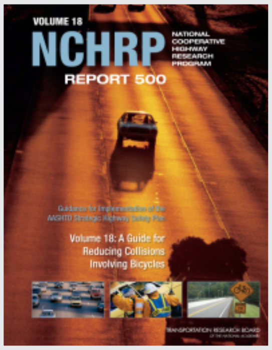

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 500

Guidance for Implementation of the AASHTO Strategic Highway Safety Plan

Volume 18: A Guide for Reducing Collisions Involving Bicycles

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in Cooperation with the Federal Highway Administration

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NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

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

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

The Transportation Research Board of the National Academies was requested by the Association to administer the research program because of the Board's recognized objectivity and understanding of modern research practices. The Board is uniquely suited for this purpose as it maintains an extensive committee structure from which authorities on any highway transportation subject may be drawn; it possesses avenues of communications and cooperation with federal, state and local governmental agencies, universities, and industry; its relationship to the National Research Council is an insurance of objectivity; it maintains a full-time research correlation staff of specialists in highway transportation matters to bring the findings of research directly to those who are in a position to use them.

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

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

NCHRP REPORT 500, VOLUME 18

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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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COOPERATIVE RESEARCH PROGRAMS

CRP STAFF FOR NCHRP REPORT 500, VOLUME 18

NCHRP PROJECT 17-18(3) PANEL
Field of Traffic—Area of Safety

FOREWORD

By Charles W. Niessner
Staff Officer
Transportation Research Board

The American Association of State Highway and Transportation Officials (AASHTO) has adopted a national highway safety goal of halving fatalities over the next 2 decades—or reducing the number of fatalities by 1,000 per year. 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 eighteenth volume of *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan* provides strategies that can be employed to reduce bicycle crashes. 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. 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 eighteenth 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-the-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://safety.transportation.org. Future volumes of the report will be published and linked to the Web site as they are completed.

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

CONTENTS

ACKNOWLEDGMENTS

This volume of *NCHRP Report 500* was developed under NCHRP Project 17-18(3), the product of which is a series of implementation guides addressing the emphasis areas of AASHTO's Strategic Highway Safety Plan. The project was managed by CH2M Hill, and the co-principal investigators were Ron Pfefer of Maron Engineering and Kevin Slack of CH2M Hill. Timothy Neuman of CH2M Hill served as the overall project director for the team. Kelly Hardy and Vanessa Bond, also of CH2M Hill, served as technical specialists on the development of the guides.

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

- Craig Raborn
  University of North Carolina Highway Safety Research Center
- Darren J. Torbic
  Midwest Research Institute

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 people and their agencies for supporting the project through their participation in workshops and meetings, as well as additional reviews of the Bicycle guide:

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SECTION I

Summary

Introduction

Bicycling has been a form of human transportation for hundreds of years and remains a healthy and enjoyable alternative to today's primarily automobile-centric transportation patterns. Before the invention of the automobile, the League of American Wheelmen led efforts to develop and improve America's roadways, leading to our modern system of roads and highways. Bicycle safety problems have a long history in the United Stated, dating back to 1896 when a motor vehicle collided with a bicycle on a New York City Street—the first recorded automobile crash. More than a century later, safety continues to be a primary concern for modern bicyclists, with the challenges of traffic congestion, increasing distances between destinations, larger vehicles, and higher speeds.

Bicyclists are recognized as legitimate roadway users. The Federal Highway Administration (FHWA) bicycle program provides guidance on numerous issues which include examples of statutory language emphasizing that bicyclists are part of the transportation system and concludes that bicyclists "should be included as a matter of routine" in the planning, design, and operation of transportation facilities (FHWA, 1999). The American Association of State Highway and Transportation Officials (AASHTO) notes that bicycle use is recognized as "a viable transportation mode," and that "All highways, except those where cyclists are legally prohibited, should be designed and constructed under the assumption that they will be used by cyclists" (AASHTO, 1999). With any roadway facility a potential bicycle facility, it is important to understand and accommodate bicyclists.

The safety interests of bicyclists are sometimes in conflict with the interests of motorists. This conflict arises primarily from the substantially different characteristics of the two modes of transportation. Although bicycles can be ridden on most types of roads, the design interests of accommodating higher motor vehicle traffic volumes and speeds during peak hour congestion may create conditions that are less safe for bicyclists. This guide includes road treatments, countermeasures, and other options that support a balanced transportation system.

Safety concerns can significantly influence a person's decision to bicycle for transportation or recreation. Bicyclists inherently understand that they are vulnerable road users. However, understanding bicyclist safety issues has proven difficult for engineers, planners, and facility designers. Traditionally, safety problems have been identified by analyzing police crash reports, and improvements have been made only after crashes have occurred. Such methods are not sufficient to fully understand and effectively address bicyclist safety concerns; waiting for crashes before responding with countermeasures carries a high price because many bicycle crashes tend to be severe.

Bicycling has received increased attention in recent years as a mode of transportation that should be encouraged for a variety of reasons. In 1994, the U.S. Department of Transportation presented the National Bicycling and Walking Study (NBWS) to the U.S. Congress, which, in addition to documenting the state of bicycling and walking in the United States, contained two overall goals (USDOT, 1994b):

- Double the number of total trips made by bicycling and walking in the United States from 7.9 percent to 15.8 percent of all travel trips.
- Simultaneously reduce by 10 percent the number of bicyclists and pedestrians killed or injured in traffic crashes.

Congress adopted the Study's goals, effectively creating a directive to Federal transportation agencies to implement the Study's Nine-Point Federal Action Plan with 60 specific action items for the Office of the Secretary, Federal Highway Administration (FHWA), National Highway Traffic Safety Administration (NHTSA), and Federal Transit Administration (FTA); and a Five-Point State and Local Action Plan with a range of suggested activities for state and local agencies. In addition, Congress has vastly increased Federal funds available for bicycle-related projects with the adoption of ISTEA in 1991, TEA-21 in 1998, and SAFETEA-LU in 2005. Federal transportation spending on bicycling and walking increased from $6 million in 1990 to more than $422 million in 2003 (Raborn, 2004).

Progress has been made on the two NBWS goals. The goal of reducing injuries and fatalities by 10 percent has been surpassed. The number of bicyclist and pedestrian fatalities decreased by 18 percent from 1993 to 2003; bicyclist fatalities dropped by 23.3 percent. The number of bicyclists injured in collisions with motor vehicles decreased by 35.3 percent over the same time period (Raborn, 2004), but these decreases may reflect a downward trend in overall bicycling as much as they indicate safety improvements. Since 2003, however, these trends have reversed: as of 2005, the decrease in bicyclist fatalities from 1993 had decreased to less than 4 percent. So, progress has been made on reducing bicyclist injuries and fatalities, but that progress appears now to be eroding.

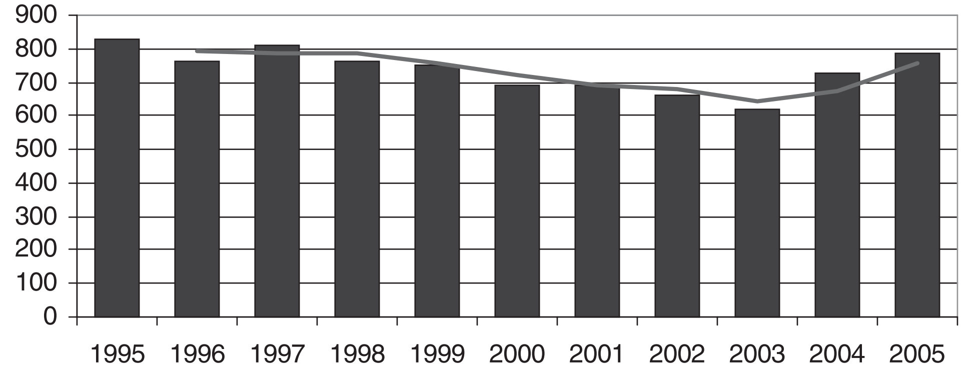
The NBWS goal of doubling the *percentage* of walking and bicycling trips has not been accomplished, although the *number* of trips increased and perhaps doubled. In 1990, there were an estimated 1.7 billion bicycling trips; in 2001, that number had almost doubled to 3.3 billion. Combined walking and bicycling trip numbers increased from 19.7 billion to 38.6 billion. The *percentage* of bicycle trips, however, increased a mere one-tenth of a percent (from 0.7 percent to 0.8 percent), while combined trips increased from 7.9 percent to 9.5 percent. The disparity between the large increase in trip numbers and the small increase in trip percentages can be explained by the explosive growth in total reported trips of all modes; from 249 billion in 1990 to 407 billion in 2001 (Raborn, 2004).

With current Federal policies and guidance and the resources now available to improve conditions for bicycling, any agency charged with construction, operation, and maintenance of transportation infrastructure must devote attention to accommodating safe bicycling activity. The trends show that progress is indeed being made to meet the national walking and bicycling goals, but opportunities remain to improve facilities and programs for bicyclists.

General Description of the Problem

Since the nationwide peak of 1,003 bicyclist fatalities reported in 1975 in the Fatality Analysis Reporting System (FARS), traffic-related bicyclist fatalities and injuries have trended downward. Over the past 10 years, the number of fatalities has generally trended downward,

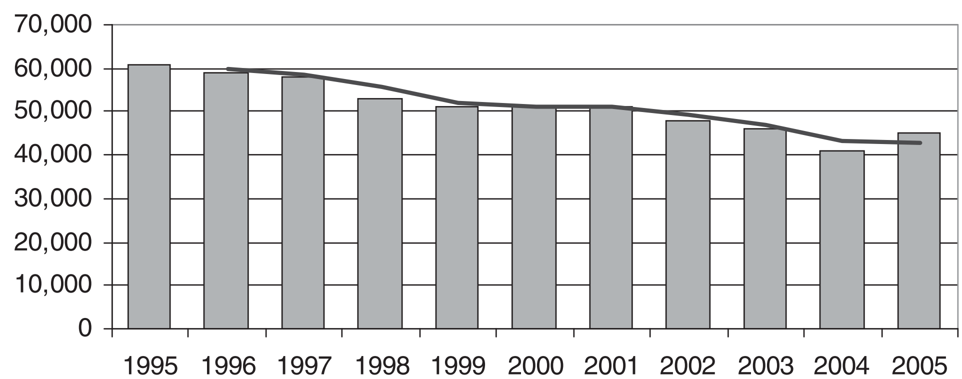
EXHIBIT I-1
Bicyclist fatalities from 1995–2005 (NHTSA, NCSA, Traffic Safety Facts 2004 Data: Pedalcyclists, from FARS data)



although the most recent 2 years have shown a clear increase (see Exhibit I-1). The NHTSA National Center for Statistics and Analysis (NCSA) reports that fatalities have been from 2 to 25 percent below the number killed in 1995 (830 bicyclists) for 8 of the 10 years, even while all motor vehicle crash fatalities have shown increases since 1995. In 2005, 784 bicyclists (5.5 percent below the 1995 level) were killed in collisions with motor vehicles, an increase of 8 percent from 2004 and nearly 27 percent from the 10-year low of 622 bicyclist fatalities recorded in 2003. The 2005 number represented about 2 percent of those killed in all motor vehicle crashes for the year, a proportion that has remained relatively constant in recent years.

A total of 45,000 bicyclists were estimated injured nationwide in crashes with motor vehicles in 2005, which represents an increase in both the number of bicyclists injured and the proportion of all traffic injuries (2 percent) from 2004 (NHTSA, NCSA, from General Estimates System [GES], Exhibit I-2). Reported injuries do not include crashes not reported to the police, even if the bicyclist may have been injured, but this figure likely captures most serious roadway crashes involving motor vehicles. While the number of bicyclist injuries and fatalities fluctuates from year to year, potentially reflecting economic conditions, variations in weather, riding exposure and other trends, as well as chance variation, the general downward trends have been good news. The recent increases in fatalities over the past 2 years, however, dramatically reinforce the need for adoption of strategies to reduce collisions involving bicyclists.

EXHIBIT I-2
Bicyclist injuries from 1995 to 2005 (NHTSA, NCSA, 1995–2004; data from GES estimates)



Crashes involving bicycles and motor vehicles are complex phenomena, and classifying the different events into mutually exclusive categories is a formidable task. Cross and Fisher (1977) were the first researchers to develop and apply crash 'typology' for bicycle crashes as part of a NHTSA response to the 1,003 bicyclist fatalities in 1975. NHTSA also developed a coder's handbook for typing bicyclist crashes to address this issue (NHTSA, n.d.).

Similar typology was used in the FHWA study by Hunter et al. (1996). In a six-state study of 3,000 bicycle crashes taken from hard copy police reports, the most frequent bicycle/motor vehicle crash types were as follows:

Crossing Path Crashes	% of All Crashes
• Motorist failed to yield to bicyclist (includes drive out/through at intersections and at Midblock/driveway locations)	21.7
• Bicyclist failed to yield to motorist at an intersection	16.8
• Bicyclist failed to yield to motorist, midblock	11.8
• Other crossing path crashes	7.2
	57.5
Parallel Path Crashes	
• Motorist turned or merged into bicyclist's path	12.2
• Motorist overtaking bicyclist	8.6
• Bicyclist turned or merged into motorist's path	7.3
• Other parallel path crashes	7.4
	35.5
Specific Circumstances Crashes	
(such as off-roadway, backing vehicle, intentional, and other unusual crash types).	7.0

Crash type proportions varied by state, however, likely reflecting differences in urbanization and other characteristics.

The types of crashes that were most severe were parallel path, rather than crossing path, crashes. Crossing path crashes occur at junctions (intersections or driveways) and more often in urbanized areas where speeds are often slower. Crash type severity was measured by the percentage of bicyclists involved in each type of crash that were seriously injured or killed, as shown below:

Crossing paths
- bicyclist turning error (23.8 percent)
- bicyclist failed to yield, midblock (22.1 percent)
- bicyclist failed to yield, intersection (20.1 percent)

Parallel paths
- operator loss of control (34.6 percent)
- wrong-way operator (most often the bicyclist) (32.1 percent)
- motorist overtaking (29.4 percent)
- bicyclist turn/merge into the path of a motorist (25.2 percent)

Children tend to be over-represented more often in crossing path crashes including ride outs at non-intersection locations (such as driveways) and at intersections and are more likely to fail to clear an intersection or make a turning error. In parallel path crashes, children are more likely to make turn/merge maneuvers in front of motorists; however, adults tend to be over-represented in other parallel path crashes (which tend to be more severe) including motorist over-taking crashes, motorist turn/merge in front of bicyclist on a parallel path, as well as in bicyclist overtaking motorist crashes.

Although declining in recent years, the fatality and injury rates among child riders, in particular the 10 to 15 year age group, remain the highest per capita among any age group. About one-fifth of bicyclist traffic fatalities were between the ages of 5 and 15 in 2004. The share of fatalities accounted for by those under age 16 has been declining in recent years, from 37 percent in 1994 to 21 percent in 2004 (NHTSA, 2004).

Both the number and the proportion of fatalities among adults ages 35 and up has been increasing, from 36 percent of all bicyclist fatalities in 1994 to 59 percent in 2004. Crashes involving adult bicyclists ages 25 and up tend to be more serious, resulting in fatal and disabling injuries a higher percentage of the time. These trends may be due in part to where adults ride, the types of crashes adults tend to be involved in, and changes in the bicycle riding population.

Objectives of the Emphasis Area

Reducing the number and severity of collisions involving bicyclists requires strategies that are targeted towards addressing the main factors that lead to collisions. Based on what is known about bicycle-related crashes, the following objectives—targeted both toward locations where crashes occur as well as toward the causal factors of crashes—are most likely to reduce the number and/or severity of crashes:

- Reduce bicycle crashes at intersections
- Reduce bicycle crashes along roadways
- Reduce motor vehicle speeds
- Reduce bicycle crashes at midblock crossings
- Improve safety awareness and behavior
- Increase use of bicycle safety equipment
- Reduce influence of hazards

Each of these strategies can be accomplished through a variety of the 23 individual strategies (i.e., treatments) presented in Exhibit I-3. Most strategies will work best when used at multiple locations, so that they become standard and expected by roadway users, and in combination with other treatments, so that multiple causal factors are addressed.

In addition, many of the strategies may help accomplish more than one single objective. It is important for transportation professionals and others charged with improving conditions for bicyclists to choose the right combination of treatments to accomplish the maximum desired effect with the available resources.

Finally, those involved in transportation engineering, planning, design, education, and safety should be aware of Safe Routes to School (SRTS) programs as a potential comprehensive technique for improving the transportation safety for children traveling to and from school. SRTS programs are comprehensive programs that involve making safety-related changes to

EXHIBIT I-3
Emphasis Area Objectives and Strategies

Objectives	Strategies
A. Reduce bicycle crashes at intersections	A1. Improve visibility at intersections (T)
	A2. Improve signal timing and detection (T)
	A3. Improve signing (T)
	A4. Improve pavement markings at intersections (T)
	A5. Improve intersection geometry (T)
	A6. Restrict right turn on red (RTOR) movements (E)
	A7. Accommodate bicyclists through roundabouts (T)
	A8. Provide an overpass or underpass (T)
B. Reduce bicycle crashes along roadways	B1. Provide safe roadway facilities for parallel travel (T)
	B2. Provide contraflow bicycle lanes (T)
	B3. Improve bicyclists' visibility (T)
	B4. Improve roadway signage (T)
	B5. Provide bicycle-tolerable shoulder rumble strips (T)
C. Reduce motor vehicle speeds	C1. Implement traffic calming techniques (P)
	C2. Implement speed enforcement (T)
D. Reduce bicycle crashes at midblock crossings	D1. Improve driveway intersections (T)
	D2. Implement access management (T)
E. Improve safety awareness and behavior	E1. Provide bicyclist skill education (T)
	E2. Improve enforcement of bicycle-related laws (T)
F. Increase use of bicycle safety equipment	F1. Increase use of bicycle helmets (P)
	F2. Increase rider and bicycle conspicuity (T)
G. Reduce effects of hazards	G1. Fix or remove surface irregularities (T)
	G2. Provide routine maintenance of bicycle facilities (T)

P = proven; T = tried; and E = experimental

the built environment, implementing extensive child bicyclist (and pedestrian) safety education, and increasing traffic law enforcement around schools. SRTS programs are also intended to increase the number of children walking or bicycling to school, so programs usually include encouragement components as well. More about SRTS, including the full range of comprehensive activities and projects, information about selecting appropriate activities, and evaluation strategies can be learned from the National SRTS Clearinghouse (established by the U.S. Department of Transportation) at: http://www.saferoutesinfo.org.

SECTION II

Introduction

Bicycling has been a form of human transportation for hundreds of years and remains a healthy and enjoyable alternative to today's primarily automobile-centric transportation patterns. Before the invention of the automobile, the League of American Wheelmen led efforts to develop and improve America's roadways, leading to our modern system of roads and highways. Bicycle safety problems have a long history in the United States, dating back to 1896 when a motor vehicle collided with a bicycle on a New York City Street—the first recorded automobile crash. More than a century later, safety continues to be a primary concern for modern bicyclists who are faced with the challenges of traffic congestion, increasing distances between destinations, larger vehicles, and higher vehicle speeds.

Bicyclists are recognized as legitimate roadway users. The Federal Highway Administration (FHWA) bicycle program provides guidance on numerous issues, including examples of statutory language emphasizing that bicyclists are part of the transportation system, and concludes that bicyclists "should be included as a matter of routine" in the planning, design, and operation of transportation facilities (FHWA, 1999). The American Association of State Highway and Transportation Officials (AASHTO) notes that bicycle use is recognized as "a viable transportation mode," and that "All highways, except those where cyclists are legally prohibited, should be designed and constructed under the assumption that they will be used by cyclists" (AASHTO, 1999). With any roadway facility a potential bicycle facility, it is important to understand and accommodate bicyclists.

The safety interests of bicyclists are sometimes in conflict with the interests of motorists. This conflict arises primarily from the substantially different characteristics of the two modes of transportation. Although bicycles can be ridden on most types of roads, the design interests of accommodating higher motor vehicle traffic volumes and speeds during peak hour congestion may create conditions that are less safe for bicyclists. This guide includes road treatments, countermeasures, and other options that support a balanced transportation system.

Safety concerns can significantly influence a person's decision to bicycle for transportation or recreation. Bicyclists inherently understand that they are vulnerable road users. However, understanding bicyclist safety issues has proven difficult for engineers, planners, and facility designers. Traditionally, safety problems have been identified by analyzing police crash reports, and improvements have been made only after crashes have occurred. Such methods are not sufficient to fully understand and effectively address bicyclist safety concerns; waiting for crashes before responding with countermeasures carries a high price because many bicycle crashes tend to be severe.

