation of quality control processes and procedures, and development of new processes to measure program costs and success.
Legislative Needs	Legislation may be necessary before implementing an automated enforcement program. The legislation is necessary to meet constitutional standards, state legal standards, state vehicle code standards, and local jurisdiction standards. A state's enabling legislation should address the broad constitutional issues (federal and state) within a framework that includes elements such as definitions of acceptable automated enforcement devices, any restricted uses, description of acceptable photographic evidence, and penalty provisions. Local legislation should cover requirements in much more detail. This should include issues such as operating criteria, the agency that is responsible for camera operation, restricted uses in that jurisdiction, and requirements for advance notification. An example of both state and local legislation authorizing red-light-running programs may be found at the site explaining the Safelight program in Charlotte, NC. (available at http://www.charmeck.org/departments/transportation/special+programs/safelight.htm). A summary of state legislation on automated enforcement may be found at: http://www.iihs.org/safety_facts/state_laws/auto_enforce.htm. The National Conference of State Legislatures tracks status of legislation and provides examples of model legislation (http://www.nhtsa.dot.gov/ncsl/Index.cfm). Additional information on related legislation can be found at www.stopredlightrunning.com.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with the other strategies for improving safety at intersections. Indeed, as noted above, this strategy should be accompanied by a public information or outreach campaign to explain the program.
Other Key Attributes to a Particular Strategy	None identified.

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

See Appendix 8 for a description of a red-light camera program in Howard County, Maryland.

Charlotte, North Carolina, has had a red-light running program in operation since 1998. It is called the "Safelight" program. Detailed information on it may be found at http://www.charmeck.org/departments/transportation/special+programs/safelight.htm.

The City of Portland, Oregon, has a summary of its red-light running program at: http://www.portlandonline.com/police/index.cfm?c=30592.

Also see http://www.ite.org/library/redlight/index.asp for descriptions of other programs.

Strategy 17.2 E4: Implement Automated Enforcement of Approach Speeds (Cameras) (T)

Enforcement of traffic regulations is an important part of an overall intersection safety improvement strategy, but limited resources constrain the efforts police can devote to providing speed enforcement. Traffic law enforcement agencies will often select locations for targeted enforcement when crash, situation, or other sources of information suggest that the site is unusually hazardous due to illegal driving practices. Crash types that might indicate speeding as a concern include right-angle and rear-end collisions. Speed-enforcement cameras (also known as photo radar) are a potential method to use in these locations.

EXHIBIT V-29
Strategy Attributes for Implementing Automated Enforcement of Approach Speeds (Cameras) (T)

Attribute	Description
Technical Attributes	
Target	The target for this strategy is drivers who speed on approaches to signalized intersections. Crash types related to these actions include angle and rear-end crashes.
Expected Effectiveness	Automated enforcement of speeds may provide a longer-term effect than on-site enforcement by police officers. It is not feasible to provide officers to constantly enforce speed limits, but a camera is more flexible regarding the duration it can operate. There is very little evidence available concerning the crash-reduction benefits of this strategy. Most studies use surrogates, such as speed reduction, to measure the effectiveness of automated speed enforcement. Several agencies have shown reductions in crashes after speed enforcement cameras were installed. Paradise Valley, Arizona, experienced a 40-percent decrease in crashes after it began using a camera mounted in a mobile vehicle. In National City, California, a 51-percent decrease in crashes was experienced in the 6-year period following installation of a camera unit in a mobile vehicle in 1991 (Institute of Transportation Engineers, 1999a). However, these individual evaluations may have methodological problems. “Other research by Bloch (1998) questions the effectiveness of automated speed enforcement versus other enforcement strategies (e.g., speed display boards or periodic police patrols). Bloch claims that more than half of the 18 studies evaluating automated enforcement programs have serious methodological problems, thereby negating the validity of their positive results” (Popolizio, 1995). Furthermore, many applications of automated speed enforcement are not directed at approaches to intersections. While results may be similar, there is no sound evidence that this would in fact be the case. In an effort to provide a more definitive answer to the question of effectiveness, a 1993 study in Riverside, California examined “the effect of photo-radar and speed display boards on traffic speed . . . on comparable streets. . . .” The study sought to determine which device is more effective (including more cost-effective) and “whether supplementing speed display boards with police enforcement makes them more effective.” Bloch reported the study’s results (1998), the primary conclusion of which was “[W]hile both photo-radar and speed display boards can be effective in reducing vehicle speeds, display boards offer better overall results.” Findings showed that photo radar and speed display boards had about the same effectiveness, reducing mean speeds by 5.1 and 5.8 miles per hour (mph),

EXHIBIT V-29 (Continued)
Strategy Attributes for Implementing Automated Enforcement of Approach Speeds (Cameras) (T)

Attribute	***Description***
	respectively, where baseline speeds averaged 34 to 35 mph in 25-mph zones. All speed control devices produced more noteworthy results on speeds 10 mph or more over the 25-mph speed limit. At the experimental site, the photo radar reduced these excessive speeds by 30.2 percent; the speed display board reduced them by 34.9 percent, and the enforced display board by 31.8 percent. However, these significant speed reduction capabilities were not sustained after the devices were removed. Researchers noted one long-term, statistically significant effect with the unenforced display board: a 1.7-mph decrease in speed continued at the experimental site after the display board was gone. The study also analyzed the cost-effectiveness in three areas of the three speed controls. Cost per deployment represented an overall estimate for a speed control program, while cost per mph of speed reduction determined whether a device had been cost-effective in achieving speed reductions. Cost per driver exposed assessed “the cost of exposing an individual driver to a speed management device.” Exhibit V-29A illustrates the overall cost estimates for the three areas. As indicated, the unenforced speed display board was the most cost-effective device on both an hourly and daily basis, and photo radar was the least cost-effective of the three speed control devices (TransSafety, 1998).