Recent practitioner experience indicates that multi-faceted approaches are more effective in achieving desired program outcomes, including creating safer walking environments (Zegeer et al., 2004), meeting public health goals (Schieber and Vegega, 2002), and increasing walking and bicycling to school (Raborn and Toole, 2006; FHWA, 2006). Although similar research has not yet been applied to bicycling-specific outcomes, it logically follows that what works for safe walking and increasing physical activity will also work for creating safer bicycling environments. Many bicycle-related safety problems cannot be solved simply by addressing one of the "three Es" (i.e., engineering, education, or enforcement) without also addressing the others. Engineers, planners, law enforcement officers, designers, teachers, public officials, and citizens should all play a role in identifying problems and planning and implementing effective countermeasures and programs for improving bicycling safety.

Particular attention should be paid to education. Skill levels vary widely within the bicycling community. Novice riders may only feel comfortable on slow-speed, neighborhood streets or off-street paths. Children may be more confident and want to bicycle to explore their environment, but may also lack the skills and experience to ride safely under varying conditions. Effective and sustained education programs, often neglected by transportation agencies that focus on engineering solutions, can significantly improve safe riding behavior for all bicyclists.

Bicycle safety issues should be addressed using proactive measures. Many of the solutions that work for proactive pedestrian safety activities should also work for bicyclists. For example, planners can host interactive public workshops, survey bicyclists and other roadway or facility users, and talk with police and traffic engineers to identify safety issues in an area before crashes occur (Zegeer et al., 2004). Bicyclist safety, both actual and perceived, and the provision of appropriate infrastructure, will influence how many people will ride, as well as the number and types of bicyclist crashes that will occur.

Finally, in making any decisions about program or countermeasure implementation, the special characteristics and needs of the targeted population should be considered. This is especially true with respect to education or enforcement interventions, but even road signs and pavement markings can be affected. People of different cultures and ethnic backgrounds, non-English speaking populations, those with physical impairments, and even children and the elderly may necessitate modifications to the countermeasures to ensure that improvements reach their intended audience and have the desired safety benefits.

Bicycling has received increased attention in recent years as a mode of transportation that should be encouraged for a variety of reasons. On April 22, 1994, the U.S. Department of Transportation presented its National Bicycling and Walking Study (NBWS) to the U.S. Congress, which, in addition to documenting the state of bicycling and walking in the United States, contained two overall goals (USDOT, 1994b):

- Double the number of total trips made by bicycling and walking in the United States from 7.9 percent to 15.8 percent of all travel trips.
- Simultaneously reduce by 10 percent the number of bicyclists and pedestrians killed or injured in traffic crashes.

Congress adopted the Study's goals, effectively creating a directive to federal transportation agencies to implement the Study's Nine-Point Federal Action Plan with 60 specific action items for the Office of the Secretary, Federal Highway Administration (FHWA), National Highway Traffic Safety Administration (NHTSA), and Federal Transit Administration (FTA), and a Five-Point State and Local Action Plan with a range of suggested activities for state and local agencies. In addition, Congress has vastly increased federal funds available for bicycle-related projects with the adoption of ISTEA in 1991, TEA-21 in 1998, and SAFETEA-LU in 2005. Federal transportation spending on bicycling and walking increased from $6 million in 1990 to more than $422 million in 2003 (Raborn, 2004).

Progress has been made on the two NBWS goals. The goal of reducing injuries and fatalities by 10 percent has been surpassed. The number of bicyclist and pedestrian fatalities decreased by 18 percent from 1993 to 2003; bicyclist fatalities dropped by 23.3 percent. The number of bicyclists injured in collisions with motor vehicles decreased by 35.3 percent over the same time period (Raborn, 2004), but these decreases may reflect a downward trend in overall bicycling as much as they indicate safety improvements. Since 2003, however, these trends have reversed: as of 2005, the decrease in bicyclist fatalities from 1993 had declined to less than 4 percent. So, progress has been made on reducing bicyclist injuries and fatalities, but that progress appears now to be eroding.

The NBWS goal of doubling the *percentage* of walking and bicycling trips has not been accomplished, although the *number* of trips has increased and perhaps doubled. In 1990, there were an estimated 1.7 billion bicycling trips; in 2001, that number had almost doubled to 3.3 billion. Combined walking and bicycling trip numbers increased from 19.7 billion to 38.6 billion. The *percentage* of bicycle trips, however, increased a mere one-tenth of a percent (from 0.7 percent to 0.8 percent), while combined trips increased from 7.9 percent to 9.5 percent. The disparity between the large increase in trip numbers and the small increase in trip percentages can be explained by the explosive growth in total reported trips of all modes; from 249 billion in 1990 to 407 billion in 2001 (Raborn, 2004).

With current Federal policies and guidance and the resources now available to improve conditions for bicycling, any agency charged with construction, operation, and maintenance of transportation infrastructure must devote attention to accommodating safe bicycling activity. The trends show that progress is indeed being made to meet the national walking and bicycling goals, but opportunities remain to improve facilities and programs for bicyclists.

Other Guidelines

In addition to this bicycling guide, many state and local agencies have developed their own design or planning guidelines that address bicycling safety. Some of these exemplary guides can be found at http://www.bicyclinginfo.org/pp/exemplary.htm.

Another recent collection of countermeasures that are intended to improve safety conditions for bicyclists can be found in BikeSafe, the Bicycle Countermeasure Selection System, available online at http://www.bicyclinginfo.org/bikesafe/.

The recent expansion of Safe Routes to School (SRTS) programs will continue to increase demand for effective and appropriate countermeasures specifically intended for children and school-related travel. The Safe Routes to School Online Guide, available at http://www.saferoutesinfo.org/guide/, includes many Safe Routes-related countermeasures and examples of implementations.

SECTION III

Type of Problem Being Addressed

General Description of the Problem

Since the nationwide peak of 1,003 bicyclist fatalities reported in 1975 in the Fatality Analysis Reporting System (FARS), traffic-related bicyclist fatalities and injuries have trended downward. Over the past 10 years, the number of fatalities has generally trended downward, although the most recent 2 years have shown a clear increase (see Exhibit III-1). The NHTSA National Center for Statistics and Analysis (NCSA) reports that fatalities have been from 2 to 25 percent below the number killed in 1995 (830 bicyclists) for 8 of the 10 years, even while all motor vehicle crash fatalities have shown increases since 1995. In 2005, 784 bicyclists (5.5 percent below the 1995 level) were killed in collisions with motor vehicles, an increase of 8 percent from 2004 and nearly 27 percent from the 10-year low of 622 bicyclist fatalities recorded in 2003. The 2005 number represented about 2 percent of those killed in all motor vehicle crashes for the year, a proportion that has remained relatively constant in recent years.

A total of 45,000 bicyclists were estimated injured nationwide in crashes with motor vehicles in 2005, which represents an increase in both the number of bicyclists injured and the proportion of all traffic injuries (2 percent) from 2004 (NHTSA, NCSA, from General Estimates System [GES], Exhibit III-2). Reported injuries do not include crashes not reported to the police, even if the bicyclist may have been injured, but this figure likely captures most serious roadway crashes involving motor vehicles. While the number of bicyclist injuries and fatalities fluctuates from year to year, potentially reflecting economic conditions, variations in weather, riding exposure, and other trends, as well as chance variation, the general downward trends have been good news. The recent increases in fatalities over the past 2 years, however, dramatically reinforce the need for adoption of strategies to reduce collisions involving bicyclists.

EXHIBIT III-1
Bicyclist Fatalities from 1995–2005 (NHTSA, NCSA, Traffic Safety Facts 2005 Data; Bicyclists and Other Cyclists, from FARS Data)

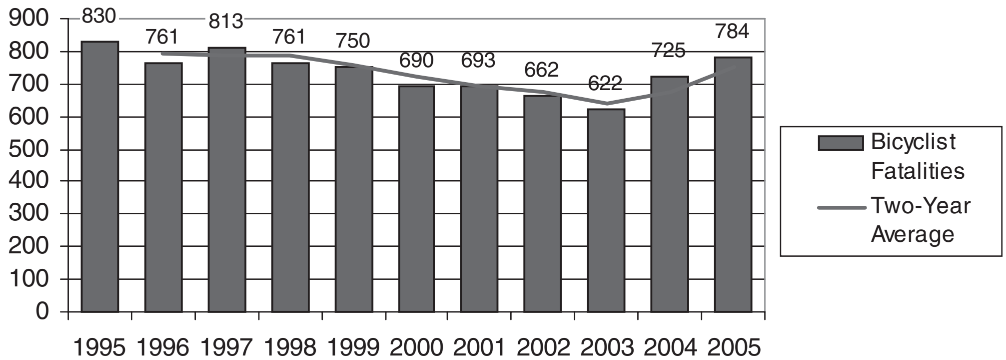
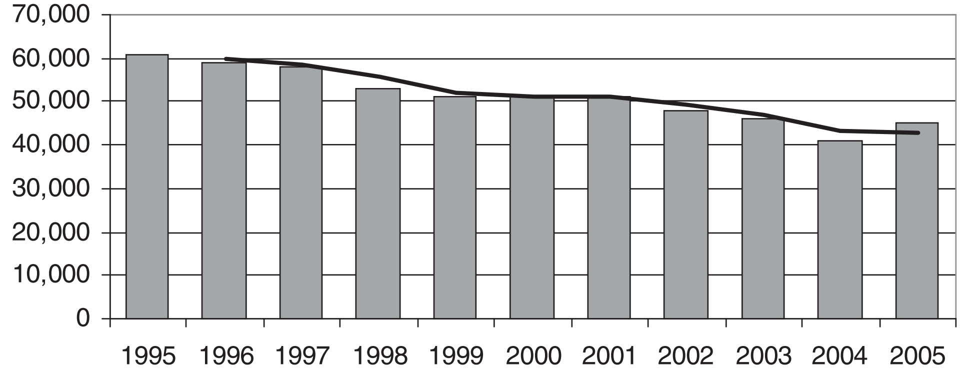


EXHIBIT III-2
Bicyclist Injuries from 1995 to 2005 (NHTSA, NCSA, 2005; Data from GES Estimates)

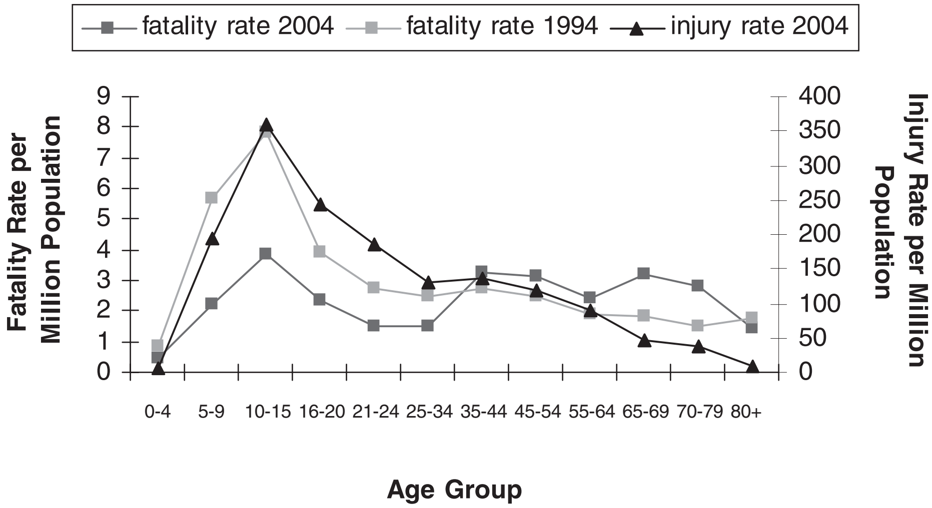


The NBWS published in 1994 stated goals of doubling the percentage of total trips made by bicycling and walking while concurrently reducing the number of bicyclists killed or injured in traffic crashes by 10 percent. The "Ten Year Status Report" released in October 2004 indicates that bicycling trips increased from 1.7 billion, representing 0.7 percent of all trips in 1990, to 3.3 billion (0.9 percent mode share) in 1995, more than doubling the number in 5 years (based on Nationwide Personal Transportation Surveys data). The estimates may not be completely comparable since new interviewing techniques were introduced with the 1995 survey that may have captured more trips. The number of trips remained static, however, from 1995 to 2001 (from 2001 National Household Travel Survey [NHTS] data), with the mode share decreasing from 0.9 to 0.8 percent by 2001. Data from the U.S. Census Journey to Work survey indicate that the number and percentage of people riding bicycles to work declined from 1990 to 2000. The increase in bicycle trips suggested by the NHTS data may therefore be due mostly to increases in other utilitarian and recreational trips (Raborn, 2004).

Although the bicycle percentage of all trips has not doubled over the past 10 years, the fact that numbers of injuries and fatalities and fatality rates per population have decreased over this general time period (see Exhibit III-3), while the number of bicycling trips has increased, is good news. The proportions of these declines that are due to improved safety of roadways and other facilities and improvements in the skill and behavior of bicyclists and motorists, or that may be due to changes in the type of riding and exposure such as the relative amounts or locations of riding by child and adult riders, is unknown because detailed exposure data for bicyclists are lacking. There are indications of possible changes in exposure by different age groups. For example, not only have adult cyclists accounted for an increasing proportion of bicyclist fatalities in recent years as the older population has increased, but the fatality rate per population for adults aged 35 and above has been increasing, while the fatality rate for children has been decreasing.

To continue toward the goals of increasing bicycling and walking trip share, states and communities are increasingly focusing on efforts to support active transportation and recreation. There are multiple reasons to improve opportunities for bicycling, including the health and fitness of community members, decreased motor vehicle congestion, and improved air quality. Some population groups, such as those with a lower income, may also depend heavily on

EXHIBIT III-3
Fatality Rates per Million Population for Years 1994 and 2004, and Injury Rate per Million Population, 2004 (NHTSA, Traffic Safety Facts, 1994–2004 Data)



bicycling for basic transportation. Children should also be able to safely bicycle to school. Communities have an obligation to provide safe access for all populations. Therefore, states and communities are tasked with improving safety and reducing the numbers of bicyclists killed and injured on our roadways while encouraging and increasing opportunities for bicycling.

States and Local Areas with the Highest Numbers of Crashes

Bicyclist fatalities and fatality rates tend to vary from year to year as well as by state and local jurisdiction. In 2005, the total bicyclist fatality rate across the United States was 2.64 per million population. Exhibit III-4 provides bicyclist fatality rates for the 50 states, the District of Columbia, and Puerto Rico. On average, bicyclists accounted for approximately 2 percent of all fatalities resulting from motor vehicle crashes in 2005. This proportion has remained relatively constant in recent years.

Factors Affecting the Number and Severity of Crashes

Bicyclists' and motorists' behaviors as well as roadway, traffic, and light conditions, many of which are discussed below, are among the factors that may contribute to bicycle crashes. Specific bicyclist and motorist maneuvers that may lead to crashes are identified in the Precipitating Events section.

Alcohol Involvement

Alcohol or other impairment is a significant factor for overall crashes and crash severity. For all crashes, nearly 11 percent of drivers were reported to be under the influence of alcohol, drugs, or medication, and alcohol was involved in 40 percent of fatalities (NHTSA, 2004). Alcohol use is also over-represented in bicyclist fatalities. Alcohol use by either the motorist

EXHIBIT III-4
Bicyclist Traffic Fatalities and Fatality Rates by State, 2005 (Source: NHTSA, 2005; FARS Data; Population Data from Bureau of the Census)

State	Total Traffic Fatalities	Resident Population (1000s)	Bicyclist Fatalities	Percent of Total	Bicyclist Fatalities per Million Population
Alabama	1,131	4,558	13	1.1	2.85
Alaska	72	664	1	1.4	1.51
Arizona	1,177	5,939	35	3.0	5.89
Arkansas	648	2,779	3	0.5	1.08
California	4,329	36,132	115	2.7	3.18
Colorado	606	4,665	8	1.3	1.71
Connecticut	274	3,510	3	1.1	0.85
Delaware	134	844	2	1.5	2.37
District of Columbia	48	551	3	6.3	5.45
Florida	3,543	17,790	124	3.5	6.97
Georgia	1,729	9,073	23	1.3	2.54
Hawaii	140	1,275	4	2.9	3.14
Idaho	275	1,429	3	1.1	2.1
Illinois	1,361	12,763	22	1.6	1.72
Indiana	938	6,272	13	1.4	2.07
Iowa	450	2,966	11	2.4	3.71
Kansas	428	2,745	4	0.9	1.46
Kentucky	985	4,173	12	1.2	2.88
Louisiana	955	4,524	21	2.2	4.64
Maine	169	1,322	3	1.8	2.27
Maryland	614	5,600	7	1.1	1.25
Massachusetts	442	6,399	5	1.1	0.78
Michigan	1,129	10,121	25	2.2	2.47
Minnesota	559	5,133	7	1.3	1.36
Mississippi	931	2,921	5	0.5	1.71
Missouri	1,257	5,800	8	0.6	1.38
Montana	251	936	4	1.6	4.28

EXHIBIT III-4 (Continued)
Bicyclist Traffic Fatalities and Fatality Rates by State, 2005 (Source: NHTSA, 2005; FARS Data; Population Data from Bureau of the Census)

State	Total Traffic Fatalities	Resident Population (1000s)	Bicyclist Fatalities	Percent of Total	Bicyclist Fatalities per Million Population
Nebraska	276	1,759	3	1.1	1.71
Nevada	427	2,415	10	2.3	4.14
New Hampshire	166	1,310	3	1.8	2.29
New Jersey	748	8,718	17	2.3	1.95
New Mexico	488	1,928	5	1.0	2.59
New York	1,429	19,255	47	3.3	2.44
North Carolina	1,534	8,683	36	1.6	4.15
North Dakota	123	637	2	1.6	3.14
Ohio	1,323	11,464	13	1.0	1.13
Oklahoma	802	3,548	7	0.9	1.97
Oregon	488	3,641	11	2.3	3.02
Pennsylvania	1,616	12,430	18	1.1	1.45
Rhode Island	87	1,076	1	1.1	0.93
South Carolina	1,093	4,255	16	1.5	3.76
South Dakota	186	776	0	0	0
Tennessee	1,270	5,963	10	0.8	1.68
Texas	3,504	22,860	46	1.3	2.01
Utah	282	2,470	3	1.1	1.21
Vermont	73	623	0	0	0
Virginia	947	7,567	21	2.2	2.78
Washington	647	6,288	13	2.0	2.07
West Virginia	374	1,817	2	0.5	1.1
Wisconsin	815	5,536	14	1.7	2.53
Wyoming	170	509	2	1.2	3.93
U.S. Total	43,443	296,410	784	1.8	2.64
Puerto Rico	453	3,912	11	2.4	2.81

or the bicyclist was reported in more than one-third of the fatal bicyclist collisions over the past 3 years (NHTSA, n.d.). In 30 percent of the 2005 crashes, either the motorist or bicyclist had a blood alcohol concentration (BAC) of 0.08 g/dl or higher. Over one-fifth (23 percent) of bicyclists killed had a BAC of 0.08 g/dl or higher and 27 percent had a BAC of 0.01 g/dl or higher.

Night Riding

According to the NCSA, 31 percent of bicyclist fatalities occurred between the hours of 5 and 9 p.m. (NHTSA, 2004 data). A sample of crashes from six states from the early 1990's found that 15 percent of crashes occurred under conditions of darkness (lighted and unlighted roadways) and another 5 percent at dusk or dawn. Additionally, serious injury and fatal crashes were disproportionately likely to occur during late night (10 p.m. to 2 a.m.) and early morning (2 a.m. to 6 a.m.) hours. Alcohol was also more likely to be a factor.

Data from the 6,951 North Carolina bicycle/motor vehicle crashes reported over 7 years indicate that 20 percent of the crashes occurred under conditions of darkness with another 5 percent at dusk or dawn (see http://www.pedbikeinfo.org/pbcat/). Serious and fatal injuries were also over-represented in North Carolina night-time crashes, particularly on unlighted roadways. The differences in crash seriousness between lighted and unlighted roadways may be largely related to other factors such as speed limit and urban (more often lighted) and rural (often unlighted) locations.

While most states have laws requiring the use of head and tail lights at night, review of crash reports reveals that many bicyclists involved in night-time crashes (4.4 percent) did not use the required equipment (Hunter et al., 1996). Better crash report information would likely raise this figure further. Additionally, requirements vary from state to state, and in some cases, the required lighting may not improve visibility sufficiently.

Wrong-way and Sidewalk Riding

Bicyclists who ride against the direction of traffic or on the sidewalk are implicated in crashes occurring along the roadway. In a study of a representative sample of 2,931 bicycle crashes from six states (California, Florida, Maryland, Minnesota, North Carolina, and Utah) prepared for FHWA in the early 1990's, bicyclists were riding against the direction of traffic in 32 percent of relevant cases and about 15 percent of bicyclists were coded as contributing to the crash by riding against traffic (Hunter et al., 1996). This factor is particularly prevalent in crashes at intersections and other junctions where the motorist and bicyclist are on crossing paths. Bicyclists riding the wrong-way are approaching from a direction where motorists do not expect them, and motorists are typically looking for a gap to the left before pulling out. The right-turn-on-red vehicle movement is an additional component to a number of these crashes. Additionally, bicyclists traveling the wrong-way may not be able to see traffic signs and signals.

Bicyclists on the sidewalk are also in a position where motorists do not expect them, particularly if also traveling the wrong-way. While about 16 percent of the cases indicated the bicyclist was riding on the sidewalk, riding off the sidewalk at a driveway or intersection was indicated as a factor in a little more than 9 percent of the cases analyzed by Hunter et al. (1996). Crashes involving sidewalk riding tended, however, to result in fewer serious and fatal injuries than other crashes. Around 10 to 11 percent of the North Carolina crashes involved sidewalk riding. Three-fourths of bicyclists riding on a sidewalk, crosswalk, or driveway crossing in these crashes were also riding facing traffic. The problem is further compounded since bicyclists are often traveling faster than pedestrians and may not have enough time to avoid a vehicle pulling across the sidewalk.

Traffic Speed

Speed influences both the severity of crashes that occur as well as the likelihood of occurrence, and has been identified as a contributing factor in all types of crashes. National data suggest that 31 percent of crashes were speed-related. Driving too fast for conditions or in excess of posted speed limit or racing was identified as a contributing factor for drivers in 30 percent of all fatal crashes in 2005 (NHTSA, 2005 data). Fatality rates are also higher for crashes on higher speed limit roadways, climbing from about 2 per 1,000 crashes at speeds of 48 km/h (30 mph) or less to more than 14 per 1,000 at 88 km/h (55 mph) or more. Fatal bicyclist injuries were more than six times as prevalent, and disabling injuries were nearly twice as prevalent, than for all bicyclist crashes in North Carolina when excessive speed was indicated. Bicyclists are vulnerable road users, and the impact of higher speeds on crash severity is obvious.

Parking and Driveways

The number of potential conflict areas increases when driveways are frequent or closely spaced and on-street parking is provided. Bicyclists are particularly vulnerable to left-turning motorists who may not observe approaching bicyclists before making left turns into driveways or side streets. Serious injury can also occur when bicyclists ride too close to parked vehicles. Motorists exiting a parked vehicle without checking behind may open a door or step out in front of a bicyclist. “Dooring” crashes are related to presence and configuration of on-street parking and adjacent travel or bike lanes. In a study conducted by Hunter et al. (1996), bicyclist-side, on-street parking was present in nearly 12 percent of crashes.

Helmet Use

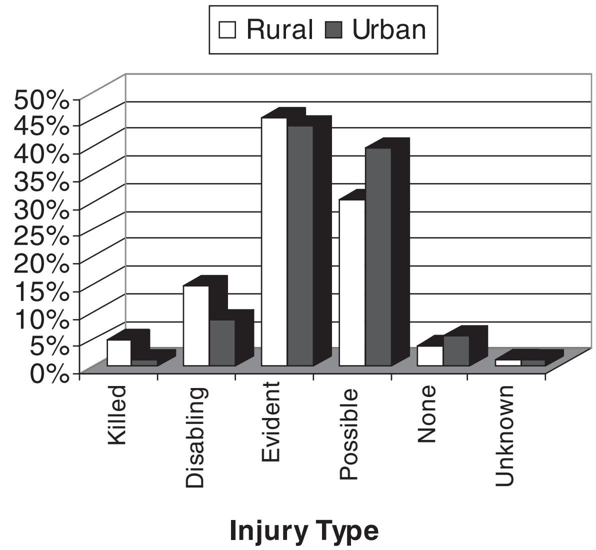
While helmets may not have an impact on the frequency of crashes, numerous studies have found that use of approved bicycle helmets significantly reduces the risk of fatal injury, serious head and brain injury, head injury, and middle and upper face injury among bicyclists of all ages involved in all types of crashes and crash severities. Relative risk reductions estimated in a meta-analysis of 16 peer-reviewed studies were 60 percent for head injury, 58 percent for brain injury, 47 percent for facial injury, and 73 percent for fatal injury (Attewell et al., 2001).

Where Crashes Occur

Area type

The majority of bicycle/motor vehicle crashes occur in urban areas, typically around two-thirds but varying with population densities and other factors, reflecting the greater populations and more frequent riding that typically occur in urban areas. In 2005, 69 percent of bicyclist

EXHIBIT III-5
Bicyclist Injury Distributions for Rural and Urban Crash Locations, 2000–2003, North Carolina Bicycle/Motor Vehicle Crashes. (Source Data NCDOT/PedBike Division)



fatalities nationwide also occurred in urban areas (NHTSA, 2005 data). However, rural crashes do tend to be more serious, reflecting higher speed roads and types of crashes that occur in rural areas, and result in a higher proportion of fatal and serious injuries (Exhibit III-5). In North Carolina, rural crashes accounted for 34 percent of all crashes over a recent 3-year period but comprised 53 percent of the fatal injuries and 57 percent of the disabling injuries.

Location Type

Nearly one-half of all bicycle traffic crashes occurred at intersections, another 4 percent were intersection-related, and driveways and other junctions accounted for about 22 percent of crashes in the FHWA study (Hunter, et al., 1996). About one-fourth of crashes occurred at non-intersection locations with no distinguishing features. Data from North Carolina crashes found that about 42 percent occurred at intersections or were intersection-related. More fatal bicyclist crashes tend to occur at non-intersection locations (70 percent), while the majority of injury crashes (62 percent) occur at intersections (NHTSA, Traffic Safety Facts, 2003 and 2005).

Road Type

The types of roads on which crashes occur likely vary from state to state. In the FHWA study, crashes occurred most frequently on local streets (34 percent), followed by county routes (28 percent), state routes (18 percent), U.S. routes (8 percent), and Interstate routes (0.2 percent). Other road types accounted for 13 percent of bicyclist crashes (Hunter et al., 1996).

When Crashes Occur

Bicycle crash frequencies are generally highest during the summer and lowest in the winter, but these trends may vary by region of the country, depending on general climate, rainfall, and other factors.

Crashes fluctuate by day of the week year-to-year but are generally fairly evenly distributed, with somewhat fewer occurring on weekend days than week days.

Various data sources indicate that crashes peak in the afternoon to early evening hours. In the Hunter et al. study (1996), the peak number of crashes occurred between the hours of 2 and 6 p.m. (41 percent). The second highest crash period was between the hours of 6 and 10 p.m. (25 percent). By contrast, only 9 percent of crashes occurred between the 4-hour periods of 6 to 10 a.m. NHTSA data mirror these time-of-day trends but also suggest that fatalities are over-represented in the later evening. More bicyclists were injured between the hours of 3 and 6 p.m. (31 percent), but the highest period for fatalities was between 6 and 9 p.m. (23 percent of fatalities) (NHTSA, 2003).

Nearly 96 percent of crashes occur during clear or cloudy weather when most riding is likely to occur, while about 4 percent of crashes occurred while it was raining (Hunter et al., 1996). Mirroring weather conditions, most crashes occur on dry roadways (92 percent), with about 7 percent occurring on wet roads and 1 percent under other conditions.

Characteristics of the Victims

Although declining in recent years, the fatality and injury rates among child riders, in particular the 10- to 15-year-old age group, remain the highest per capita among any age group (Exhibit III-3), and about one-fifth of bicyclist traffic fatalities were between the ages of 5 and 15 in 2004. The share of fatalities accounted for by those under age 16 has been declining in recent years, however, from 37 percent in 1994 to 21 percent in 2004 (NHTSA, 1994–2004 data).

Both the number and the proportion of fatalities among adults ages 35 and up has been increasing, from 36 percent of all bicyclist fatalities in 1994 to 59 percent in 2004. Crashes involving adult bicyclists ages 25 and up tend to be more serious, resulting in fatal and disabling injuries a higher percentage of the time. These trends may be due in part to where adults ride and the types of crashes in which they tend to be involved.

Males of all ages account for the largest proportion of injured and killed bicyclists (76 percent and 87 percent in 2004, respectively), and the rates of injury and death are 3.4 times and 6.8 times those of females. These trends tend to hold up in various locations and jurisdictions and other data generally indicate that males account for around 70 to 80 percent of riders in most locations.

As mentioned previously, alcohol use on the part of the bicyclist may be a factor in about 20 to 25 percent of bicyclist fatalities.

Child bicyclists are deemed to be solely at fault 70 to 80 percent of the time in crashes with motor vehicles, while only about 40 percent of adult bicyclists are deemed to be at fault

(Hunter et al. 1996). Both bicyclist and motorist are identified as contributing to the crash in 5 to 20 percent of crashes over various bicyclist ages. Motorists were deemed to be solely at fault in from 5 percent of crashes with the youngest aged cyclists to about 36 percent of crashes involving adults ages 50 to 59.

Precipitating Events

Crashes involving bicycles and motor vehicles are complex phenomena, and classifying the different events into mutually exclusive categories is a formidable task. Cross and Fisher (1977) were the first researchers to develop and apply crash 'typology' for bicycle crashes as part of a NHTSA response to the 1,003 bicyclist fatalities in 1975. NHTSA also developed a coder's handbook for typing bicyclist crashes to address this issue (NHTSA, n.d.).

Similar typology was used in the FHWA study by Hunter et al. (1996). In a six-state study of 3,000 bicycle crashes taken from hard copy police reports, the most frequent bicycle/motor vehicle crash types were as follows:

Crossing Path Crashes	% of All Crashes
• Motorist failed to yield to bicyclist (includes drive out/through at intersections and midblock/driveway locations)	21.7
• Bicyclist failed to yield to motorist at an intersection	16.8
• Bicyclist failed to yield to motorist, midblock	11.8
• Other crossing path crashes	7.2
	57.5
Parallel Path Crashes	
• Motorist turned or merged into bicyclist's path	12.2
• Motorist overtaking bicyclist	8.6
• Bicyclist turned or merged into motorist's path	7.3
• Other parallel path crashes	7.4
	35.5
Specific Circumstances Crashes (such as off-roadway, backing vehicle, intentional, and other unusual crash types).	7.0

Crash type proportions varied by state, however, likely reflecting differences in urbanization and other characteristics.

The most severe crashes, as measured by the percentage of involved bicyclists seriously injured or killed, were as follows:

Crossing paths
- Bicyclist turning error (23.8 percent)
- Bicyclist failed to yield, midblock (22.1 percent)
- Bicyclist failed to yield, intersection (20.1 percent)

Parallel paths
- Operator loss of control (34.6 percent)
- Wrong-way operator (most often the bicyclist) (32.1 percent)

- Motorist overtaking (29.4 percent)
- Bicyclist turn/merge into the path of a motorist (25.2 percent)

The high proportions of severe crashes, therefore, were all parallel path crashes. Crossing path crashes occur at junctions (intersections or driveways) and more often in urbanized areas where speeds are often slower.

Children tend to be over-represented more often in crossing path crashes including ride outs at non-intersection locations (such as driveways) and at intersections, failing to clear an intersection, and turning errors, and in turn/merge maneuvers in front of motorists traveling on parallel paths. Adults tend to be over-represented in parallel path crashes (which tend to be more severe) including motorist overtaking crashes, motorist turn/merge in front of bicyclist on a parallel path, as well as in bicyclist overtaking motorist crashes.

The crash typologies developed by Cross and Fisher, by NHTSA, and in the FHWA study evolved into the development of an automated crash typing software, the Pedestrian and Bicycle Crash Analysis Tool (PBCAT) (Harkey et al., 1999), which is currently being further refined for version 2. These and other studies have resulted in the identification of a number of specific crash types that have been classed into thirteen groups (plus an additional miscellaneous group comprising non-roadway, and some rarer and unusual crash types) for the purposes of identifying appropriate countermeasures. The definitions of these crash groups are shown in Exhibit III-6.

EXHIBIT III-6
Example Bicycle/Motor Vehicle Crash Types and Descriptions

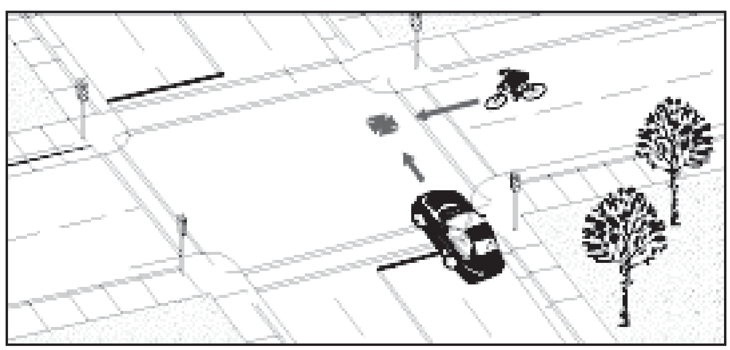
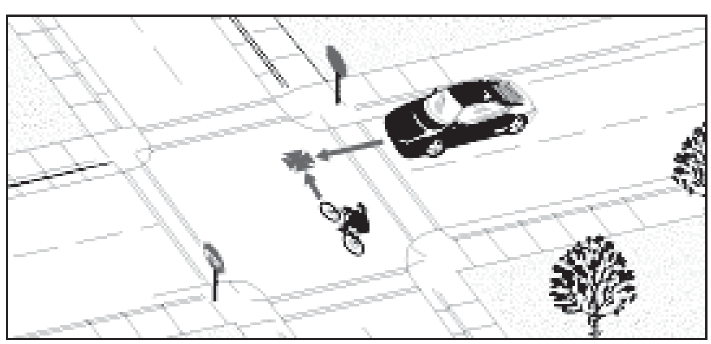
Crash Group	Example Image
1. Motorist failed to yield—signalized intersection *Description*—The motorist drove into the crosswalk area or intersection and collided with the bicyclist. The motorist either violated the signal or did not properly yield right-of-way to the bicyclist.	
2. Motorist failed to yield—non-signalized intersection *Description*—The motorist drove into the crosswalk area or intersection and collided with the bicyclist. The motorist either violated the sign (stop, yield, flashing signal) or did not properly yield right-of-way to the bicyclist.	

EXHIBIT III-6 (Continued)
Example Bicycle/Motor Vehicle Crash Types and Descriptions

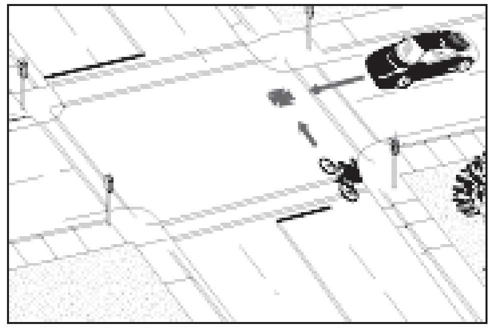
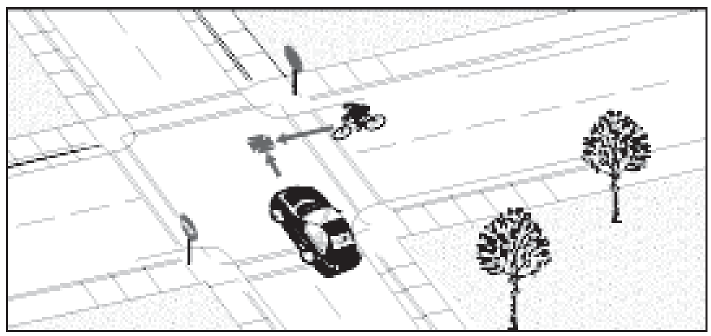
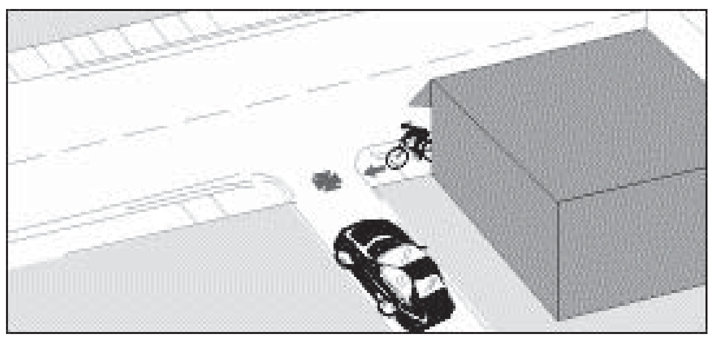
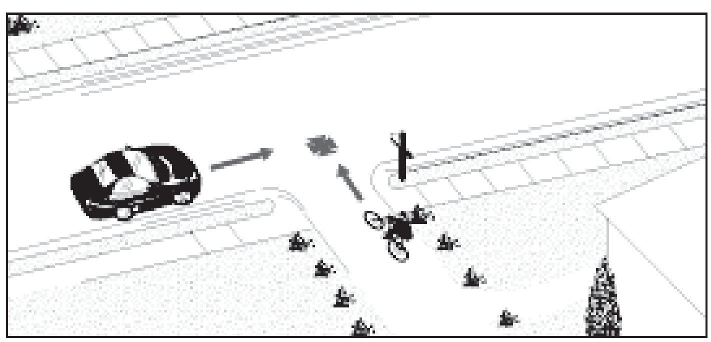
Crash Group	Example Image
3. Bicyclist failed to yield—signalized intersection *Description*—The bicyclist rode into the intersection and collided with the motorist. The bicyclist either violated the signal or did not properly yield right-of-way to the motorist.	
4. Bicyclist failed to yield—non-signalized intersection *Description*—The bicyclist rode into the intersection and collided with the motorist. The bicyclist either violated the sign (stop, yield, flashing signal) or did not properly yield right-of-way to the motorist.	
5. Motorist drove out—midblock. *Description*—The motorist drove across the sidewalk or into the street from a non-intersection location (including residential or commercial driveway or other midblock location) without yielding to the bicyclist.	
6. Bicyclist rode out—midblock. *Description*—The bicyclist rode into the street from a non-intersection location (including residential or commercial driveway or other midblock location) without yielding to the motorist.	

EXHIBIT III-6 (Continued)
Example Bicycle/Motor Vehicle Crash Types and Descriptions

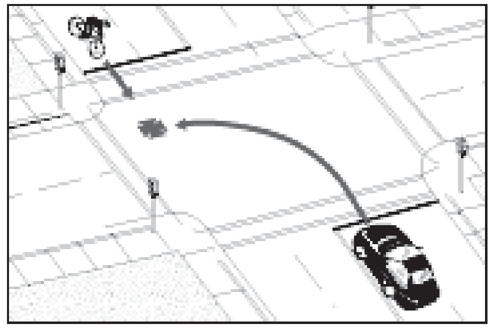
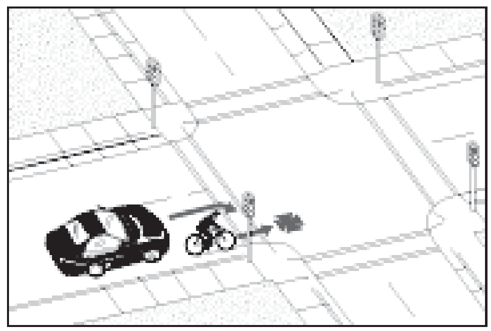
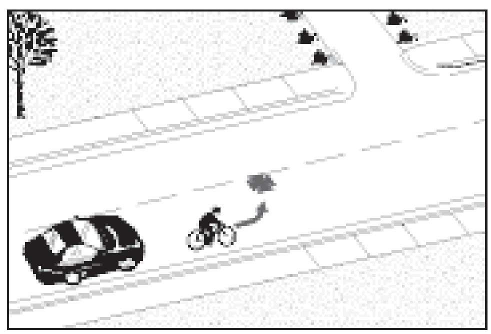
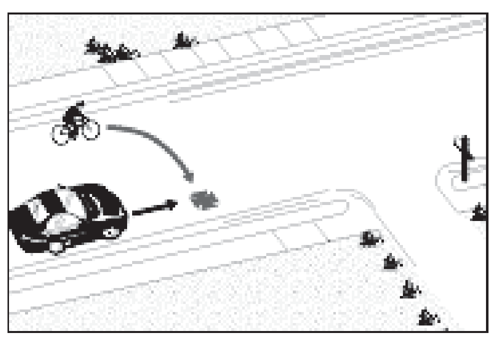
Crash Group	Example Image
7. Motorist turned or merged left into path of bicyclist. *Description*—The motorist made a left turn or merge into the path of a bicyclist traveling in the same or opposite direction.	
8. Motorist turned or merged right into path of bicyclist. *Description*—The motorist made a right turn or merge into the path of a bicyclist traveling in the same or opposite direction.	
9. Bicyclist turned or merged left into path of motorist. *Description*—The bicyclist made a left turn or merge into the path of a motor vehicle traveling in the same or opposite direction.	
10. Bicyclist turned or merged right into path of motorist. *Description*—The bicyclist made a right turn or merge into the path of a motor vehicle traveling in the same or opposite direction.	