EXHIBIT V-29A
Cost-Effectiveness Estimates for Enforced and Unenforced Speed Display Boards and Photo Radar

	Cost-Effectiveness Measure			
		Cost per MPH of Speed Reduction		
Type of Speed Control	**Per Deployment**	**Per Hour of Deployment**	**Per 12-Hour Day**	**Per Driver Exposed**
Photo radar (police costs only)	$155.00	$8.42	$119.23	$0.39
Photo radar (police and equipment)	$220.36	$11.98	$169.51	$0.55
Unenforced speed display board	$10.29	$0.20	$2.39	$0.01
Enforced speed display board	$91.79	$1.27	$16.39	$0.08

Keys to Success	A key to the success of this strategy is planning the enforcement and prioritizing the intersections that need it (Transportation Research Board, 1998). Such intersections should have a combination of high-speed violation rates and related crash patterns. In some cases, public input or observations by law enforcement personnel may suggest that a location should be targeted with enforcement. It is important that both the highway agency and the law enforcement agency(ies) in the jurisdiction be involved jointly in planning and operating the program. Another critical key to the success of an automated enforcement program is public awareness and acceptance. Acceptance by local law enforcement is another critical element necessary for the success of a program.

(*continued on next page*)

EXHIBIT V-29 (Continued)
Strategy Attributes for Implementing Automated Enforcement of Approach Speeds (Cameras) (T)

Attribute	Description
Potential Difficulties	There are many opponents to speed enforcement cameras. Arguments against this strategy include violation of personal privacy, violation of constitutional rights, lower effectiveness than other types of enforcement, high cost outweighing the benefits, accuracy of the devices and the settings, and implementation solely to generate revenue. For an example of organized opposition, see http://www.sense.bc.ca/. For the perspective of a defense attorney on the legal issues, see http://www.azbar.org/ArizonaAttorney/June98/6-98a1.asp. For a position in favor of the technology, see http://www.safety-council.org/news/media/letters/sept17-photoradar.html. In addition, this technology has spawned an industry focused upon defeating it. For example, see http://photo-radar.net/ and http://www.phantomplate.com.
Appropriate Measures and Data	A key process measure is the number of intersection approaches on which automated speed enforcement is applied. A more detailed measure is the number of citations issued from the program, as well as the number of traffic convictions resulting. Crash frequency and severity data by type are key safety effectiveness measures. Data describing these crashes and data on the frequency of violations are needed for periods both before and after installation of the cameras. Traffic volume data are needed to represent exposure. Where feasible, the effect of automated speed enforcement on total crashes and crash types potentially related to speed violations should be evaluated separately. Surrogate safety impact measures include mean speed, 85th-percentile speed, and percentage of drivers exceeding the speed limit by specific amounts.
Associated Needs	PI&E is needed to make automated enforcement successful. Public opinion and acceptance can "make or break" an automated enforcement program. Information and awareness efforts and materials typically include the following information: (1) documentation of the problem (in nontechnical terms), (2) objectives of the automated enforcement program, (3) advantages of automated enforcement or conventional enforcement, (4) general locations or areas of automated enforcement systems, (5) uses of revenue generated by automated enforcement, and (6) information on what to do when a citation is received in the mail. As one approach, the public is being informed about the presence of automated technology by placing signs on each approach to an intersection. Having members of local law enforcement speak on television shows, radio shows, or panels at local meetings has been helpful to some agencies installing cameras. The City of Tempe, Arizona, publishes a schedule of locations at which photo enforcement will be occurring (see http://www.tempe.gov/police/Public%20Information%20Office/photo_radar_shedule.htm). The City of Calgary, Canada, also lists locations and information at: http://www.gov.calgary.ab.ca/police/news/photoradarf.html.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agency crash analysis and field reconnaissance procedures should include methods to identify the need for automated speed enforcement. It is important that the program be handled in a coordinated manner by the highway, law enforcement, and judicial agencies. Nearly every highway and police agency has intersections under its jurisdiction where this strategy may be applied. Any speed control program should be based upon well-established policies and procedures regarding the setting of speed limits. Speed limits should reflect sound principles and application of current scientific knowledge on what

EXHIBIT V-29 (Continued)
Strategy Attributes for Implementing Automated Enforcement of Approach Speeds (Cameras) (T)

Attribute	Description
	speeds are considered safe, as well as protect against demands based solely on political considerations.
Issues Affecting Implementation Time	The time to implement speed enforcement cameras can vary somewhat, depending upon the extent of public involvement, the need to purchase new equipment, and whether new legislation is needed.
Costs Involved	Costs may vary depending upon the effort put into public information and need for additional legislation. Equipment costs can vary somewhat due to the type of camera selected (i.e., 35-mm, video, or digital), collections and records maintenance, and maintenance of equipment. Funding may be available at the national level through NHTSA. Information on grants obtained from NHTSA under TEA 21 may be found at http://www.nhtsa.dot.gov/nhtsa/whatsup/tea21/tea21programs/402Guide.html. While any cost data will soon become outdated, Exhibit V-29A quotes costs in a cost-productivity context.
Training and Other Personnel Needs	Training for highway engineers, safety analysts, and police officers should address automated speed enforcement.
Legislative Needs	Legislation may be necessary before implementing an automated enforcement program if such legislation has not already been enacted. The legislation is necessary to meet constitutional standards, state legal standards, state vehicle code standards, and local jurisdiction standards. A state's enabling legislation should address the broad constitutional issues (federal and state) within a framework that includes elements such as definitions of acceptable automated enforcement devices, any restrictive uses, description of acceptable photographic evidence, and penalty provisions. Local legislation should cover requirements that address local needs for automated enforcement programs in much more detail and should include issues such as operating criteria, the agency that is responsible for camera operation, restrictive uses to that jurisdiction, and requirements for advance notification.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with the other strategies for improving safety at intersections.
Other Key Attributes to a Particular Strategy	None identified.

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

Portland and Beaverton, Oregon have jointly published an excellent report on the Internet regarding their experience with photo radar. Although this was not focused upon intersection approaches, it should provide insights that are equally applicable thereto. http://www.portlandonline.com/police/index.cfm?&a=32388&c=29870.

A description of the program in Calgary, Canada, may be found at: http://www.gov.calgary.ab.ca/police/news/photoradarf.html. It is directed at public information.

A description of the program in Boulder, Colorado, may be found at: http://www.ci.boulder.co.us/publicworks/depts/transportation/safety/photoradar.html.

Refer to Appendix 4 for information on several European countries' experiences with automatic speed enforcement.

Strategy 17.2 E5: Control Speed on Approaches (E)

General Description

Since speed contributes to crash severity, lowering speeds on approaches to intersections can help reduce the severity of crashes. Slowing vehicle speeds on intersection approaches can improve safety for motorists, pedestrians, and bicyclists. Various techniques for attempting to control speeds on approaches involve geometric design, signal control technology, and other traffic calming treatments.

While warning signs or reduction of speed limits on an intersection approach cannot be expected to be extremely effective in lowering speeds, redesign of the approach can be more effective. Construction of a horizontal curve with an appropriate design speed could accomplish speed reduction. However, the curve should be designed so as not to create problems related to violations of driver expectancy or limited sight distance to the intersection.

Some jurisdictions are using signal control technology to change the signal indication to red when a vehicle is detected traveling at a speed significantly over the speed limit on the approach to the intersection. These systems can be accompanied by a sign warning drivers that the technology is in use. Speeding vehicle activated traffic signals have been deployed in the northern Virginia suburbs of Washington, D.C. Additional information can be found on the US DOT's Intelligent Transportation System Joint Program Office (ITS JPO) Web site. (http://www.its.dot.gov/inform/p79.htm). This technology is also used by several European countries. Refer to Appendix 4 on this and other strategies used in Europe to improve intersection safety.

A raised intersection is another example of a design that could be implemented to slow vehicles. Traffic calming is not intended to be used in place of a signal that meets warrants but can be used as a method of addressing crash severity if designed to slow vehicle speeds.

Roadway treatments such as chicanes, speed tables, and reduced lane widths through widening sidewalks or landscaped areas can be used to slow speeds on roadway approaches to intersections. These are discussed in more detail in the pedestrian guide.

Traffic calming strategies are typically intended to reduce vehicle speeds or traffic volumes on collector and local streets. A main benefit of traffic calming is the potential improvement in pedestrian safety. The history of traffic calming is one centered upon neighborhood traffic management rather than collector and arterial streets. Care must be taken not to extend these methods beyond their range of appropriate application.

The Institute of Transportation Engineers has assembled information on traffic calming on its Web site, which is also sponsored by FHWA: http://www.ite.org/traffic/index.html. The ITE site includes links to Web sites for organizations that are implementing traffic calming strategies. Traffic calming is discussed in the guide for crashes at unsignalized intersections and in even more detail in the guide for crashes involving pedestrians.

Objective 17.2 F—Improve Access Management near Signalized Intersections

Effective access management is a key to improving safety at, and adjacent to, intersections. The number of access points, coupled with the speed differential between vehicles traveling along the roadway and vehicles using driveways, contributes to rear-end crashes. The AASHTO Policy on Geometric Design states that driveways should not be located within the functional area of an intersection. The ITE *Traffic Engineering Handbook* suggests that the functional area include storage lengths for turning movements and space to maneuver into turn lanes, and consideration should be given to locating driveways, so as to provide enough space to store queues ahead of or behind driveways.

Closing or relocating driveways will reduce turning movements near intersections. Prohibiting turn movements is another strategy to address access management at intersections.

Strategy 17.2 F1: Restrict Access to Properties Using Driveway Closures or Turn Restrictions (T)

General Description

Restricting access to commercial properties near intersections by closing driveways on major streets, moving them to cross streets, or restricting turns into and out of driveways will help reduce conflicts between through and turning traffic. Such conflicts can lead to rear-end and angle crashes related to vehicles turning into and out of driveways and speed changes near the intersection and the driveway(s).

Locations of driveways on both the cross street and major street should be determined based on the probability that a queue at the signal will block the driveway. Directing vehicles to exits on signalized cross streets will help eliminate or restrict the access to the main roadway. Restricting turns to rights-in and rights-out only will address conflicts involving vehicles turning left from the road and left from the driveway.

Restricting access to properties is discussed in greater detail in the guide for crashes occurring at unsignalized intersections.

Strategy 17.2 F2: Restrict Cross-Median Access near Intersections (T)

General Description

When a median opening on a high-volume street is near a signalized intersection, it may be appropriate to restrict cross-median access for adjacent driveways. For example, left and U-turns can be prohibited from the through traffic stream, and left turns from adjacent driveways can be eliminated. Restrictions can be implemented by signing, by redesign of driveway channelization, or by closing the median access point via raised channelization. When access patterns are changed or restricted, the movements restricted in that location should be accommodated at a safe location nearby.