EXHIBIT III-6 (Continued)
Example Bicycle/Motor Vehicle Crash Types and Descriptions

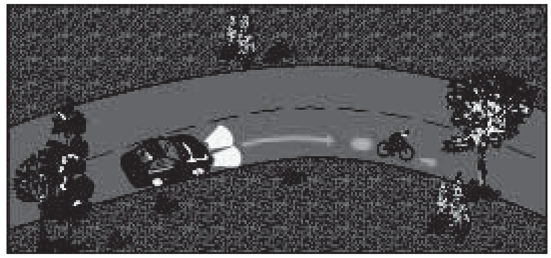
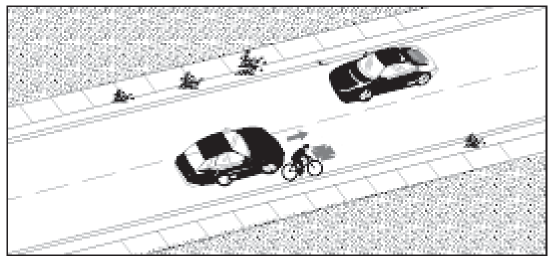
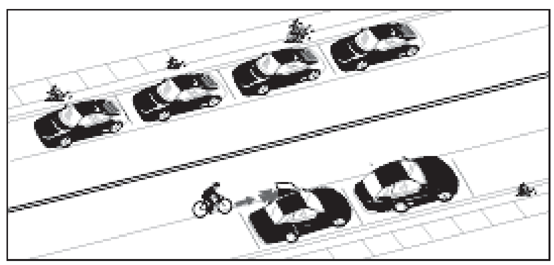
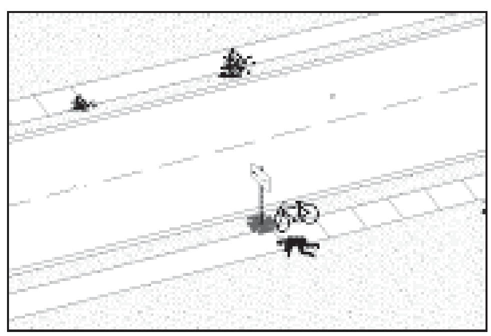
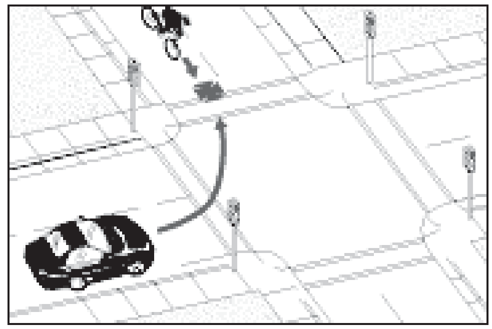
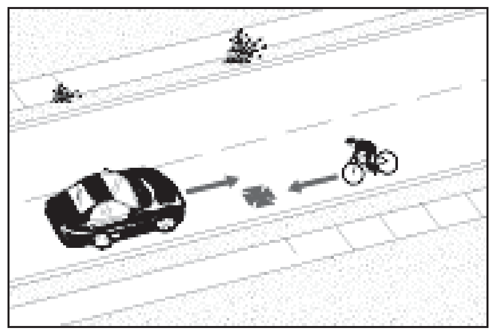
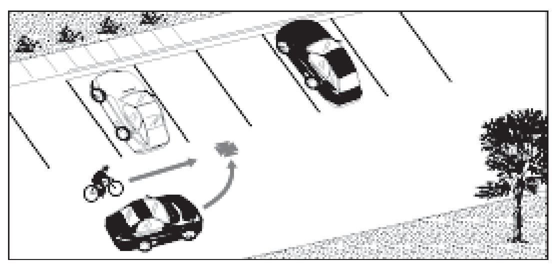
Crash Group	Example Image
11. Motorist overtaking bicyclist *Description*—The motorist was overtaking the bicyclist at the time of the crash.	 
12. Bicyclist overtaking motorist *Description*—The bicyclist was overtaking the motorist (passing on the right or the left) at the time of the crash. (Includes crashes involving bicyclists striking parked cars or extended doors.)	
13. Non-motor vehicle crashes. *Description*—These crashes do not involve a motor vehicle and may occur in a variety of ways including bike only falls, bike-bike, bike-pedestrian, and bike into object crashes.	

EXHIBIT III-6 (Continued)
Example Bicycle/Motor Vehicle Crash Types and Descriptions

Crash Group	Example Image
14. Other and non-roadway crashes *Description*—Includes a variety of specific crash types such as turning errors by the bicyclist or motorist, head-on crashes resulting from the bicyclist or the motorist traveling in the wrong lane, intentional crashes, other unusual crashes, and crashes occurring in parking lots, driveways, and other off-roadway areas.	  

SECTION IV

Index of Strategies by Implementation Timeframe and Relative Cost

Exhibit IV-1 classifies strategies according to the expected timeframe and relative cost for this emphasis area. The implementation time will be dependent upon such factors as the agency's procedures, the extent of the education and enforcement program, roadway-section length, street width, and other factors. The range of costs may also vary for some of these strategies due to many of these same factors. Cost ranges are given in the detailed description of each strategy. A strategy may include several treatments, with different costs and timeframes. The table is meant to reflect the most common application of each strategy.

EXHIBIT IV-1
Implementation Classification of Strategies

Timeframe for Implementation	Relative Cost to Implement and Operate			
	Low	Moderate	Moderate to High	High
Short (less than a year)	A3. Improve signing	A4. Improve pavement markings at intersections		
	A6. Restrict right turn on red (RTOR) movements	E2. Improve enforcement of bicycle-related laws		
	B4. Improve roadway signage	F1. Increase use of bicycle helmets		
	C2. Implement speed enforcement	G1. Fix or remove surface irregularities		
	E1. Provide bicyclist skill education	G2. Provide routine maintenance of bicycle facilities		
	F2. Increase rider and bicycle conspicuity			
Medium (1-2 years)		A2. Improve signal timing and detection	A1. Improve visibility at intersections	
		A7. Accommodate bicyclists through roundabouts	B2. Provide contraflow bicycle lanes	
		B1. Provide safe roadway facilities for parallel travel	B3. Improve bicyclists' visibility	

EXHIBIT IV-1 (Continued)
Implementation Classification of Strategies

Timeframe for Implementation	Relative Cost to Implement and Operate			
	Low	Moderate	Moderate to High	High
		B5. Provide bicycle-tolerable shoulder rumble strips C1. Implement traffic calming techniques	D1. Improve driveway intersections	
Long (more than 2 years)			A5. Improve intersection geometry D2. Implement access management	A8. Provide an overpass or underpass

SECTION V

Description of Strategies

Objectives of the Emphasis Area

Deciding on the set of treatments that will provide the greatest safety benefits for bicyclists and other roadway users requires transportation and land-use planners, engineers, law enforcement officials, educators, and community leaders to engage in problem-solving. The problem-solving effort will often require application of professional judgment, as well as judgments based upon understanding of the character and needs of the particular community.

Tools and extensive resources are available to help those planning to improve safety for bicyclists. AASHTO has produced the Green Book supplement, "Guide for the Development of Bicycle Facilities," with a revision expected in 2008. The Pedestrian and Bicycle Information Center (PBIC) and FHWA supported development of a software package called "BikeSafe," which provides guidance on improvement measures and matching countermeasures to precipitating causes, and includes a catalogue of more than 70 case studies. BikeSafe may be found at http://www.bicyclinginfo.org/bikesafe.

PBIC also hosts "BikeCost," a cost-benefit estimation tool for bicycle-related infrastructure construction and maintenance. Professionals considering infrastructure improvements can use BikeCost to estimate costs for many facilities, and improve their project selection process by better understanding project costs. BikeCost may be found at http://www.bicyclinginfo.org/bikecost.

Reducing the number and severity of collisions involving bicyclists requires strategies that are targeted towards addressing the main factors that lead to collisions. Based on what is known about bicycle-related crashes, the following objectives—targeted either toward locations where crashes occur or toward the causal factors of crashes—are most likely to reduce the number and severity of crashes:

- Reduce bicycle crashes at intersections
- Reduce bicycle crashes along roadways
- Reduce motor vehicle speeds
- Reduce bicycle crashes at midblock crossings
- Improve safety awareness and behavior
- Increase use of bicycle safety equipment
- Reduce influence of hazards

Each of these strategies can be accomplished through a variety of the 23 individual strategies (treatments) presented in Exhibit V-1. Most strategies will work best when

EXHIBIT V-1
Emphasis Area Objectives and Strategies

Objectives	Strategies
A. Reduce bicycle crashes at intersections	A1. Improve visibility at intersections (T)
	A2. Improve signal timing and detection (T)
	A3. Improve signing (T)
	A4. Improve pavement markings at intersections (T)
	A5. Improve intersection geometry (T)
	A6. Restrict right turn on red (RTOR) movements (E)
	A7. Accommodate bicyclists through roundabouts (T)
	A8. Provide an overpass or underpass (T)
B. Reduce bicycle crashes along roadways	B1. Provide safe roadway facilities for parallel travel (T)
	B2. Provide contraflow bicycle lanes (T)
	B3. Improve bicyclists' visibility (T)
	B4. Improve roadway signage (T)
	B5. Provide bicycle-tolerable shoulder rumble strips (T)
C. Reduce motor vehicle speeds	C1. Implement traffic calming techniques (P)
	C2. Implement speed enforcement (T)
D. Reduce bicycle crashes at midblock crossings	D1. Improve driveway intersections (T)
	D2. Implement access management (T)
E. Improve safety awareness and behavior	E1. Provide bicyclist skill education (T)
	E2. Improve enforcement of bicycle-related laws (T)
F. Increase use of bicycle safety equipment	F1. Increase use of bicycle helmets (P)
	F2. Increase rider and bicycle conspicuity (T)
G. Reduce effect of hazards	G1. Fix or remove surface irregularities (T)
	G2. Provide routine maintenance of bicycle facilities (T)

P = proven; T = tried; E = experimental

used at multiple locations, so that they become standard and expected by roadway users, and in combination with other treatments, so that multiple causal factors are addressed. It is important to note that most of the strategies—although tried—have not been proven effective at reducing bicyclist-motor vehicle crashes. More research is needed to demonstrate crash reduction effects.

In addition, many of the strategies (treatments) may help accomplish more than one single objective. It is important for transportation professionals and others charged with improving conditions for bicyclists to choose the right combination of treatments to accomplish the greatest desired effect with the available resources.

In some cases, there may be a tradeoff between bicyclist and vehicular crashes, i.e., a particular strategy, implemented in a particular location, may succeed in reducing either vehicular or bicyclist crashes, but also contribute to an increase in crashes of the other mode. In general, all types of road users must be considered when selecting a strategy for implementation. Factors such as vehicular speeds and volumes, volumes of bicycle traffic, roadway function, and availability of alternate routes should be considered when making decisions about measures for reducing bicycle crashes. Those involved in these decisions must remember that bicycle travel is often utilitarian, although it is a common misperception that much bicycle travel is for recreation or exercise. FHWA guidance reinforces that bicyclists should be expected on all facilities where they are legal, and designers should accommodate them as a matter of routine practice (FHWA, 1999). In the best situations, bicycle-related improvements also increase safety for all road users, including motorists and pedestrians.

Comprehensive Safe Routes to School Programs

Those involved in transportation engineering, planning, design, education, and safety should be aware of Safe Routes to School (SRTS) programs as a potential comprehensive technique for improving the transportation safety for children traveling to and from school. These are summarized here to reinforce their comprehensive and cross-cutting nature. All of the projects or activities recommended as strategies in this guide could be implemented as part of an SRTS program, as the types of goals likely to be part of SRTS programs closely align with the objectives of this guide.

SRTS programs are comprehensive programs that involve making safety-related changes to the built environment, implementing extensive child bicyclist (and pedestrian) safety education, and increasing traffic law enforcement around schools. SRTS programs are also intended to increase the number of children walking or bicycling to school, so SRTS programs usually include encouragement components as well. A federal SRTS program was established by FHWA in 2005, and state and local programs have been operating since the late 1990s. In addition to their comprehensive nature regarding infrastructure and noninfrastructure activities, SRTS programs are characterized by a collaborative and participatory process involving transportation professionals, parents and teachers, school officials, local officials, and students.

The recent expansion of SRTS programs will continue to increase demand for effective and appropriate countermeasures specifically intended for children and school-related travel. The Safe Routes to School Online Guide, available at http://www.saferoutesinfo.org/guide/, includes many Safe Routes-related countermeasures and examples of implementations.

More about the broad SRTS concept and specific applications, including the full range of comprehensive activities and projects, information about selecting appropriate activities, and evaluation strategies can be learned from the National SRTS Clearinghouse at http://www.saferoutesinfo.org, which also includes links to other key resources and publications. The National Clearinghouse will also develop a brief guide for incorporating SRTS programs into state strategic highway safety plans.

Classification of Strategies

The strategies in this guide were identified from a number of sources, including the literature, contact with state and local agencies throughout the United States, and federal programs. Some of the strategies are widely used, while others are used at a state or even a local level. Some have been subjected to well-designed evaluations to prove their effectiveness. 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 a letter symbol throughout the guide:

Proven (P): *Those strategies which have been used in one or more locations and for which properly designed evaluations have been conducted that show them to be effective.* These strategies may be employed with a good degree of confidence, but with an 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 judge which strategies are 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 there very likely will be a positive one. It is intended that as the experiences of implementation of these strategies continue under the AASHTO Strategic Highway Safety Plan initiative, appropriate evaluations will be conducted, so that effectiveness information can be accumulated to provide better estimating power for the user and so that the strategy can be upgraded to "proven" status.

Experimental (E): *Those strategies that are ideas that have been suggested and that at least one agency has considered sufficiently promising to try on a small scale in at least one location.* These strategies should be considered only after the others have 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 "proven" status.

It is particularly difficult to evaluate the impacts of countermeasures on bicyclist crashes for the following reasons:

- Bicycle crashes are substantially more rare than vehicle crashes not involving bicyclists, making it difficult to assess impacts at a given location and over reasonable lengths of time.

- Street improvements for bicyclists are often made in conjunction with other improvements for other roadway users, making it difficult to separate the effects of the bicyclist-oriented improvements.
- Behavioral elements often play a significant role in bicyclist-related crashes, and differentiating between the precipitating factors in any given crash and the effect of each applicable countermeasure (both environmental and behavioral) is extremely difficult.

As a result of these types of difficulties, evaluation work has often focused upon surrogate measures, primarily related to bicyclist and vehicle behaviors and conflicts. Although these surrogates have not been solidly demonstrated to be linked to crash experience, they may serve as interim indications of safety impacts, until more valid evaluations become available.

When designing facilities for bicyclists, it is important to account for the interaction of bicyclists with other roadway users. For example, large trucks may create special problems for bicyclists, such as exaggerated lateral trailer movement during regular travel down a lane, or trailer off-tracking while turning right (and possibly striking a bicyclist well before the intersection). Also, compared to other motor vehicles, some trucks have longer stopping distances, limited visibility (e.g., blind spots), and problems with nighttime visibility. Pedestrians also use roadway facilities and sometimes conflict with bicyclists. In short, those planning improvements for bicyclists (or any other roadway users) need to provide a roadway environment that balances the needs of all road users.

Related Strategies for Creating a Truly Comprehensive Approach

The strategies listed above, and described in detail below, are those considered unique to this emphasis area. However, to create a truly comprehensive approach to the highway safety problems associated with this emphasis area, there are related strategies recommended as candidates in any program planning process. These are of five types: Public information and education (PI&E) programs, enforcement of traffic laws, strategies to improve emergency medical and trauma system services, strategies directed at improving the safety management system, and strategies detailed in other emphasis area guides.

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 desired to focus a PI&E campaign on a location-specific problem. While this is a relatively untried approach, as compared to area-wide campaigns, use of roadside signs and other experimental methods may be tried on a pilot basis. Within this guide, where the application of PI&E campaigns is deemed appropriate, it is usually in support of some other strategy. In such a case, the description of that strategy will suggest this possibility (see the attribute for each strategy entitled, “Associated Needs for, or Relation to, Support Services”). Since independent PI&E campaigns are deemed appropriate for the bicyclist emphasis area, they are explained in greater detail as part of implementing Strategies E1, E2, F1, and F2.

Enforcement of Traffic Laws

Well-designed and well–managed law-enforcement programs can have a significant positive 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 (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 are conducted at specific locations by the nature of how they must be performed. The effect (e.g., lower speeds, greater use of seatbelts, giving right-of-way to pedestrians or bicyclists, reduced red-light running, safer vehicles, and reduced impaired driving) may occur at or near the specific location where the enforcement is applied. Coordinating the effort with an appropriate PI&E program can often enhance this effect. However, in many cases (e.g., speeding, yielding right-of-way to pedestrians and bicyclists, and seatbelt usage) the impact is area-wide 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).

A pilot program is recommended when it is unclear how the enforcement effect may impact behavior or where it is desired to try an innovative and untried method. Within this guide, the application of enforcement programs is often deemed appropriate in support of some other strategy. Many of those strategies can be targeted at either the whole system or a specific location. In such cases, the description for that strategy will suggest this possibility (see the attribute area for each strategy entitled, "Associated Needs for, or Relation to, Support Services"). For the bicyclist emphasis area, an independent enforcement program is deemed appropriate and explained in detail in Strategy E2.

Strategies to Improve Emergency Medical and Trauma System Services

When bicyclists are struck by vehicles, the risk of serious or fatal injury is high. Rapid and proper treatment of injured parties at highway crashes can have a significant impact on survival, as well as recovery. Thus, a comprehensive emergency care program is a basic part of a highway safety infrastructure. 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 improvements could be made, especially for programs that are focused upon location-specific (e.g., corridors) or area-specific (e.g., rural areas) issues.

Strategies Directed at Improving the Safety Management System

The management of the highway safety system is essential to success. There should be in place a sound organizational structure, as well as infrastructure of laws, policies, etc., to monitor, control, direct, and administer a comprehensive approach to highway safety. It is important that a comprehensive program not be limited to one jurisdiction, such as a state DOT. Local agencies are often responsible for the majority of the road system and its related safety problems. They may also have a better understanding of local problems. Jurisdictions need to work together and coordinate their safety programs in metropolitan areas, regions, and throughout the state.

Strategies Detailed in Other Emphasis Area Guides

Bicyclists move along and across all types of road facilities. The strategies in this guide attempt to reflect that by addressing a wide range of facility elements and roadway locations. However, there are other emphasis areas that address roadway features, which also relate to bicyclist safety. Further details on other applicable strategies may be found in the companion guides for unsignalized intersections, signalized intersections, older drivers, and pedestrians.

Objective A—Reduce Bicycle Crashes at Intersections

Strategy A1: Improve Visibility at Intersections (T)

General Description

Improving the visibility at intersections will enhance the safety of bicyclists and all other users traveling through the intersections. The two primary purposes for improving the visibility at intersections are:

- To make drivers and bicyclists more aware they are approaching an intersection so they are better prepared to comply with the traffic control devices and rules of the road at the intersection
- To provide drivers and bicyclists better views of one another to avoid potential conflicts.

The visibility at intersections can be enhanced by improving the sight distance/sight lines near the intersection and/or by improving the conspicuity of traffic control devices at and near intersections. For example, improving the visibility at intersections could involve:

- Increasing the sight distance along the approach to an intersection so that drivers have a better view of the geometric and cross sectional features of the intersection;
- Clearing sight triangles so that users have better views of vehicles operating on side streets;
- Improving the visibility of traffic control devices which could involve removing vegetation or other roadside objects that obstruct the view of signs and signals or improving the conspicuity of traffic control devices (e.g., installing larger signs, additional signal heads, larger signal lenses, or signal backplates); or
- Improving the lighting along the approaches to the intersection and at the intersection proper.