EXHIBIT V-30
Strategy Attributes for Restricting Cross-Median Access near Intersections (T)

Attribute	Description
Technical Attributes	
Target	The target of this strategy is crashes involving drivers making turns across medians on approaches to signalized intersections. Angle crashes between vehicles turning through the median and opposing vehicles, as well as rear-end crashes involving vehicles waiting to turn and following vehicles, are crashes related to the cross-median movement. Sideswipe crashes may occur when a following vehicle on the major road attempts to pass a vehicle waiting to turn left through the median.
Expected Effectiveness	Restricting cross-median access is expected to eliminate conflicts related to vehicles using the median opening, as well as related rear-end and angle crashes.
Keys to Success	Provision of alternative locations for turning maneuvers is a key to the successful restriction of access at a median opening. Care should be taken to prevent the safety problems related to the median opening from being transferred to another location. It is also important for land owners and affected persons to be involved early in the planning process. The quadrants of many signalized intersections are developed with commercial land uses that rely on pass-by traffic. Demonstrating a linkage to the safety of their customers as well as the operational efficiency of the street serving their business can be a key to overcoming resistance to this strategy. The most successful access management techniques rely on physical barriers to restrict movements. Reliance on only signing and pavement markings requires strong enforcement to be effective, which in many cases will not be feasible.
Potential Difficulties	Restricting access at one location will cause turning movements to shift to another location. Care should be taken to ensure adequate capacity and access are provided to accommodate this and that the diversion to alternative access points will not create a safety problem. Adjacent land owners, particularly commercial businesses, are generally opposed to closing and restricting access that they believe will adversely affect their businesses.
Appropriate Measures and Data	Key process measures include the number of intersection approaches for which median access restriction is implemented and the number of potential or actual conflicts eliminated by improvements. Crash frequency and severity by type of crash are key safety effectiveness measures. It is especially useful to identify crashes related to the median access and analyze them separately. A surrogate safety measure is the actual frequency of conflicts occurring at the target locations. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to the targeted median access points at the intersection should be analyzed separately. Traffic volume data are needed to represent exposure. It is especially desirable to obtain data on the volume of vehicles using the median opening and the conflicting volumes.
Associated Needs	There is a definite need to inform the public, especially adjacent property owners, about the safety benefits of access management techniques, as well as methods available to overcome potentially adverse effects of restricting access. In particular, relating the benefits to the specific location is generally required. Thus, accessible, quality data describing the actual safety performance of the location in question is a strong need.

EXHIBIT V-30 (Continued)
Strategy Attributes for Restricting Cross-Median Access near Intersections (T)

Attribute	Description
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	The optimal situation is to avoid driveway conflicts before they develop. This requires coordination with local land use planners and zoning boards in establishing safe development policies and procedures. Avoidance of high-volume driveways near congested, or otherwise critical, intersections is desirable. Driveway permit staff within highway agencies also needs to have an understanding of the safety consequences of driveway requests. Any highway agency can participate in implementing this strategy. While this strategy is applicable to both rural and urban locations, the greatest need is for agencies that operate extensive systems of urban and suburban arterials. Highway agencies should establish formal policies concerning driveways located near intersections to guide the planning and permitting process and to provide a basis for remedial treatments at existing locations where driveway-related safety problems occur. Local units of government, working as partners with local highway and transportation agencies, should commit to development and implementation of access management guidelines governing land use and site access near signalized intersections for newly constructed facilities. Avoiding safety problems and conflicts with landowners is the preferred approach.
Issues Affecting Implementation Time	Implementation of driveway closures and relocations can require 3 months to 3 years. While an extensive project development process usually is not required, discussions with affected property owners must be carried out to reach agreement on access provisions. Essential aspects of such an agreement may include driveway permits, easements, and driveway sharing agreements. Where agreement cannot be reached, the highway agency may choose to initiate legal proceedings to modify access rights. Contested solutions are undesirable and require considerable time to resolve.
Costs Involved	Costs of closing median access points are low, but the cost of providing access in other locations can vary. The materials and labor needed to install signing or additional median curbs or barriers may be low, but relocation of driveways could increase costs.
Training and Other Personnel Needs	Training for highway agency personnel in access management techniques is important to help ensure that the strategies are properly implemented.
Legislative Needs	The power of a highway agency to modify access provisions is derived from legislation that varies in its provision from state to state. Highway agencies generally do not have the power to deny access to any particular parcel of land, but many do have the power to require, with adequate justification, relocation of access points. Where highway agency powers are not adequate to deal with driveways close to intersections, further legislation may be needed.
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with the other strategies for improving safety at signalized intersections.
Other Key Attributes to a Particular Strategy	Since the safety effectiveness of this strategy has not been adequately quantified, it would be desirable to conduct formal evaluations of any projects that are implemented.

A number of major efforts have produced useful guidance documents on access management. The Transportation Research Board Committee on Access Management (ADA70) recently completed and published an Access Management Manual. (See http://www.accessmanagement.gov/manual.html.) The Florida DOT has developed an Access Management CD-Library which can be obtained through http://www.dot.state.fl.us/planning/systems/sm/accman.

Objective 17.2 G—Improve Safety through Other Infrastructure Treatments

Safety problems at signalized intersections may not be specifically related to traffic control, geometry, enforcement, or driver awareness of the intersection. This section provides information on strategies for special intersection conditions that were not covered in the objectives above.

Strategy 17.2 G1: Improve Drainage in Intersection and on Approaches (T)

General Description

One of the most important principles of good highway design is drainage. Drainage problems on approaches to and within intersections can contribute to crashes just as they can on roadway sections between intersections. However, within an intersection, the potential for vehicles on cross streets being involved in crashes contributes to the likelihood for severe crashes, specifically angle crashes. It is necessary to intercept concentrated storm water at all intersection locations before it reaches the highway and to remove over-the-curb flow and surface water without interrupting traffic flow or causing a problem for vehicle occupants, pedestrians, or bicyclists.

Where greater volumes of truck traffic cause rutting in asphalt pavement, especially in the summer when the pavement is hot, consideration should be given to replacing the asphalt with a concrete pavement. Though this is more expensive than a flexible pavement, less rutting will occur, and repair of pavement damage due to trucks will be needed less frequently.

EXHIBIT V-31
Strategy Attributes for Improving Drainage in Intersection and on Approaches (T)

Attribute	Description
Technical Attributes	
Target	The target for this strategy is crashes at signalized intersections that are related to poor drainage. Such crashes involve vehicles that hydroplane and hence are not able to stop when required; these crash types include angle, rear end, and head on. Pedestrians and bicyclists would also be at risk.
Expected Effectiveness	Improved drainage can help improve safety, increase traffic capacity, and increase the load capacity of the pavement. However, no adequate documentation of the effect on crash experience seems to be published. It can be expected that improved drainage would reduce crashes related to hydroplaning.
Keys to Success	A key to success for this strategy is involving hydrologic and hydraulic specialists during the initial phases to ensure that proper considerations are given to drainage aspects.

EXHIBIT V-31 (Continued)
Strategy Attributes for Improving Drainage in Intersection and on Approaches (T)

Attribute	Description
	Notification of proposed projects should be communicated to other agencies and the public. Any permits and regulations needed by the project should be identified as soon as possible so there are no delays due to legal processes. The success of this strategy will be significantly aided when provision is made for regular condition surveys of existing structures and hydraulic performance to evaluate the functionality of the improvements.
Potential Difficulties	Problems related to drainage design include (1) lateral encroachments on a channel; (2) disruption of water supplies, irrigation facilities, or storm drainage systems; (3) encroachments into environmentally sensitive areas; and (4) failure to plan for ROW.
	Pavement cross slopes in intersections should be considered in relation to vehicle speeds. For further information, see Appendix 9.
	Increased maintenance costs and responsibilities due to change in material costs or drainage systems, regardless of how minor, may present problems in implementing drainage improvements. The responsibilities may include many needs, from mowing grass banks to clearing a channel of debris or ice.
	A serious potential problem associated with drainage design is the legal implications that may be overlooked or not investigated thoroughly. Overlooking a needed permit or regulation can delay a project for months.
Appropriate Measures and Data	Key process measures include the number of intersections at which drainage improvements have been made and the number of each type of improvement (improving inlet structures, redirecting flow away from pavement). The daily volume of vehicles affected by the change is another process measure to consider.
	Frequency and severity of crashes related to insufficient drainage should be tracked before and after implementation of the improvements. Traffic volume data are needed to represent exposure.
Associated Needs	There is no need for special PI&E programs. Adjacent property owners could be informed of the safety benefits of proper drainage maintenance procedures that will need to be performed by the agency with jurisdiction in the area.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Nearly all highway agencies can make use of this strategy. This strategy is applicable to rural, urban, and suburban areas. Highway agencies should review their design manuals regarding drainage design to ensure that proper drainage design/techniques are being used on all projects.
	Policy guidance on drainage design/techniques is discussed in AASHTO's *A Policy on Geometric Design of Highways and Streets (2001)* and *Highway Drainage Guidelines (1993)* and other policy manuals. Highway agencies should consider these policies if they are not covered in their own guidelines.
Issues Affecting Implementation Time	Many small projects that could include drainage improvements, such as spot safety improvements, single bridge replacements, and similar work, are often planned and constructed within several months. Longer-term improvements sometimes require as much time to complete as construction of an entirely new section of highway.
Costs Involved	While minor drainage improvements can be low cost, the costs involved in designing and implementing a drainage system is not an incidental or minor task on most roads.

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EXHIBIT V-31 (Continued)
Strategy Attributes for Improving Drainage in Intersection and on Approaches (T)

Attribute	Description
	Careful attention should be given to adequate drainage and protection of the highway from floods in all phases of location and design; this will be effective in reducing both construction and maintenance costs. Drainage is usually more challenging and costly for urban projects than for rural projects due to more rapid runoff rates and larger volumes of runoff, increases in cost due to potential damage to adjacent property by flooding, greater restrictions because of urban developments, lack of natural areas of water bodies to receive flood water, and higher volumes of traffic or pedestrians.
Training and Other Personnel Needs	Effective drainage techniques should be addressed in highway training concerning design applications/methods of intersections.
Legislative Needs	None identified
Other Key Attributes	
Compatibility of Different Strategies	This strategy can be used in conjunction with the other strategies for improving safety at signalized and unsignalized intersections.
Other Key Attributes to a Particular Strategy	None identified.

Strategy 17.2 G2: Provide Skid Resistance in Intersection and on Approaches (T)

Slippery pavement should be addressed to reduce the potential for skidding. The coefficient of friction is most influenced by vehicle speed, vehicle tire condition, and surface condition. Consideration should be given to improving the pavement condition to provide good skid resistance, especially during wet weather. This can be accomplished by

- Providing adequate drainage,
- Grooving existing pavement, and
- Overlaying existing pavement.

Refer to the guide for addressing run-off-road crashes, which contains a discussion of providing skid-resistant pavements.

Strategy 17.2 G3: Coordinate Closely Spaced Signals near at-Grade Railroad Crossings (T)

General Description

At-grade railroad crossings on approaches to intersections have potential safety problems related to vehicle queues forming across the railroad tracks. The railroad and nearby traffic control signals should be coordinated to provide preemption of the traffic signals when trains are approaching the intersection.