This strategy is related to several objectives and strategies provided in companion guides, in particular the guides that address reducing collisions at unsignalized (http://safety.transportation.org/guides.aspx?cid=26) and signalized (http://safety.transportation.org/guides.aspx?cid=33) intersections and the guide that addresses collisions involving older drivers (http://safety.transportation.org/guides.aspx?cid=30). The reader is directed to these companion guides for more detailed information related to improving the visibility at intersections. The related objectives and strategies in the companion guides are as follows:

- *NCHRP Report 500, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*
  - Objective 17.1 C—Improve sight distance at unsignalized intersections
    - Strategy 17.1 C1: Clear sight triangles on stop- or yield-controlled approaches to intersections
    - Strategy 17.1 C2: Clear sight triangles in the medians of divided highways near intersections
    - Strategy 17.1 C3: Change horizontal and/or vertical alignment of approaches to provide more sight distance
    - Strategy 17.1 C4: Eliminate parking that restricts sight distance
  - Objective 17.1 E—Improve driver awareness of intersections as viewed from the intersection approach
    - Strategy 17.1 E1: Improve visibility of intersections by providing enhanced signing and delineation
    - Strategy 17.1 E2: Improve visibility of the intersection by providing lighting
    - Strategy 17.1 E3: Install splitter islands on the minor-road approach to an intersection
    - Strategy 17.1 E4: Provide a stop bar (or provide a wider stop bar) on minor-road approaches
    - Strategy 17.1 E5: Install larger regulatory and warning signs at intersections
    - Strategy 17.1 E8: Provide supplementary stop signs mounted over the roadway
    - Strategy 17.1 E11: Install flashing beacons at stop-controlled intersections
  - Objective 17.1 G—Improve driver compliance with traffic control devices and traffic laws at intersections

- *NCHRP Report 500, Volume 12: A Guide for Reducing Collisions at Signalized Intersections*
  - Objective 17.2 C—Improve Sight Distance at Signalized Intersections
    - Strategy 17.2 C1: Clear Sight Triangles
    - Strategy 17.2 C2: Redesign Intersection Approaches
  - Objective 17.2 D—Improve Driver Awareness of Intersections and Signal Control
    - Strategy 17.2 D1: Improve Visibility of Intersections on Approach(es)
    - Strategy 17.2 D2: Improve Visibility of Signals and Signs at Intersections
  - Objective 17.2 E—Improve Driver Compliance with Traffic Control Devices

- *NCHRP Report 500, Volume 9: A Guide for Reducing Collisions Involving Older Drivers*
  - Objective 3.1 B—Improve the Roadway and Driving Environment to Better Accommodate Older Driver's Special Needs
    - Strategy 3.1 B7: Improve lighting at intersections, horizontal curves, and railroad grade crossings

A treatment that helps to improve the visibility at intersections which is unique to bicycles and bicycle facilities involves installing bicycle racks near street corners (Zegeer et al., 1994). This type of treatment has been implemented at several intersections in Germany where cars parked too close to the intersection created a visibility problem for motorists on the side streets. Installing bike racks on the street corners physically prevented cars from parking close to the intersection and opened up the sight distance for side street traffic. With this type of treatment, it is probably desirable to install barriers to protect bicyclists near the bike racks or potentially install the bike racks in conjunction with the construction of a bulbout at the intersection.

Another visibility issue unique to bicycles is the ability of bicyclists to see the signal heads from their typical location, in most cases the right edge of the roadway. For programmed visibility heads, this may require that the signal heads be adjusted slightly to be visible to bicyclists (see Strategy A2).

Improving the visibility at path/roadway intersections is also important. In an effort to improve the crossing situations for trail users at path/roadway intersections, Maryland DOT has installed several innovative treatments, which are discussed in detail in Appendix 1.

Strategy A2: Improve Signal Timing and Detection (T)

General Description

At signalized intersections bicycle traffic should be considered during the development of the traffic signal timing. In many cases of mixed flow traffic, bicyclists can safely travel through a signalized intersection when the phasing plan is timed strictly to accommodate motor vehicles; however, the signal timing at all signalized intersections where bicycle traffic is present or is anticipated should be reviewed to determine if bicycle traffic is sufficiently accommodated. In those cases where it is not, the signal timing should be modified. When the signal is actuated, detection of bicycles is crucial for safety.

Several ways to improve signal timing and detection to better accommodate bicycle traffic include:

- Providing an adequate clearance interval
- Providing a leading bicycle phase or bicycle-only phase (which will also involve installation of bicycle signals)
- Providing sensors that detect the presence of a bicycle (which may also involve marking the roadway to indicate the optimum location for bicycle detection)

The AASHTO *Bicycle Guide* (1999) provides guidance on calculating adequate clearance intervals for bicyclists. The total clearance interval (i.e., yellow change interval plus red clearance interval) is calculated as:

$$y + r_{clear} \geq t_r + \frac{v}{2b} + \frac{w + l}{v}$$

y = yellow interval(s)
r_{clear} = red clearance interval(s)
t_r = reaction time (1.0 s)
v = bicyclist speed (mph)
b = bicyclist's braking deceleration (4 to 8 ft/s^2)
w = width of crossing (ft)
l = bicycle length (6 ft)

AASHTO indicates that approximately 98 percent of bicyclists should be able to clear an intersection assuming the following speeds: 19 km/h (12 mph) for advanced bicyclists, 13 km/h (8 mph) for basic bicyclists, and 10 km/h (6 mph) for children bicyclists. These speeds provide guidance for calculating clearance intervals in the absence of field data. However, recent research by Rubbins and Handy (2005) presents data on bicycle clearance times for

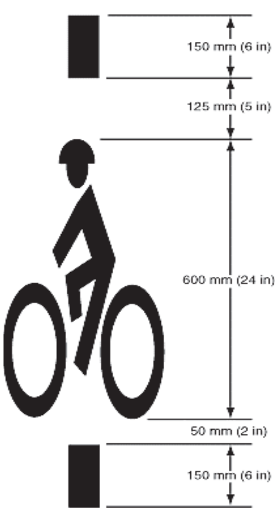
EXHIBIT V-2
Bicycle Signal Head
(http://www.bayareatrafficsignals.org/toolbox/Tools/ToolboxPhotos/BikeSigHead.jpg)

different intersection distances that indicates bicyclists' speeds are considerably slower than the assumed speeds recommended by AASHTO, meaning longer clearance times for bicyclists may be necessary.

Providing a leading bicycle phase in the signal timing plan gives priority to bicyclists and enables bicyclists to at least establish their presence within, if not clear, the intersection which should reduce the potential for conflicts with motor vehicle traffic. During a bicycle-only phase, the mixed traffic is separated to facilitate the flow of all types of traffic. A variation of the bicycle-only phase is a bicycle scramble phase which allows bicyclists from all intersection approaches to cross an intersection at the same time. Providing a leading bicycle phase or bicycle-only phase requires a separate bicycle signal (Exhibit V-2) to direct bicycle traffic through the intersection and would only be implemented at intersections with marked bicycle lanes or separated paths. It is possible that bicycle signal heads could be installed with pedestrian heads, or potentially in conjunction with pedestrian count down signals.

Many actuated signal systems were designed and installed without attention to their effects on bicyclists (Williams et al., 1998). As a result, bicyclists may find it frustrating and impossible to get a green indication. Providing a detector that senses the presence of a bicycle will encourage more bicyclists to follow the rules of the road at actuated signals rather than disregard the signal. A bicycle detector pavement marking may be placed on the pavement indicating the optimum position for a bicycle to actuate the signal (Exhibit V-3). A bicycle detector pavement marking should be provided when bicycle detection cannot be reliably achieved while riding along the expected path of bicyclists, particularly when the loop detector is not apparent. Bicycle detector pavement markings are also useful on actuated side street approaches and actuated left-turn lanes, where motor vehicle traffic may be infrequent, and bicyclists have difficulty getting a green indication.

EXHIBIT V-3
Example of Bicycle Detector Pavement Marking
(USDOT, 2003)



Information on Agencies or Organizations Currently Implementing this Strategy

In 2004, the city of Portland, Oregon, installed a bicycle-only traffic signal at the intersection of Interstate Avenue and Oregon Street. For more details on this installation, visit their website at http://www.trans.ci.portland.or.us/bicycles/Scramble.htm.

The city of Davis, California, has also installed several bicycle signals, which seem to have reduced the number of bicycle/motor vehicle crashes, although no scientifically sound before-after evaluations have been conducted to prove their safety effectiveness.

EXHIBIT V-4
Strategy Attributes for Improving Signal Timing and Detection. (T)

Attribute	Description
Technical Attributes	
Target	This strategy concerns bicycle-related problems with traffic signal installations. It focuses on signalized intersections where bicyclists have difficulty clearing the intersection before the cross traffic receives a green indication. In most cases, bicyclists have difficulty clearing intersections of multilane roads (4, 5, 6+ lanes), not single lane roadways (Tan, 1996). This strategy also focuses on actuated signal installations that do not sense the presence of bicycles.
Expected Effectiveness	It has been estimated that bicycle clearance-time crashes, where a motor vehicle hits a bicyclist who has entered a signalized intersection lawfully but has been unable to clear the intersection before the signal changes, constitute approximately 6 percent of urban bicycle/motor vehicle crashes (Wachtel et al., 1995). No studies have been conducted to evaluate the decrease (or increase) in bicycle/motor vehicle crashes due to modifying the clearance interval to better accommodate bicycle traffic, but it is expected that by better accommodating bicyclists during the clearance interval, these types of bicycle/motor vehicle crashes will decrease. Korve and Niemeier (2002) performed a benefit-cost analysis of adding a bicycle phase at a single signalized intersection in the city of Davis, California. One of the measures considered in the analysis was the crash history. Although a formal before and after evaluation was not performed, the crash history showed a total of 14 accidents during the 35 months prior to the signal modification and 2 accidents during the first 35 months after the signal modification. An earlier study was also conducted in 1996 by the city of Davis, California, on the use of bicycle signal heads (Pelts et al., 1996). They installed bicycle signal heads at a single signalized intersection due to the volumes of bicycles interacting with motor vehicles. The intersection was a T-intersection with a three-phase signal. The bicycle signal heads were installed for northbound and southbound traffic to provide bicyclists a separate signal phase for movements through the intersection. Based upon the results of a before and after questionnaire of both bicyclists and motorists, most respondents noted a marked increase in safety through the intersection. The accident history showed that in 3 years before modification 14 crashes occurred at the intersection, and over 50 percent of these crashes involved either bicyclists or pedestrians. In the 16 months following the treatment, 2 crashes occurred, and neither involved a bicyclist or a pedestrian. No studies have been conducted on the safety effectiveness of providing bicycle detection at actuated signals. However, it is expected that this type of treatment will increase bicyclist compliance with traffic signals, which should reduce the number of bicycle/motor vehicle crashes that result when bicyclists ride out into an intersection during a red indication, rather than yielding the right of way to motor vehicle traffic on the cross street.
Keys to Success	While there may be a need to better accommodate bicyclists during the clearance interval, there is also a need to balance operations and safety. Especially at wider intersections, clearance intervals required for bicyclists are much longer than those required for motor vehicles, but long clearance intervals have a number of disadvantages (see discussion on Potential Difficulties). The *Manual on Uniform Traffic Control Devices for Streets and Highways* (MUTCD) suggests that the yellow change interval should have a duration of approximately 3 to 6 seconds, and the red clearance interval shall not exceed 6 seconds (USDOT, 2003). It may be (based upon the assumptions made during the calculations for bicycle clearance interval) that bicyclists cannot clear the intersection during the clearance interval that is initially provided in the signal timing

EXHIBIT V-4 (Continued)
Strategy Attributes for Improving Signal Timing and Detection. (T)

Attribute	Description
Technical Attributes	
	plan. However, it is key that bicyclists' needs, as well as the needs of all highway users, be balanced when finalizing signal timing plans. Providing a leading bicycle phase or a bicycle-only phase requires the installation of bicycle signals. Similar to the traffic signal warrants that are already provided in the MUTCD, development of a bicycle signal warrant or policy that may be used to justify the installation of a bicycle signal would provide credibility to the treatment. For example, the California Traffic Control Devices Committee (CTCDC) developed a bicycle signal warrant that takes into consideration both bicycle and motor vehicle volumes, accident history, and the geometrics of the intersection (Appendix 2). When a leading bicycle phase is provided to facilitate left-turning bicyclists, installation of a bicycle box at the head of the intersection is also necessary. Being in the bicycle box in front of the queued motor vehicles, bicyclists are more visible to motorists, which tends to reduce the number of bicycle/motor vehicle conflicts (see Strategy A4). The key for providing bicycle detection is to install a system that can reliably detect bicycles and provide inputs to traffic signals for call and extend functions. Several types of systems are available for detecting bicycles. Most of the systems are passive devices such as loop detectors and infrared or video detection systems. Others are active, such as the bicycle push-button that is similar to those used by pedestrians (Nabti and Ridgway, 2002). Several recent studies have been conducted to evaluate the ability of these various technologies to detect bicycles. • The Federal Highway Administration (FHWA) and Minnesota Department of Transportation funded a study to identify the applications and evaluate the accuracy of different non-intrusive technologies in detection of non-motorized traffic, namely bicyclists and pedestrians. Five types of technologies were evaluated (USDOT, 2003): passive infrared/ultrasonic, infrared, microwave, video, and inductive loop. • Noyce and Dharmaraju (2002) conducted a similar study for Massachusetts Highway Department. The objective of this study was to identify and evaluate existing technologies that may accurately and efficiently detect, count, and classify non-motorized modes of transportation (i.e., bicyclists and pedestrians). Microwave, ultrasonic, acoustic, video image processing, piezoelectric, passive infrared, active infrared, magnetic and traditional (inductive loops and pneumatic traffic classifiers) were considered. The active infrared technology was evaluated most in depth and was found to be very effective in detecting bicyclists. • Several sources such as Wachtel (2000) and Williams et al. (1998) provide guidance on inductive loop systems that are sensitive enough to detect bicycles. Another key at signalized intersections is that bicyclists must be able to see the signal heads, in most cases from the right edge of the roadway. For programmed visibility heads, this may require that the signal heads be adjusted slightly to be visible from typical bicyclist locations. Finally, coordinated traffic signals are designed to facilitate vehicular traffic flow. To better accommodate bicyclists, it may be possible to coordinate the signals based upon bicycle speeds rather than motor vehicle speeds. This could serve as a traffic calming measure, reducing the advantage of motor vehicles traveling faster than the speed for which the signals are timed (Bicycle Advisory Committee, 1997). This type of treatment would only be appropriate on low-speed facilities where it makes sense for motor vehicles to slow to the speeds of bicyclists.

EXHIBIT V-4 (Continued)
Strategy Attributes for Improving Signal Timing and Detection. (T)

Attribute	Description
Technical Attributes	
Potential Difficulties	To accommodate bicyclists, clearance intervals may need to be lengthened. However, long clearance intervals have several disadvantages (Wachtel et al., 1995): • Cause extra delay to traffic • May encourage motorists to enter the intersection, believing they are protected • May confuse waiting drivers who do not understand why the signal fails to change Similar to extending the clearance interval, providing a leading bicycle phase or bicycle-only phase may cause the intersection to operate less efficiently for motor vehicle traffic. Other disadvantages of a leading bicycle phase and/or a bicycle-only phase include (Nabti and Ridgway, 2002): • Cost of installation and on-going operation and maintenance of additional signal hardware may be a concern. • Unfamiliar drivers may be confused or uncertain about the intended purpose of signals. Bicycle-only traffic signals can also greatly increase intersection delay to bicyclists who could otherwise have proceeded with the other traffic in the same direction. In addition, bicycle signals may promote non-uniformity of traffic control for bicyclists. Bicyclists will be expected to operate in a significantly different manner at the intersections controlled by these signals (Moeur, 1999), and it is possible that at a conventional street intersection any bicycle-only traffic signal that restricted bicycle crossing when parallel motor vehicle traffic had a green indication would be ignored. Depending upon the type of technology used to detect bicycles, vandalism could be an issue if the system is installed above ground. Due to their slower speeds, bicycles may adversely affect the capacity and operation of motor vehicles at single point urban interchanges (SPUIs). The required green and all-red clearance intervals necessary for a bicyclist to clear most SPUIs are substantially longer than what is needed for motorists. The required extended signal timing increases delay for motorists. To better accommodate bicyclists, SPUIs should be designed as compactly as possible (Qureshi et al., 2004).
Appropriate Measures and Data	Appropriate process measures may include (a) the percentage of signalized intersections where bicyclists can safely cross the intersection during the clearance interval as calculated based upon the equation provided, (b) the percentage of actuated signals that have sensors capable of reliably detecting bicycles, and (c) the number of signals that have a leading bicycle phase or bicycle-only phase. Appropriate measures used to evaluate the safety effectiveness of the signal modifications include (a) the number of bicycle/motor vehicle crashes that are correctable due to modifications in signal timing and/or detection, (b) the change in level of service (i.e., delay) to motor vehicle traffic due to modifications in signal timing, and (c) the percentage of bicyclists who clear the intersection based on the clearance interval. Bicycle exposure data is also critical (i.e., bicycles per hour that enter the respective intersections) for determining the number of bicycle/motor vehicle crashes that could potentially be reduced if this treatment were implemented.

EXHIBIT V-4 (Continued)
Strategy Attributes for Improving Signal Timing and Detection. (T)

Attribute	Description
Technical Attributes	
Associated Needs	Field observations may be desirable to calculate clearance intervals based upon local conditions. Bicycle and motor vehicle volumes will also be necessary to develop a modified signal timing plan. The agencies responsible for maintaining traffic signal systems will incur additional maintenance work if new hardware is installed in the field. It may also be necessary to install additional signs in association with bicycle signals. In addition, bicycle signals are not an accepted traffic control device in the MUTCD. An agency should follow the provisions outlined in Section 1A.10 of the MUTCD for design, application, and placement of traffic control devices that are not adopted in the most recent edition of the MUTCD. In addition, it would be desirable to develop warrants for bicycle signals, similar to the 8 traffic signal warrants currently provided in the MUTCD. If bicycle detection is going to be installed, a decision needs to be made where bicyclists will likely be in order to detect them. A decision needs to be made whether detection will occur at the intersection proper and/or in advance of the intersection on the approach. A Bicycle Signal Actuation sign (R10-22) (Exhibit V-5) may also be installed where markings are used to indicate the location where a bicyclist is to be positioned to actuate the signal (USDOT, 2003). The MUTCD indicates that if the Bicycle Signal Actuation sign is installed, it should be placed at the roadside adjacent to the marking to emphasize the connection between the marking and the sign.

EXHIBIT V-5
Bicycle Signal Actuation Sign (USDOT, 2003)

R10-22

Attribute	Description
	Finally, agencies may need to develop a formal policy for improving signal timing and detection. Such a policy could involve one or more of the associated issues (i.e., providing adequate clearance intervals for bicyclists, providing a bicycle signal with a lead bicycle phase or bicycle-only phase, or providing bicycle detection).
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	Agencies should make it mandatory that bicyclists be considered during the development of all signal timing plans.
Issues Affecting Implementation Time	It may be desirable to collect field data (i.e., clearance times and exposure data) at local sites. Because bicycle signals and/or bicycle detection are not typical treatments around the country, agencies may find it desirable to invest some time in researching previous applications and/or available technologies. Bicycle signals may not be supported by local traffic laws, so legislative action may be necessary which could impact implementation time (Nabti and Ridgway, 2002). In

EXHIBIT V-4 (Continued)
Strategy Attributes for Improving Signal Timing and Detection. (T)

Attribute	Description
Organizational and Institutional Attributes	
	addition, if a formal policy is required to guide installation/implementation of such a treatment, cultural effects may impact acceptance of the policy. For example, decision makers may have an underlying assumption that all bicyclists proceed through signalized intersections when available gaps in traffic are present rather than waiting for the right of way from the green signal indication. If decision makers have such an assumption, they may question the need to adopt a formal policy on bicycle detection.
Costs Involved	Data collection costs may be incurred to collect clearance intervals and exposure data. Capital costs may also be incurred for poles, bicycle signal heads, detection hardware, and detection software. Installation and maintenance costs will also be involved. Appendix 3 provides cost estimates of several ITS technologies that can be used for bicycle detection.
Training and Other Personnel Needs	If ITS technologies are used for bicycle detection, personnel may need initial training on the software and how to calibrate the detector systems.
Legislative Needs	Local traffic laws may need to be modified to support bicycle signals.
Other Key Attributes	
	None identified

Appendix 4 provides additional information on other agencies' experiences with implementing this strategy.

Strategy A3: Improve Signing (T)

General Description

Signs are placed within the right of way to provide regulation, warning, and guidance information to road users. This strategy focuses on providing additional regulatory and warning signs to improve bicycle safety at intersections and on modifying existing signage. The AASHTO *Bicycle Guide* (1999) and MUTCD (2003) should be consulted concerning bicycle-related signs that can improve safety at intersections. Several regulatory and warning signs that should be considered for improving safety include:

- Begin Right Turn Lane Yield To Bikes (R4-4)
- Intersection Warning Signs (W2 Series)
- Advance Traffic Control Signs (W3 Series)
- Bicycle Warning Sign (W11-1)

The Begin Right Turn Lane Yield To Bikes sign (Exhibit V-6) may be installed at intersections with marked bicycle lanes and right turn only lanes. At intersections with exclusive or channelized right-turn lanes, bicyclists are at risk because motor vehicles entering the exclusive or channelized right-turn lane must weave across the path of bicycles traveling straight through the intersection. The MUTCD indicates that where motor vehicles entering an exclusive right-turn lane must weave across bicycle traffic in a bicycle lane, the Begin Right Turn Lane Yield

EXHIBIT V-6
Begin Right Turn Lane Yield to Bikes Sign(USDOT, 2003)

R4-4

To Bikes sign may be used to inform both the driver and the bicyclist of this weaving area (USDOT, 2003). This sign, in conjunction with the associated pavement markings, is intended to encourage motorists and bicyclists to cross paths in advance of intersections in a merging fashion (Hunter et al., 1999) and encourage bicyclists to follow the rules of the road (i.e., through-vehicles, including bicyclists, proceed to the left of right-turning vehicles) (WSDOT, 2001). The primary advantages of having through bicyclists and right-turning motor vehicles cross prior to the intersection include:

- Moving this conflict away from the intersection and other conflicts
- Enabling the motorist to pass a bicyclist rather than ride side-by-side due to the difference in travel speeds

Exhibit V-7 illustrates several signs for bicycle lanes at intersections where the bicycle lanes continue to the left of the right-turn only lanes. These signs convey to both motorists and bicyclists the proper channelization through the intersections.