EXHIBIT V-32
Strategy Attributes for Coordinating Closely Spaced Signals near at-Grade Railroad Crossings (T)

Attribute	Description
Technical Attributes	
Target	This strategy targets crashes related to queues on approaches to signalized intersections in close proximity to at-grade railroad crossings. This situation presents a significant potential for vehicle-train crashes, but vehicle-vehicle crashes could also occur if drivers try to speed through an intersection to avoid waiting in a queue near the railroad. Rear-end and angle crashes between vehicles should be analyzed to determine if they are related to the presence of the railroad crossing.
Expected Effectiveness	Coordination of signals to clear the tracks when a train is approaching should eliminate the potential for vehicles to be trapped on the tracks.
Keys to Success	A key to success is the compatibility of the traffic signal and railroad active warning devices in order to safely control vehicle, train, bicycle, and pedestrian movements. Vehicles must be provided with adequate green time to clear the railroad tracks when a train is approaching. This means that potential queue lengths during congested periods must be considered and train detection systems provided on the railroad tracks far enough upstream of the crossing for the signal preemption to clear all vehicles. A gate is an integral part of the active warning system.
Potential Difficulties	The MUTCD states that warning lights shall flash for at least 20 seconds before a train approaches (for train speeds of 20 mph or more). Train detection may need to occur earlier than when the train is 20 seconds away from the crossing, depending upon the amount of time needed to preempt the nearby signal and clear the tracks (Korve, 1999). The railroad track may be so close to the intersection that a design vehicle cannot fit between the tracks and the intersection if it has to stop for a red signal. A presignal can be used to control traffic approaching the at-grade crossing. Presignals are installed on the near side of an at-grade railroad crossing, upstream of the traffic signal. The presignal turns red as a train approaches; this will occur before the downstream traffic signal turns red in order to allow vehicles to clear the railroad tracks. Care must be taken that a driver with a red presignal does not mistakenly think the green track-clearance signal at the intersection is their signal. A special design of the signal face may be needed to ensure vehicles approaching the track do not misunderstand the signals (see Strategy 17.2 D2). A railroad crossing gate would also contribute to understanding of the presignal, since it would be lowered when the presignal is red. Traffic engineers should communicate with railroad agencies to verify the signal preemption system being designed is compatible with the railroad signal systems. Often there are problems with differences in terminology between various agencies (such as “preemption”), and care should be taken to clarify terminology.
Appropriate Measures and Data	Key process measures include the number of signalized intersections near at-grade railroad crossings for which coordination between the train detection and warning system and the traffic signal is implemented. Crash frequency and severity by type of crash and involvement of trains are key safety effectiveness measures. It is useful to separately analyze crashes that did not involve trains by type and whether they occurred during a preempted signal cycle. Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to signal preemption and vehicles clearing the tracks (mainly rear-end crashes) and to driver unawareness of signals (rear-end crashes) should be analyzed. Traffic volume data are needed to represent exposure.

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EXHIBIT V-32 (Continued)
Strategy Attributes for Coordinating Closely Spaced Signals near at-Grade Railroad Crossings (T)

Attribute	Description
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Communication between railroad and highway agencies is an important issue in improving the safety at railroad grade crossings and nearby intersections. The American Association of Railroads has information concerning the type of signal equipment to be used. State and local regulations should also be consulted when determining how the traffic signal will operate.
Issues Affecting Implementation Time	Implementation time can vary, depending on the communication and coordination among railway, highway, and any other agencies that would be involved in improvement of signal control at and near railroad grade crossings.
Costs Involved	Costs involved in improving signal control near at-grade crossings can vary, depending upon the compatibility of existing equipment with the desired treatment. Installation of new equipment that allows coordination of signals will increase costs. Maintenance is another cost element to be considered.
Training and Other Personnel Needs	Coordination of traffic control signals with railroad warning and train detection systems should be addressed in highway agency training concerning intersection operation and railroad grade crossing safety.
Legislative Needs	None identified.
Other Key Attributes	
Compatibility of Different Strategies	Coordination of traffic signals with train detection and warning systems is compatible with most other strategies to improve signalized intersection safety.
Other Key Attributes to a Particular Strategy	A traffic signal preemption system should be designed considering many geometric, traffic flow, and vehicle and train characteristics. The ITE document entitled *Preemption of Traffic Signals At or Near Railroad Grade Crossings with Active Warning Devices* contains discussion on these items (Institute of Transportation Engineers, 1997). Additional information can be found in *NCHRP Synthesis 271: Traffic Signal Operation Near Highway-Grade Crossings,* including discussion on traffic signal and train detection systems (Korve, 1999).

Strategy 17.2 G4: Relocate Signal Hardware out of Clear Zone (T)

General Description

Traffic signal hardware represents a potential roadside hazard similar to utility poles, trees, and other large fixed objects. Traffic signal supports and controller cabinets should be located as far from the edge of pavement as is possible, especially on high-speed facilities, as long as this does not adversely affect visibility of the signal indications. Consideration should be given to shielding the signal hardware if it cannot be relocated. Where there is an existing roadside barrier, the cabinet should be located behind the barrier when feasible. If practical, signal supports in medians should be located to provide more than the minimum clearance required by the agency. The signal hardware should not obstruct sight lines.

Post-mounted signals in the median of a road are often deemed appropriate to reinforce the information presented by the overhead signal heads at the intersection, especially at left-turn lanes, but they are a hazard in that location. However, their benefit may outweigh the disadvantage of the location of the post in the median.

EXHIBIT V-33
Strategy Attributes for Relocating Signal Hardware Outside of Clear Zone (T)

Attribute	Description
Technical Attributes	
Target	This strategy is targeted at crashes with signal hardware at signalized intersections, especially on high-speed roadways, where signal hardware is located within the clear zone or is a sight obstruction. Single-vehicle run-off-road crashes involving the signal hardware, as well as angle crashes related to insufficient sight distance, could occur when signal hardware is in an improper location.
Expected Effectiveness	Relocating the signal hardware outside the clear zone should reduce the likelihood of vehicles striking the hazard. The effectiveness of this strategy is difficult to estimate given the range of conditions and relative infrequency of such conflicts at any one location.
Keys to Success	The new location of the signal hardware should not present a greater safety hazard than the previous location by creating a sight distance obstruction.
Potential Difficulties	Care should be taken to ensure signal hardware is not relocated to a position where it obstructs sight distance or presents a safety hazard to pedestrians or bicyclists. The Americans with Disabilities Act should be consulted to ensure compliance.
Appropriate Measures and Data	A process measure is the number of intersection approaches for which signal hardware is relocated. Frequency and severity of crashes involving signal hardware are key safety effectiveness measures. Traffic volume data are needed to represent exposure. These data should be collected before and after installation of the system for comparison purposes. Traffic volume data are also needed to establish levels of exposure.
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should review their traffic engineering and design policies regarding clear zone and location of signal hardware to ensure appropriate action is being taken on routine projects. Nearly any highway agency can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas.
Issues Affecting Implementation Time	Implementation time will be relatively short if additional ROW is not needed in order to move the hardware outside of the clear zone. Acquisition of ROW will increase implementation time.
Costs Involved	Costs will be moderate if acquisition of ROW is not required to move the hardware outside of the clear zone. Acquisition of ROW will increase costs.
Training and Other Personnel Needs	Clear zone issues should be addressed in highway agency training concerning traffic signal installation and roadside design.
Legislative Needs	None identified.

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EXHIBIT V-33 (Continued)
Strategy Attributes for Relocating Signal Hardware Outside of Clear Zone (T)

Attribute	Description
Other Key Attributes	
Compatibility of Different Strategies	Relocation of signal hardware is compatible with most other strategies to improve safety at signalized intersections.
Other Key Attributes to a Particular Strategy	None identified.

Strategy 17.2 G5: Restrict or Eliminate Parking on Intersection Approaches (P)

General Description

Parking adjacent to turning and/or through lanes on intersection approaches may create a hazard. It can cause a frictional effect on the through traffic stream, can often block the sight triangle of stopped vehicles, and may occasionally cause the blocking of traffic lanes as vehicles move into and out of parking spaces. Restricting and/or eliminating parking on intersection approaches can reduce the workload imposed on the driver and limit additional collision opportunities. Parking restrictions can be implemented through signing, pavement markings, or restrictive channelization. Restrictions can be implemented for specific times of day or specific vehicle types. Enforcement of parking restrictions, accompanied by public information, including towing offending vehicles, is a necessary component to this strategy.

EXHIBIT V-34
Strategy Attributes for Restricting or Eliminating Parking on Approaches (P)

Attribute	Description
Technical Attributes	
Target	This strategy targets crashes related to parking on intersection approaches. The parking, though currently permitted, may present a safety hazard by blocking sight distance (and contributing to angle crashes) or due to parking maneuvers (contributing to rear-end and sideswipe crashes). On-street parking can decrease pedestrian safety if parked vehicles block drivers' and pedestrians' views of each other. Curb extension can be constructed where pedestrians cross streets, and parking should not be permitted on approaches to crosswalks. Further information on this aspect of the problem is covered in the pedestrian crash guide.
Expected Effectiveness	The ITE *Traffic Engineering Handbook* (Pline, 1999) states that based upon a review of crash data, 20 percent of nonfreeway crashes in cities are in one way or another related to parking. Midblock crash rates on major streets with parking stalls that are used about 1.6 million hours per year per kilometer could be expected to decrease up to 75 percent after parking is prohibited. An Australian Bureau of Transport Economics study (available at http://www.dotars.gov.au/transprog/downloads/road_bs_matrix.pdf) of a black spot treatment program showed that banning parking adjacent to an intersection resulted in an average

EXHIBIT V-34 (Continued)
Strategy Attributes for Restricting or Eliminating Parking on Approaches (P)

Attribute	Description
	decrease in crashes of 10 percent on the approach that formerly had parking (Appendix C of Bureau of Transport Economics, 2001). These decreases were seen in the rear-end-, lane-change-, pedestrian-, and parking-maneuver-related crash types.
Keys to Success	Parking regulation signs need to be posted conspicuously. Consistent and rigorous enforcement of these regulations is necessary as well. Working with adjacent land owners to communicate the reasons for prohibiting parking is also essential to achieving success.
Potential Difficulties	The Uniform Vehicle Code does not require use of No Parking signs in some circumstances. Drivers are often not aware of some of the locations where parking is prohibited, however, and signs should be used to convey this information to drivers. Adjacent land owners, particularly commercial businesses, may be opposed to the removal of on-street parking. Removal of parking requires a commitment to enforcement through ticketing and towing where needed.
Appropriate Measures and Data	Key process measures include the number of signalized intersections for which parking has been prohibited on the approaches, the number of approaches on which parking has been restricted, the number of parking spaces eliminated by restrictions, and the percent of problem parking spaces eliminated by restrictions. Crash frequency and severity by type of crash are also key safety effectiveness measures. It is especially useful to separately analyze crashes that are related, directly or indirectly, to on-street parking on the approach (for example, crashes involving vehicles making parking maneuvers, or limited sight distance due to parked vehicles). Crash frequency and severity data are needed to evaluate such improvements. If feasible, both total crashes and crashes related to on-street parking should be analyzed. Traffic volume data are needed to represent exposure.
Associated Needs	Public involvement activities may be required in order to gain understanding and acceptance of the proposed changes in parking regulations.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Highway agencies should review their traffic engineering and design policies regarding on-street parking to ensure appropriate action is being taken on projects. All stakeholders should be involved from the earliest stages of planning, including owners of adjacent properties and representatives of legislative bodies for the jurisdictions involved. Nearly any highway agency can participate in implementing this strategy, which is applicable to rural, urban, and suburban areas.
Issues Affecting Implementation Time	Time to implement parking restrictions is low if no new ordinances are required. Implementation may, however, require passing of ordinances by city councils.
Costs Involved	Costs to implement parking restrictions with signing are low. If enforcement is used to help implement the restrictions, costs will be increased.
Training and Other Personnel Needs	Safety issues related to parking should be addressed in highway agency training concerning intersection design and operation.