Intersection warning signs (Exhibit V-8) may be used on a roadway, street, or shared-use path in advance of an intersection to indicate the presence of an intersection and the possibility of turning or entering traffic (USDOT, 2003). The MUTCD states that when engineering judgment determines that the visibility of an intersection is limited on a shared-use path approach, intersection warning signs should be installed. However, intersection warning signs should not be used where the shared-use path approach to an intersection is controlled by a STOP sign, YIELD sign, or a traffic control signal.

Advance traffic control signs include Stop Ahead (W3-1), Yield Ahead (W3-2), and Signal Ahead (W3-3) (Exhibit V-9). These signs shall be installed on an approach to a primary traffic control device that is not visible for a sufficient distance to permit the road user to respond to the device (USDOT, 2003). These signs may also be used for additional emphasis of the primary traffic control device even when the visibility distance to the device is satisfactory.

A Bicycle Warning sign (Exhibit V-10) may be used to alert road users to unexpected entries into the roadway by bicyclists. In many cases, this sign may be installed at the intersection of a shared-use path and a roadway. This sign may be installed in advance of the specific crossing point, and a supplemental plaque with the legend “Ahead” or “XXX Feet” may be used with the sign. This sign may also be installed at the location of the crossing. When used at the location of the crossing, the Bicycle Warning sign shall be supplemented with a diagonal downward pointing arrow (Exhibit V-10) plaque to show the location of the crossing.

In addition to installing regulatory and warning signs, consideration should be given to whether existing signs and traffic control are the most appropriate for the intersection. For example, consideration should be given to changing STOP signs to YIELD signs where appropriate (see The Bicycle Matrix at http://www.bicyclinginfo.org/matrix/counter2.cfm?record=16&num=2a). Bicyclists are often reluctant to stop at STOP signs because they lose all their momentum. As a result, there is a tendency for bicyclists to treat STOP signs as YIELD signs if they occur quite frequently and are at intersections with little traffic. Danger arises when bicyclists behave this way at a busier intersection and fail to yield to motor vehicle traffic. One solution is to reevaluate the use of STOP signs in the community to determine whether some could be changed to YIELD signs, leaving STOP signs at the intersections

EXHIBIT V-7
Signing for Bicycle Lanes Adjacent to Right-Turn Only Lanes (Chicago DOT, 2002; Caltrans, 2005)

EXHIBIT V-8
Intersection Warning Signs (USDOT, 2003)

EXHIBIT V-9
Advance Traffic Control Signs (USDOT, 2003)

where they are really needed. The MUTCD states that at intersections where a full stop is not necessary at all times, consideration should be given to using less restrictive measures such as YIELD signs (USDOT, 2003). On shared-use paths, many agencies automatically install STOP signs at every path/roadway intersection regardless of the importance of the road being crossed. In these situations, the impact of the STOP signs is lost because they are being used in too many inappropriate locations. When assigning priority, the least restrictive control that is appropriate should be placed on the lower priority approaches, and STOP signs should not be used where YIELD signs would be acceptable (USDOT, 2003).

This strategy is related to Strategy A1—Improve Visibility at Intersections. This strategy is also related to Strategy 17.1 E1—Improve visibility of intersections by providing enhanced signing and delineation (T) in *NCHRP Report 500, Volume 5: Guide for Addressing Unsignalized Intersection Collisions.*

EXHIBIT V-10
Bicycle Warning Signs (USDOT, 2003)

EXHIBIT V-11
Strategy Attributes for Improving Signage (T)

Attribute	Description
Technical Attributes	
Target	The target for this strategy should be both signalized and unsignalized intersections that are not clearly visible to approaching bicyclists and/or motorists. This strategy is also particularly appropriate at intersections where bicyclists and/or motorists frequently do not comply with existing traffic control devices and at intersections with exclusive right-turn lanes.
Expected Effectiveness	The safety effectiveness of this strategy has not been quantified. However, making bicyclists and/or motorists aware that they are approaching an intersection through improved signing should improve safety at the intersection because bicyclists and motorists will be more alert to potential conflicts. This heightened awareness will quicken bicyclists' and drivers' reaction times.
Keys to Success	A key to success in applying this strategy is to select the appropriate combination of signing for conditions on particular intersection approaches. This engineering assessment should, where possible, be accompanied by a human-factors assessment of signing needs. Another key to success is the ability and commitment of the highway agency to adequately maintain the signing. Where "Stop" signs are replaced with "Yield" signs, this type of treatment may be implemented in conjunction with the development of a bicycle boulevard. A bicycle boulevard is defined as a roadway that has been modified as needed to enhance bicyclists' safety and convenience (Berkeley Bicycle Plan, 1999). The purpose of a bicycle boulevard is to improve bicycle safety and circulation (compared to other streets) by having or creating one or more of the following conditions: • Low traffic volumes (or bike lanes where traffic volumes are medium) • Discouragement of non-local motor vehicle traffic • Free-flow travel for bikes by assigning right of way to the bicycle boulevard at intersections wherever possible • Traffic control to help bicycles cross major streets • A distinctive look and feel such that bicyclists become aware of the existence of the bike boulevard and motorists are alerted that the roadway is a priority route for bicyclists
Potential Difficulties	Care should be taken not to overuse traffic signs. If used in excess, regulatory and warning signs tend to lose their effectiveness. There may be resistance from a portion of the community if (or when) a "Stop" sign is replaced with a "Yield" sign. This resistance may be based upon the perception that "Stop" signs always result in safer operations than "Yield" signs.
Appropriate Measures and Data	A key process measure is the number of intersection approaches on which signing was improved. Crash frequency and severity, by type, are key safety effectiveness measures. Crash frequency and severity data are needed. Bicycle and motor vehicle volume data are needed to represent exposure.

EXHIBIT V-11 (Continued)
Strategy Attributes for Improving Signage (T)

Attribute	Description
Technical Attributes	
Associated Needs	If an agency decides to design and install signs that are not an accepted traffic control device in the MUTCD, an agency should follow the provisions outlined in Section 1A.10 of the MUTCD for design, application, and placement of traffic control devices that are not adopted in the most recent edition of the MUTCD.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	One type of improvement to signage that should be considered is changing “Stop” signs to “Yield” signs where appropriate. Changing the traffic control at an intersection from “Stop” controlled to “Yield” controlled, primarily for bicycle safety, would not be necessary if bicyclists were permitted to treat “Stop” signs as “Yield” signs. This is already the case in Idaho and Montana. Agencies should consider whether this is a viable option in conjunction with this strategy; however, it should be noted that permitting bicyclists to treat “Stop” signs as “Yield” signs may train young bicyclists, who ultimately become drivers of motor vehicles, to ignore traffic control devices.
Issues Affecting Implementation Time	This strategy does not require a long development process. Signing improvements can typically be implemented in 3 months or less.
Costs Involved	Costs to implement signing are relatively low. An agency’s maintenance costs may increase.
Training and Other Personnel Needs	Training regarding use of this strategy should be provided in highway agency courses covering the use of traffic control devices.
Legislative Needs	In association with changing “Stop” signs to “Yield” signs to improve bicycle safety, some states (i.e., Idaho and Montana) permit bicyclists to treat “Stop” signs as “Yield” signs. Legislation would need to be introduced to make this bicycle maneuver legal in other states.
Other Key Attributes	
	None identified

Strategy A4: Improve Pavement Markings at Intersections (T)

General Description

When discussing bicycle-related pavement markings at intersections, generally the first item that comes to mind is how to mark or stripe bicycle lanes at intersections. The AASHTO *Bicycle Guide* (1999) and MUTCD (2003) provide sufficient detail for such situations and treatments. Exhibit V-12 illustrates typical pavement markings for bicycle lanes in the vicinity of intersections along a two-way street, and Exhibit V-13 illustrates typical striping techniques at T-intersections given the presence or absence of painted crosswalks and bus stops. However, the most complicated scenario for marking bicycle lanes at intersections

EXHIBIT V-12
Example of Pavement Markings for Bicycle Lanes on a Two-Way Street (USDOT, 2003)

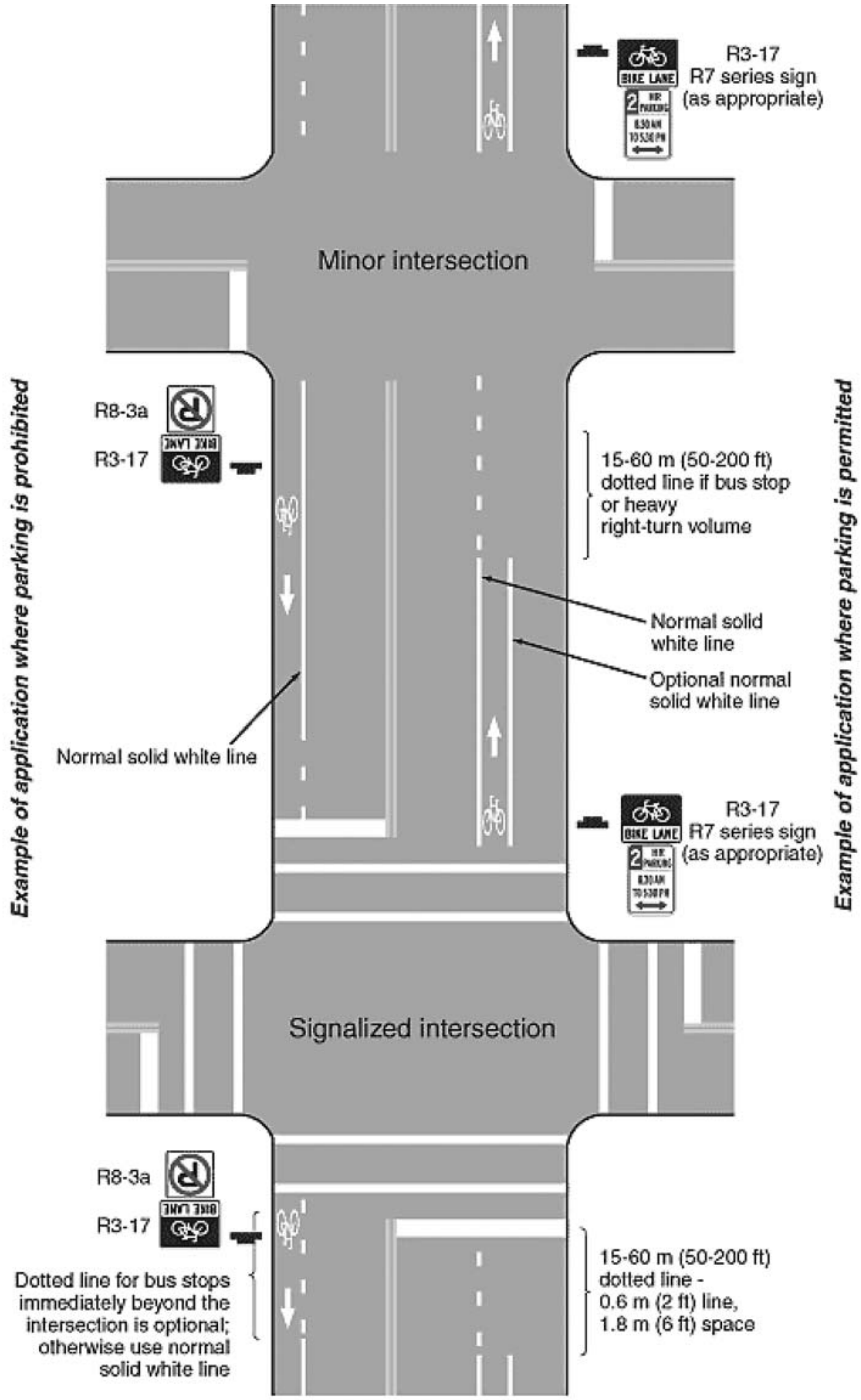
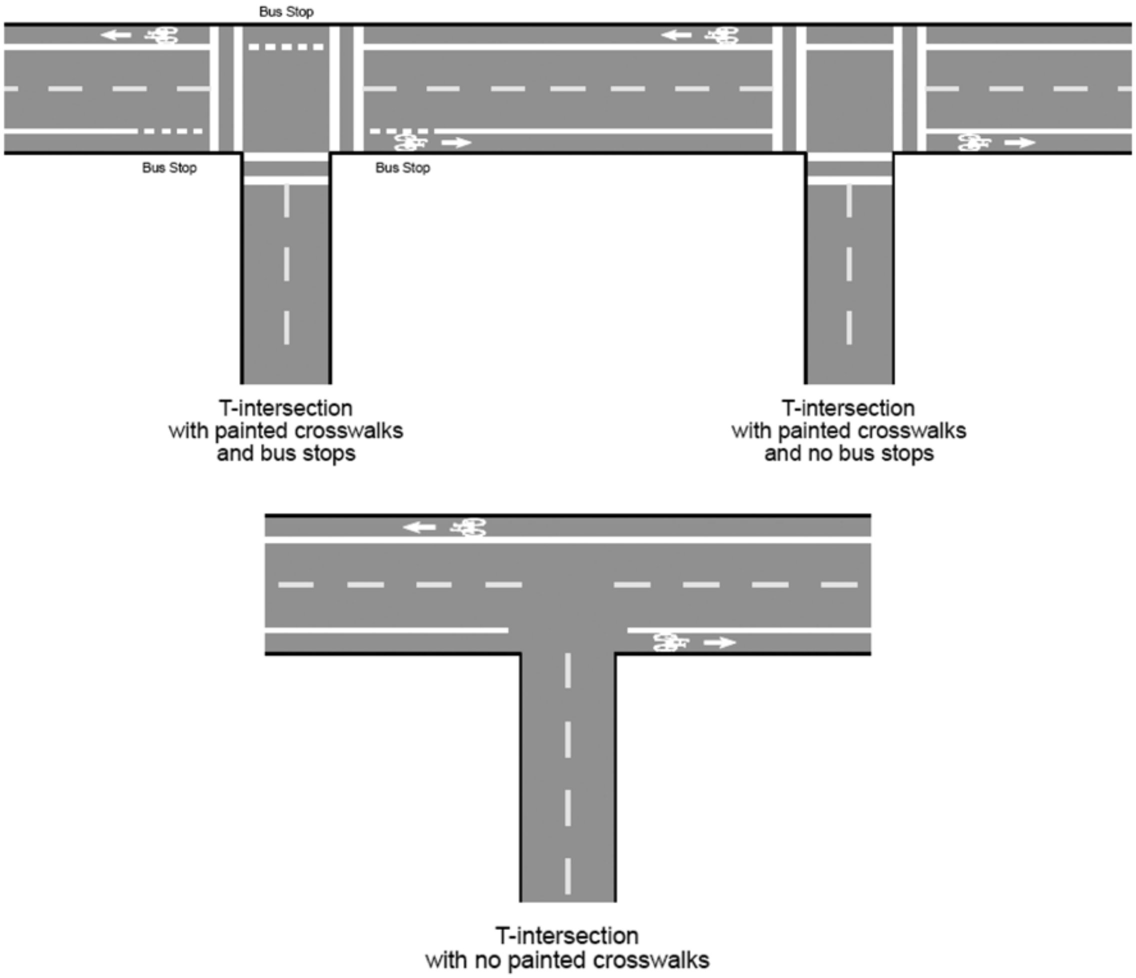


EXHIBIT V-13
Typical Bike Lane Striping at T-Intersections (AASHTO, 1999)

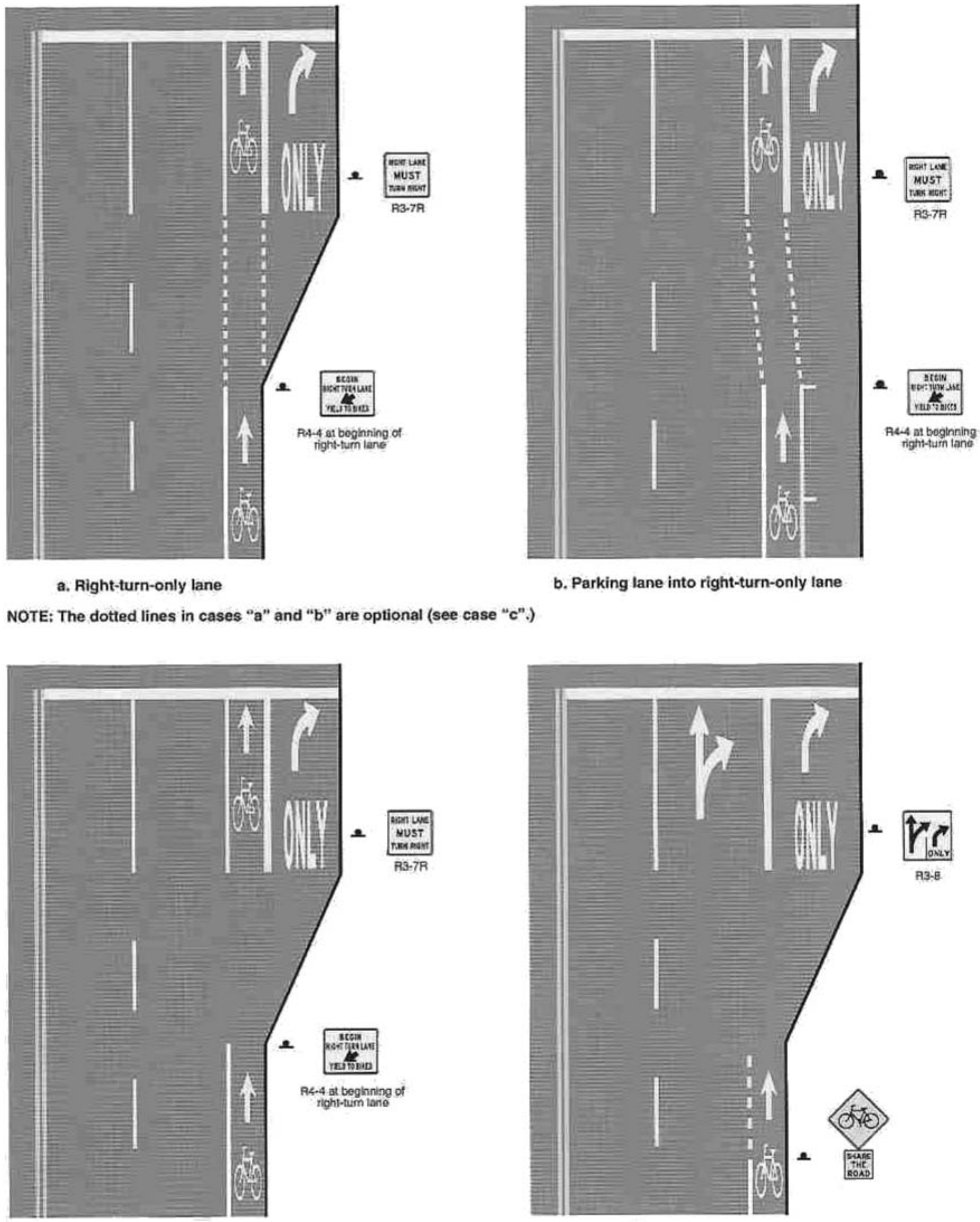


probably occurs at intersections with turning lanes. Both the AASHTO *Bicycle Guide* (1999) (Exhibit V-14) and the MUTCD (USDOT, 2003) (Exhibits V-15 and V-16) provide optional treatments for marking such intersections. The reader is referred to these sources for more detail.

In addition to the typical bicycle lane treatments that may be installed at intersections, several innovative (i.e., non-typical or non-traditional) pavement marking treatments have been installed to improve bicycle safety at intersections. These innovative pavement marking treatments include:

- Advance stop lines (or bicycle box)
- Combined bicycle lane/right-turn lanes
- Colored bicycle lanes

EXHIBIT V-14
Bike Lanes Approaching Right-Turn-Only Lanes (AASHTO, 1999)



a. Right-turn-only lane

b. Parking lane into right-turn-only lane

NOTE: The dotted lines in cases "a" and "b" are optional (see case "c".)

c. Right-turn-only lane

d. Optional right/straight and right-turn-only lane

EXHIBIT V-15
Example of Bicycle Lane Treatment at a Right-Turn-Only Lane (USDOT, 2003)

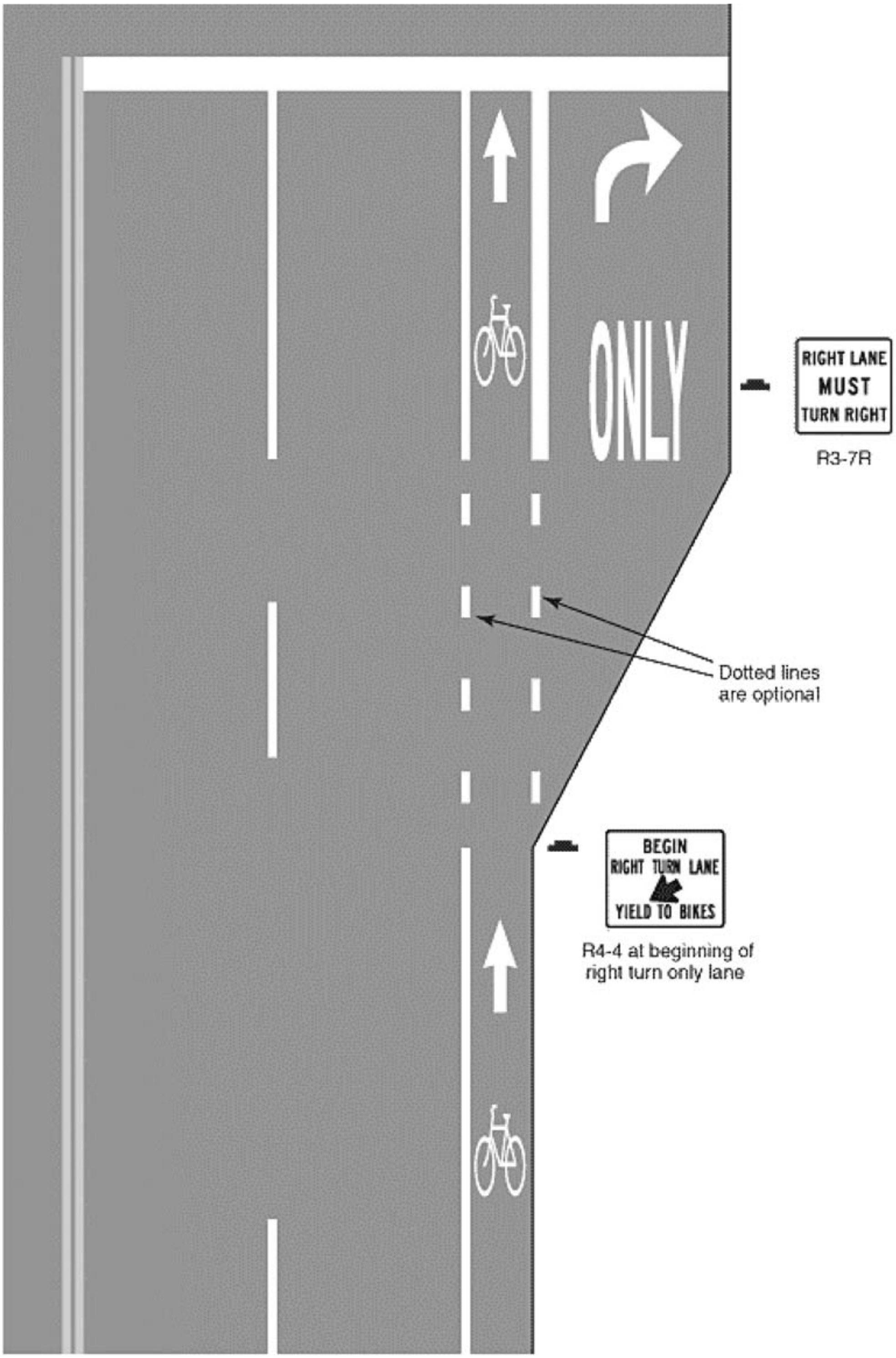
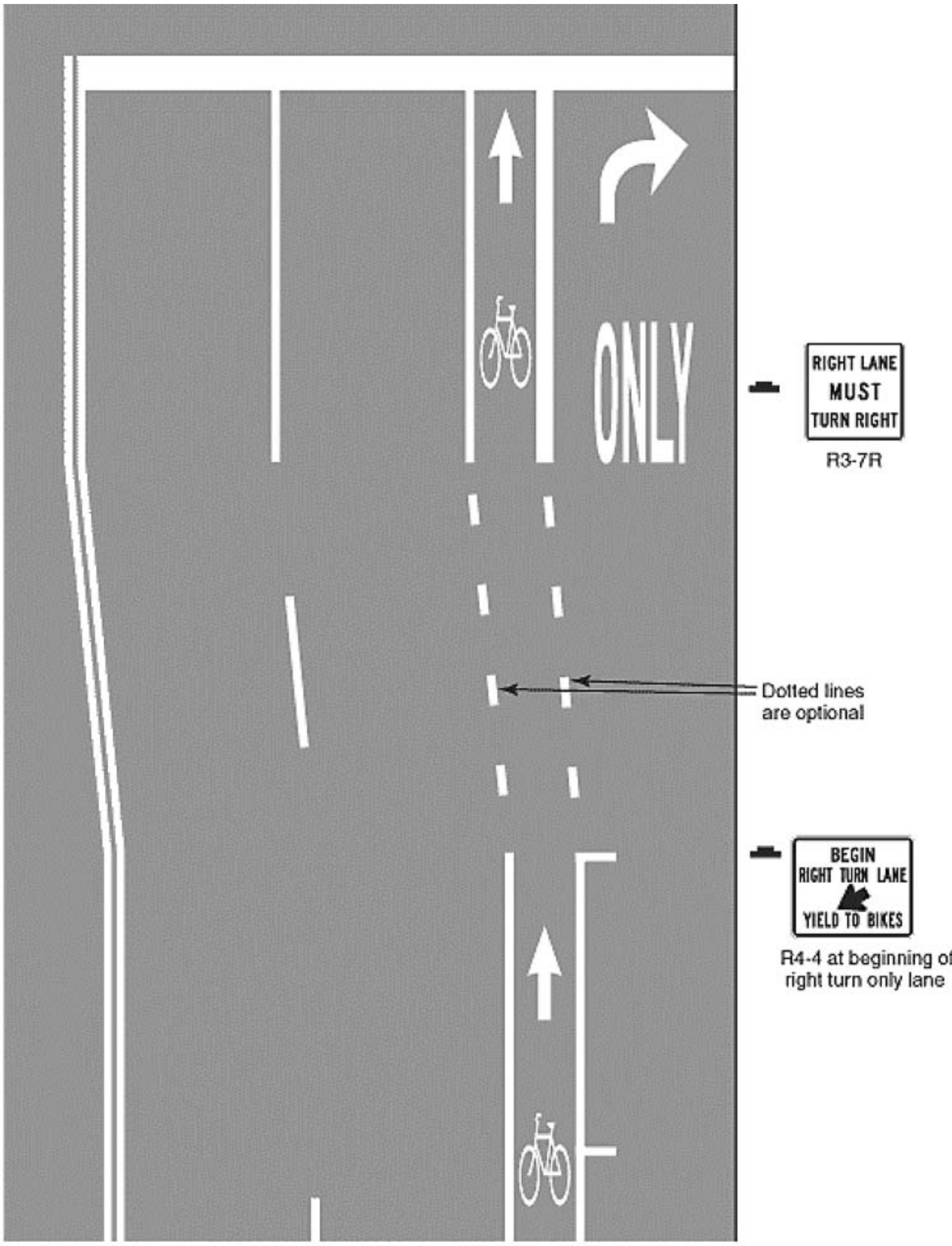


EXHIBIT V-16
Example of Bicycle Lane Treatment at a Parking Lane into a Right-Turn-Only Lane (USDOT, 2003)



An advance stop line (or bicycle box) is a right-angle extension to a bike lane at the head of a signalized intersection (Exhibit V-17). It is basically a bicycle reservoir located between the motor vehicle stop line and the pedestrian crosswalk. The box allows bicyclists to get to the head of the traffic queue on a red traffic signal indication and proceed first when the signal indication changes to green. The primary purpose of a bicycle box is to improve the visibility of bicyclists at intersections and to enable bicyclists to correctly position themselves for turning movements during the red signal phase by allowing them to proceed to the front of the queue. The primary advantages of such a treatment include the following (Nabti and Ridgway, 2002; Hunter, 2000b):

EXHIBIT V-17
Bicycle Box
(http://www.hcaog.net/RBT.2004/AppendixB.htm)

- Increasing the visibility of bicyclists by allowing them to move to the front of the queue where they are in full view of motorists on all sides of the intersection
- Enabling bicyclists to maneuver to the correct position for turning movements during the red signal phase
- Not significantly increasing delay to motor vehicle traffic
- Reducing conflicts between turning bicycles and motor vehicles by clearly delineating locations for movements to occur
- Providing a buffer between motor vehicle traffic and pedestrian crosswalk

The combined bicycle lane/right-turn lane is a standard width bicycle lane that is installed on the left side of a dedicated right-turn lane. A dashed pavement marking divides the bicycle portion and the right-turn portion of the lane. Exhibit V-18 shows the utilization of this combined lane by both modes of traffic. The purpose of the combined lane is to encourage bicyclists to use the left side of the dedicated right-turn lane where there is not enough space to mark a minimum standard bike lane to the left of the right-turn lane. Several advantages of this treatment include the following (Nabti and Ridgway, 2002; Hunter, 2000a):

- Guiding bicyclists to the correct position at intersections with a dedicated right-turn lane
- Encouraging motorists to yield to bicyclists when crossing into the narrow right-turn lane
- Requiring motorists to slow down more to make their turn

Colored bicycle lanes are short sections of the bicycle lane that are painted in high conflict zones (e.g., where motorists are permitted or required to merge into or cross the bicycle

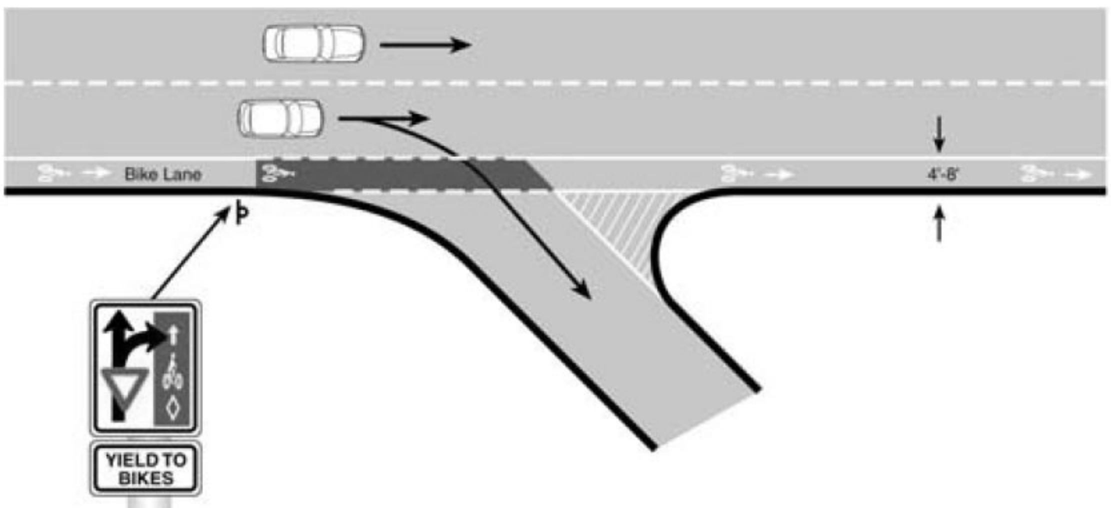
EXHIBIT V-18
Combined Bicycle Lane and Right-Turn Lane (http://www.hcaog.net/RBT.2004/AppendixB.htm)

lane). Exhibit V-19 illustrates the use of blue pavement markings at intersections with channelized right-turn lanes. Several advantages of this type of treatment include (Nabti and Ridgway, 2002; Hunter et al., 2000):

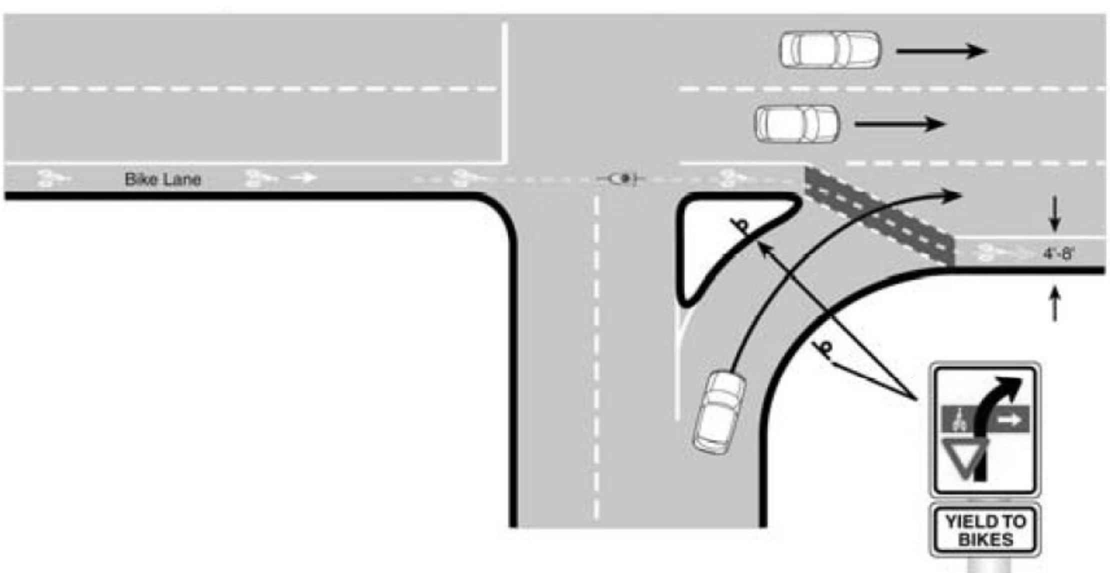
- Improving visibility of bicycle lane at key locations
- Warning bicyclists and motorists of especially hazardous areas

Pavement guide lines at signalized intersections can also be used to facilitate the movement of left-turning bicyclists (Exhibit V-20).

EXHIBIT V-19
Colored Pavement Markings at Intersections with Channelized Right-Turn Lanes (San Francisco Department of Parking and Traffic, 2003)



a. At entrance to channelized right-turn roadway



b. At exit of channelized right-turn roadway

EXHIBIT V-20
Guide Lines through Signalized Intersections (Williams et al., 1998)

EXHIBIT V-21
Strategy Attributes for Improving Pavement Markings at Intersections (T)

Attribute	Description
Technical Attributes	
Target	In general, this strategy is intended to indicate the separation of lanes for road users, assist the bicyclist by indicating assigned travel paths, and provide advance information for turning and crossing maneuvers. The bicycle box is intended for use at intersections with high motor vehicle and bicycle volumes, frequent turning conflicts, and a high percentage of turning movements by both bicyclists and motorists (Nabti and Ridgway, 2002). The combined bicycle lane/right-turn lane is intended for use at intersections where there is not enough space to implement a standard width bicycle lane and a standard width dedicated right-turn lane. Preferably, this treatment is installed at intersections with slow vehicle speeds and low heavy vehicle volumes (Nabti and Ridgway, 2002). Colored bicycle lanes are intended for use at hazardous intersections, especially where motorists fail to yield the right of way to bicyclists (Nabti and Ridgway, 2002), or at nonconventional intersections with atypical movements by bicyclists relative to motorists.
Expected Effectiveness	No accident studies have been conducted to evaluate the safety effectiveness of marking bicycle lanes at intersections or of the three innovative pavement marking treatments discussed above. However, several safety studies have been performed which looked at surrogate safety measures to evaluate these treatments, and these evaluations are summarized below. Hunter et al. (1999) compared the safety for bicyclists between marked bicycle lanes and wide curb lanes. Among other things, Hunter et al. found that left turns can present a problem for bicyclists at intersections and were made in a variety of ways. Proportionally, more bicyclists at intersections with wide curb lanes made motor vehicle-style left turns with improper lane destination positioning compared to intersections with marked bicycle lanes. In addition, statistical modeling of conflict data showed lower conflict rates for straight through and right-turning bicycles at intersections where the

EXHIBIT V-21 (Continued)
Strategy Attributes for Improving Pavement Markings at Intersections (T)

Attribute	Description
Technical Attributes	
	bicycle lane stripe continued all the way to the intersection and the wide curb lane was not narrowed at the intersection. This is a reasonable finding in that bicyclists would have more space in these configurations. Hunter (2000b) evaluated the installation of a bicycle box at a busy downtown intersection featuring two one-way streets in Eugene, Oregon. The major findings of this evaluation are as follows: • The use of the box was reasonably good. Bicyclists utilized the box in several ways. • There was a problem with motor vehicle encroachments into the box. In 52 percent of the red traffic signal indications, motor vehicles encroached into the box. • The bicycle box had no effect on signal violations by bicyclists. Approximately 6 to 7 percent of bicyclists violated the red signal indication both before and after installation of the box. • The rate of conflicts between bicycles and motor vehicles changed little from before to after installation of the box. However, the pattern of conflicts changed, and no conflicts took place when the bicycle box was used as intended. Hunter (2000a) compared the behaviors of bicyclists and motorists at two intersections in Eugene, Oregon. One intersection had a combined bicycle lane/right-turn lane, and the other intersection had a standard width right-turn lane and accompanying bicycle lane (pocket) to the left of the right-turn lane. The major findings from this study included: • More than 17 percent of surveyed bicyclists using the combined lane felt it was safer than the comparison location, and another 55 percent felt that the combined lane was no different safety-wise than the comparison location. • It was quite easy for bicyclists in the combined lane to ride up to the intersection and position themselves beside passenger cars and light trucks. On a few occasions, bicyclists were forced into the adjacent traffic lane, usually the result of a heavy truck taking extra space. • Sometimes bicyclists would shift to the right turn portion of the combined lane if a heavy vehicle was in the through lane. • Right turns on red by motor vehicles were rarely prevented when bicyclists were present at the front of the queue in the combined lane. • No conflicts between bicyclists and motor vehicles, other bicyclists, or pedestrians took place at either intersection. Hunter et al. (2000) studied the use of blue pavement markings and associated signing to delineate 10 conflict areas in Portland, Oregon. All ten sites had a high level of bicycle and motor vehicle interaction, and both bicyclists and motorists had expressed safety concerns to the city of Portland about each of the locations. The major findings of this study are as follows: • The findings tend to point to safer conditions for bicyclists as a result of using blue pavement and the associated signing to define conflict areas between bicycles and motor vehicles.

EXHIBIT V-21 (Continued)
Strategy Attributes for Improving Pavement Markings at Intersections (T)

Attribute	Description
Technical Attributes	
	• The percentage of bicyclists following the recommended marked path through the conflict area increased in the after period. • The percentage of motorists yielding to bicyclists increased in the after period. • A concern is that this treatment creates a false sense of security in bicyclists evidenced by the fact that significantly fewer bicyclists turned their heads to the rear to scan for approaching motor vehicles after the blue pavement was in place, and significantly fewer bicyclists used hand signals to indicate their movement through the conflict area, although the percentage using a hand signal was not high in the before period. • With regard to conflicts between bicycles and motor vehicles, the conflict rate per 100 entering bicyclists decreased from 0.95 in the before period to 0.59 in the after period. • Surveyed bicyclists riding through the marked conflict zones indicated that (a) the colored surfaces were no more slippery than before, (b) motorists were yielding to bicyclists more than before, and (c) the locations with blue pavement were safer than before. Motorists thought the locations were safer with the colored pavement markings in place and that the markings increased motorist awareness of the conflict areas.
Keys to Success	The primary key to success of marking bicycle lanes at intersections is consistency. Several optional treatments are identified for marking bicycle lanes at intersections. Agencies should select a preferred treatment and use it throughout their jurisdiction. Another key to safe operations for bicyclists through marked bicycle lanes at intersections is minimizing the number of illegally parked motor vehicles in the bicycle lane. This may require additional signing and enforcement. There are several keys to success associated with the bicycle box. It is suggested that the bicycle box be about 4.0 to 5.0 m (13.0 to 16.5 ft) deep. If it is shallower, bicyclists tend to feel intimidated by the motor vehicles, and if it is deeper, motorists tend to encroach. To increase its effectiveness, bold demarcation of the box is vital. This could be achieved with a bicycle stencil placed in the box and perhaps painting the box a contrasting surface color. Instructional signs and possibly separate bicycle signals can be installed in conjunction with the bicycle box. Finally, steps should be taken to limit motor vehicle encroachment. This could be achieved by setting the stop bars back a short distance from the box, and by increasing police presence at the intersection to issue warnings and ticket violations (Nabti and Ridgway, 2002; Hunter, 2000b). Providing related signs is important to the success of combined bicycle lane/right-turn lanes and colored pavement treatments. Exhibit V-22 suggests signing for combined lanes, and Exhibit V-23 illustrates unique signs installed in Portland which show the blue markings and yield signs for motorists. Finally, because several of these treatments have not been implemented on a larger scale, it would be useful to educate both bicyclists and motorists as to their intended purpose and use. This could be accomplished through newspaper articles, radio or television service announcements, and printed brochures.