(*continued on next page*)

EXHIBIT V-34 (Continued)
Strategy Attributes for Restricting or Eliminating Parking on Approaches (P)

Attribute	Description
Legislative Needs	Approval of appropriate legislative body (mayor, town council, etc.) may be required before no-parking zones can be created.
Other Key Attributes	
Compatibility of Different Strategies	Restriction of parking is compatible with most other strategies for improving signalized intersection safety.
Other Key Attributes to a Particular Strategy	On-street parking has a detrimental effect on capacity of the roadway. Improved flow of vehicles to and through the intersection may be enough to warrant parking prohibition as well.

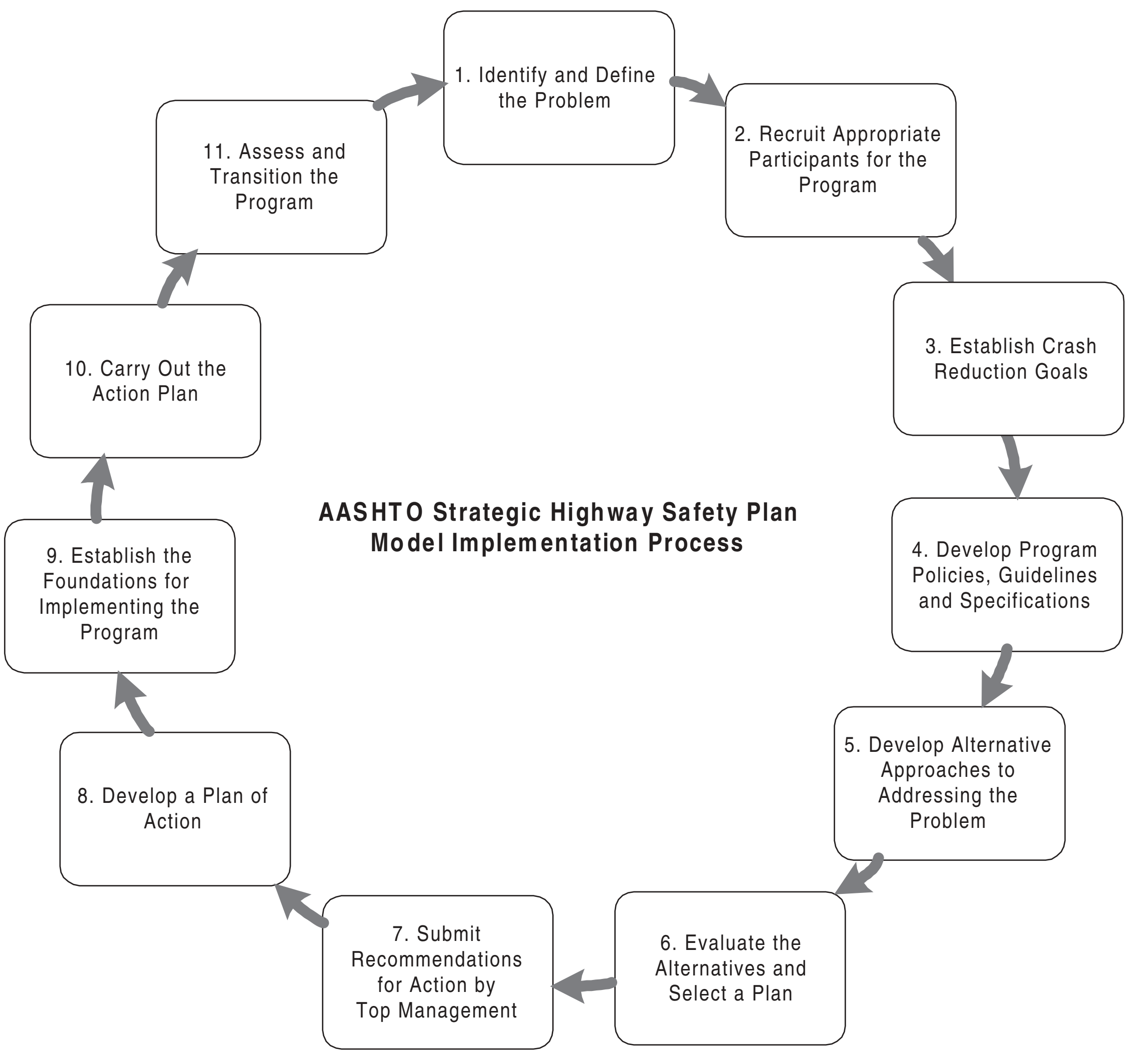
SECTION VI

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 Alternative Permissive Left-Turn Signal Indications
2 Establishing a Clearance Interval
3 Methods for Providing Dilemma Zone Protection
4 European Strategies for Improving Signalized Intersection Safety
5 Emergency Vehicle Detection Technologies
6 Considerations for Left-Turn Lane Design
7 Methods for Improving Visibility of Traffic Signals and Signs
8 Agency Profile: Red-Light-Running Cameras in Howard County, Maryland
9 Intersection of Roadway Profiles
10 Table of Crash Attributes vs. Candidate Strategies for Crashes Occurring at Signalized Intersections
11 Traffic Enforcement in Europe
12 Cost-Benefit Analysis of Road Safety Improvements

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