EXHIBIT V-21 (Continued)
Strategy Attributes for Improving Pavement Markings at Intersections (T)

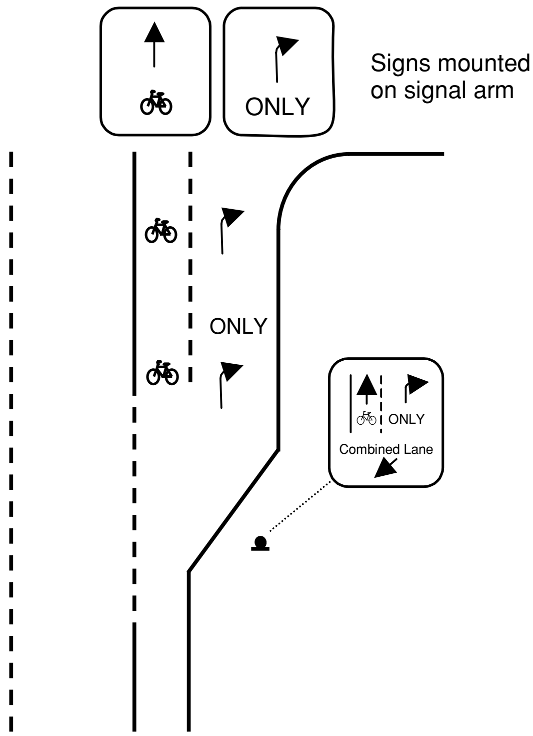
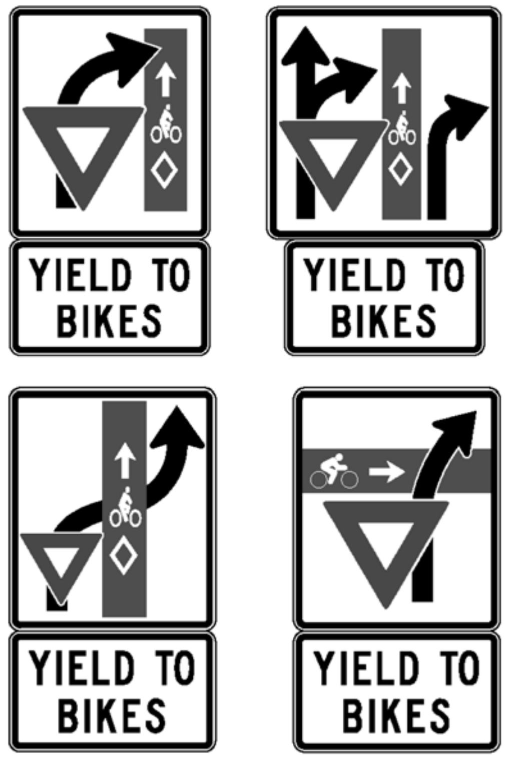
Attribute	Description
Technical Attributes	
	EXHIBIT V-22 Signing Associated with Combined Lane (adapted from Hunter, 2000a) 
Potential Difficulties	Potential difficulties or disadvantages associated with the bicycle box include (Nabti and Ridgway, 2002): • Decreased effectiveness during the green signal phase • Motorists encroaching into the box • Increased hazards to bicyclists when right turn on red maneuvers by motorists are permitted since the approach bicycle lane leads up to the front of the intersection In addition, it may be difficult to install bicycle boxes at intersections with offset left-turn lanes. Potential difficulties or disadvantages associated with the combined bicycle lane/right-turn lane include (Nabti and Ridgway, 2002): • Forcing bicyclists into the adjacent through lane when heavy vehicles are turning right • Bicyclists shifting to the right turn portion of the combined lane if a heavy vehicle is in the through lane • Decreased effectiveness where a right turn island is required

EXHIBIT V-21 (Continued)
Strategy Attributes for Improving Pavement Markings at Intersections (T)

Attribute	Description
Technical Attributes	

EXHIBIT V-23
Signing Associated with Combined Lane (Hunter et al., 2000)



Potential difficulties or disadvantages associated with the colored pavement treatments include (Nabti and Ridgway, 2002):

- The colored markings may confuse bicyclists (especially when making right turns at right-turn lanes)
- The colored markings may confuse disabled road users
- State or local traffic laws may not permit the use of this treatment

In addition, colored pavement markings may reduce skid resistance.

Finally, because several of these treatments are relatively new and not widely used, drivers unfamiliar with them may be confused or uncertain about the intended purpose of the markings.

Attribute	Description
Appropriate Measures and Data	A key process measure is the number of intersections where pavement markings have been improved. Crash frequency and severity, by type, are key safety effectiveness measures.

EXHIBIT V-21 (Continued)
Strategy Attributes for Improving Pavement Markings at Intersections (T)

Attribute	Description
Technical Attributes	
	Crash frequency and severity data are needed. Bicycle and motor vehicle volume data are needed to represent exposure.
Associated Needs	Because several of these treatments are relatively new and not widely used, it may be beneficial to develop a PI&E program to educate both bicyclists and motorists of their intended purpose and use. Because several of these pavement marking treatments have not been approved by FHWA for incorporation into the MUTCD, agencies would need to develop their own standards for these pavement treatments. In addition, agencies may desire to develop related signing to install in conjunction with the pavement marking treatments. Because some of these markings are not an accepted traffic control device in the MUTCD, an agency should follow the provisions outlined in Section 1A.10 of the MUTCD for design, application, and placement of traffic control devices that are not adopted in the most recent edition of the MUTCD. Agencies will need to decide on an appropriate color to mark bicycle lanes under their jurisdiction. Different colors have been used for bicycle lanes. Red, blue, yellow, and green have been used in several European countries. Blue was used in Portland, Oregon, namely because (a) yellow, green, and red have meanings that conflict with the intended purpose of the markings, (b) color-blind individuals are often more able to differentiate blue than other colors, and (c) blue tends to stand out in low visibility conditions such as rain, fog, and nighttime. Precedence for blue has been established by the city of Portland.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	Agencies may need to adopt these pavement marking treatments and the associated signing as an acceptable traffic control device in their jurisdiction.
Issues Affecting Implementation Time	This strategy does not require a long development process. Installation of pavement markings can typically be implemented in 3 months or less. Adoption as an acceptable traffic control device may require a longer time period.
Costs Involved	Costs are dependent upon the materials (e.g., paint or thermoplastic) and whether associated signage is necessary. In the case of a bicycle box, new signal heads may be desirable which are costly. Maintenance costs are expected to increase, especially for the colored bicycle lane treatment. Appendix 5 provides details related to costs of colored bicycle lanes.
Training and Other Personnel Needs	Training regarding use of this strategy should be provided in highway agency courses covering the use of traffic control devices.
Legislative Needs	Several of these pavement marking treatments have not been approved by FHWA for incorporation into the MUTCD. Therefore, legislation may need to be introduced and/or local traffic laws may need to be modified to permit their use. Along the same lines, laws may be required to allow bicycles in right-turn lanes.
Other Key Attributes	
	None identified.

Information on Agencies or Organizations Currently Implementing this Strategy

For additional details on improving pavement markings at intersections, the reader is referred to the following studies that are available on the internet:

- *A Comparative Analysis of Bicycle Lanes Versus Wide Curb Lanes: Final Report,* http://www.fhwa.dot.gov/tfhrc/safety/pubs/99034/99034.pdf (Hunter et al., 1999)
- *Evaluation of an Innovative Application of the Bike Box,* http://www.walkinginfo.org/pdf/r&d/bikebox.pdf (Hunter, 2000b)
- *Evaluation of a Combined Lane/Right-Turn Lane in Eugene, Oregon,* http://www.walkinginfo.org/pdf/r&d/blue_box_combined.pdf (Hunter, 2000a)
- *Evaluation of the Blue Bike Lane Treatment Used in Bicycle/Motor Vehicle Conflict Areas in Portland, Oregon,* http://www.walkinginfo.org/pdf/r&d/bluelane.pdf (Hunter et al., 2000)

Appendix F provides contact information for individuals if additional details are desired.

Strategy A5: Improve Intersection Geometry (T)

General Description

There are several ways to modify the geometry of an intersection to improve bicycle safety, including:

- Reducing the crossing distance for bicyclists
- Realigning intersection approaches to reduce or eliminate intersection skew
- Modifying the geometry to facilitate bicycle movement at interchange on-ramps and off-ramps
- Providing refuge islands and raised medians

These geometric improvements are addressed below.

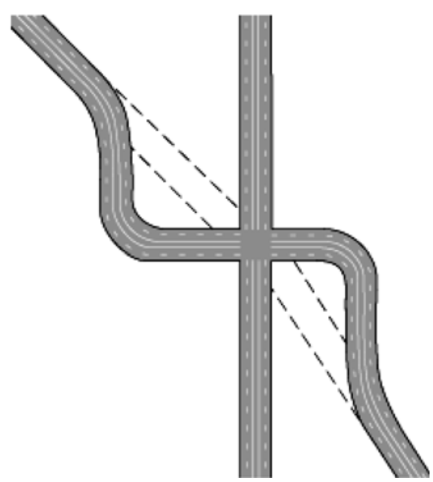
It may be reasoned that as crossing distances increase at an intersection, a bicyclist's exposure to motor vehicle traffic increases, particularly at unsignalized intersections, increasing the potential for a bicycle/motor vehicle crash. Thus, by reducing the crossing distance across an intersection, the safety of bicyclists should be improved. Crossing distances can be reduced by narrowing the lane widths. This can be accomplished either through restriping the pavement markings or by reconstructing the intersection such that the physical distance between curbs is narrower. Curb extensions, a form of traffic calming, may also be used to shorten crossing distances. Reducing the crossing distance or narrowing the lane widths may also result in reduced vehicular speeds, which is a safety benefit to bicyclists. To minimize the crossing distance for bicyclists at single-point urban interchanges (SPUIs), SPUIs should be designed to be as compact as possible.

When roadways intersect at skewed angles, bicyclists and motorists may experience one or more of the following problems at the intersection:

- Bicyclists and motorists may have a longer distance to traverse while crossing or turning onto the intersecting roadway, resulting in an increased time of exposure to the cross-street traffic.
- Older drivers may find it more difficult to turn their head, neck, or upper body for an adequate line of sight down an acute-angle approach.
- The driver's sight angle for convenient observation of opposing traffic and bicycle crossings is decreased.
- Bicyclists and drivers may have more difficulty aligning their bicycles or motor vehicles as they enter the cross street to make a right or left turn.
- Drivers making right turns around an acute-angle radius may encroach on lanes intended for oncoming traffic from the right.
- The larger intersection area may confuse bicyclists and drivers or cause them to deviate from their intended path.
- Bicyclists and drivers making left turns across an obtuse angle may attempt to maintain a higher than normal turning speed and cut across the oncoming traffic lane on the intersecting street.
- Motor vehicles may obstruct the line of sight of drivers with an acute-angle approach to their right.

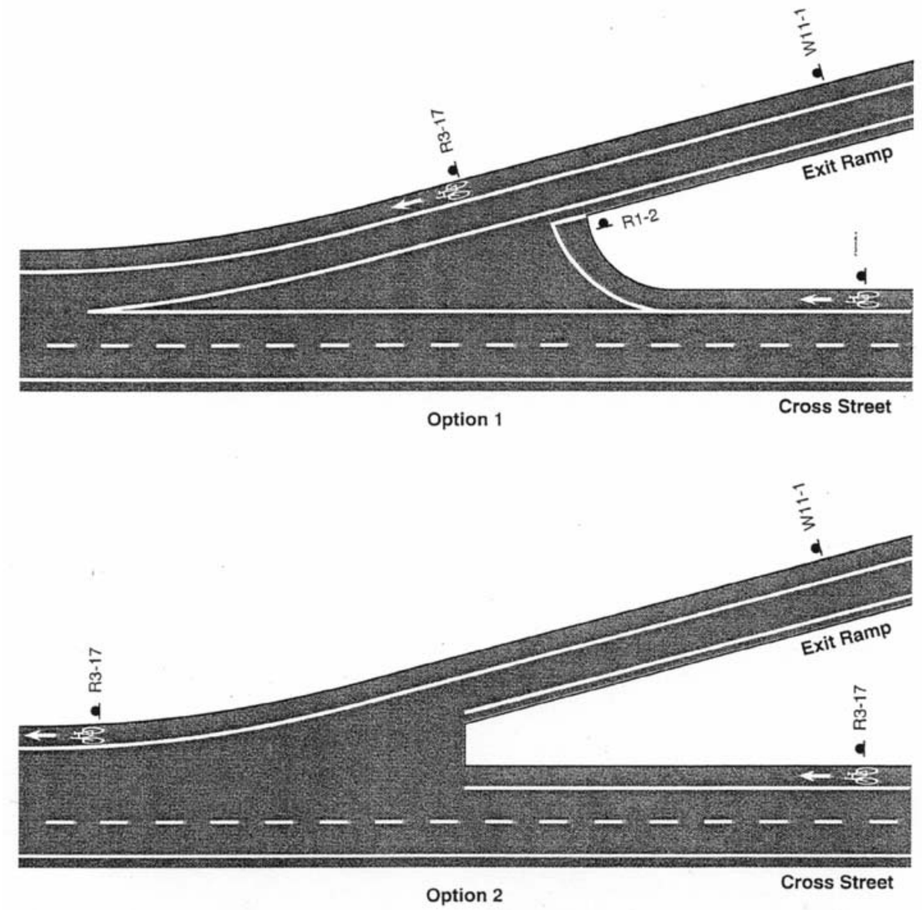
Realignment of intersection approaches to reduce or eliminate intersection skew may be desirable to improve safety for all road users (i.e., bicyclists, motorists, and pedestrians) at a skewed intersection (Exhibit V-24). This type of geometric improvement is related to Strategy 17.1 B16—Realign Intersection Approaches to Reduce or Eliminate Intersection Skew in *NCHRP Report 500, Volume 5: Guide for Addressing Unsignalized Intersection Collisions* and Strategy 17.2 B4—Revise Geometry of Complex Intersections in *NCHRP Report 500, Volume 12: Guide for Reducing Collisions at Signalized Intersections.*

EXHIBIT V-24
Skewed Intersection Realigned to a Right Angle (Oregon DOT, 1995)



Roadways at interchange areas often require bicyclists to perform merging, weaving, or crossing maneuvers with ramp vehicles. These conflict points are hazardous to bicyclists because there is often a wide disparity in speed between the motor vehicle traffic and bicyclists. Exhibits V-25 through V-27 provide guidance for delineating bicycle lanes through interchange areas. The AASHTO *Bicycle Guide* (1999) presents two treatments (Exhibit V-25) related to the design of bicycle lanes at interchange exit ramps. Option 1 redirects the bicycle lane towards the channelized roadway, intersecting at a 90-degree angle. Bicyclists are to yield to the motor vehicle traffic on the channelized roadway before crossing. In Option 2, striping of the bicycle lane is discontinued to indicate to bicyclists that they must merge with entering traffic from the channelized

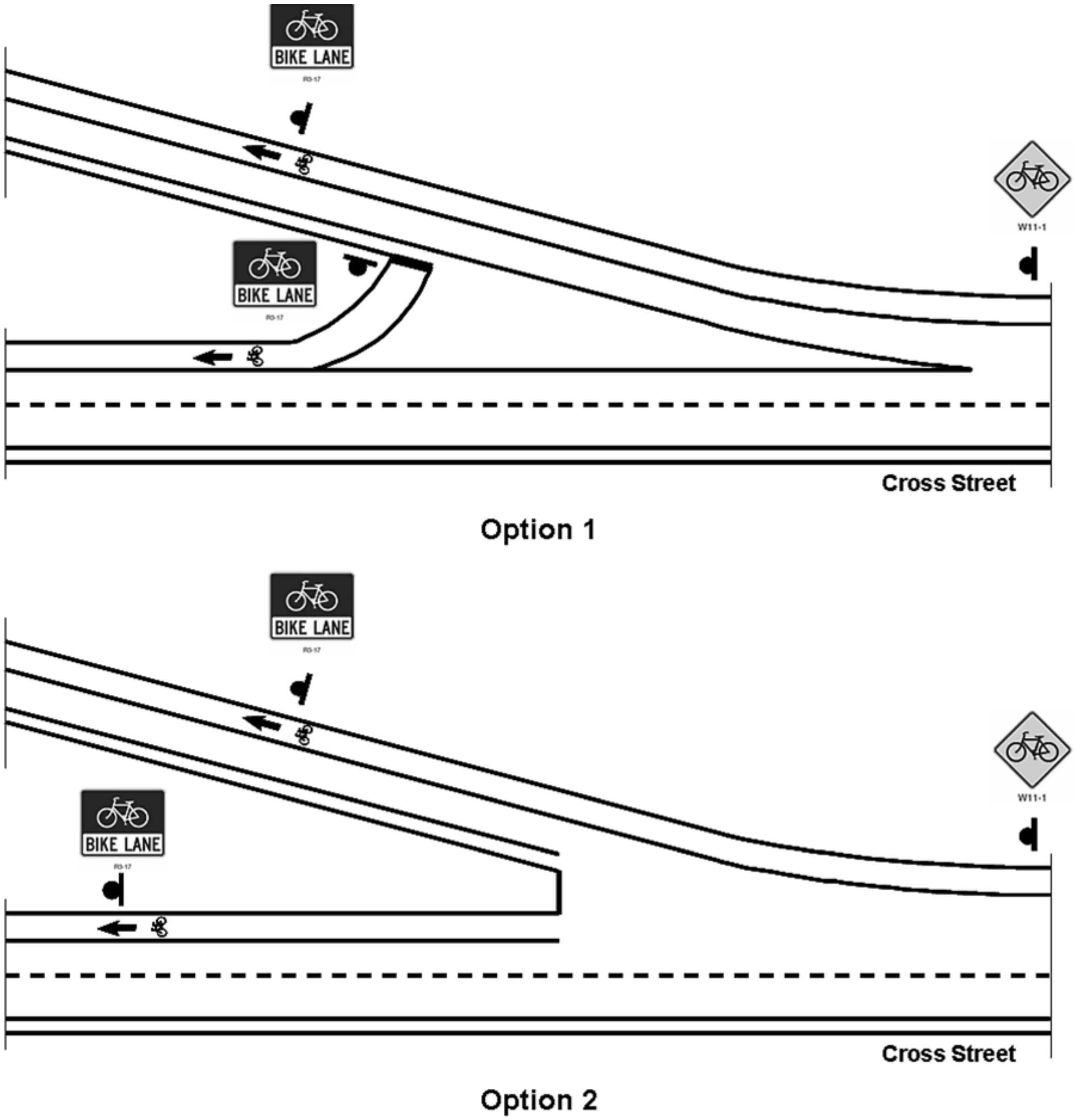
EXHIBIT V-25
Bicycle Lanes Crossing Interchange Exit Ramps (AASHTO, 1999)



roadway (i.e., the exit ramp). Exhibit V-26 presents an optional treatment for marking bicycle lanes near interchange entrance ramps (WSDOT, 2001). In Option 1, the bicycle lane continues along the right side of the entrance roadway, and then bicyclists cross at 90 degrees at a designated location along the channelized roadway to return to the bicycle lane. This treatment may be preferable to bicyclists who prefer to use crosswalks to negotiate intersections. In Option 2, striping of the bicycle lane is discontinued to indicate to bicyclists that they must weave through traffic entering the channelized roadway (i.e., the entrance ramp). Exhibit V-27 presents another optional treatment for marking bicycle lanes near interchange entrance ramps, and in this option the bicycle lane is separated from the roadway for a short distance along the channelized roadway in order to loop around and intersect the channelized roadway close to a 90 degree angle (Oregon DOT, 1995).

Raised refuge islands or medians at intersections provide another strategy to reduce exposure between bicycles and motor vehicles. Raised refuge islands and medians provide bicyclists a more secure place of refuge during the street crossing. This simplifies the crossing maneuver by allowing bicyclists to focus and cross one direction of traffic at a time. The minimum width of a median refuge should be 2.4 m (8 ft) for storage purposes. When a large number of

EXHIBIT V-26
Bicycle Crossing of Interchange Entrance Ramp (adapted from Washington State DOT, 2001)

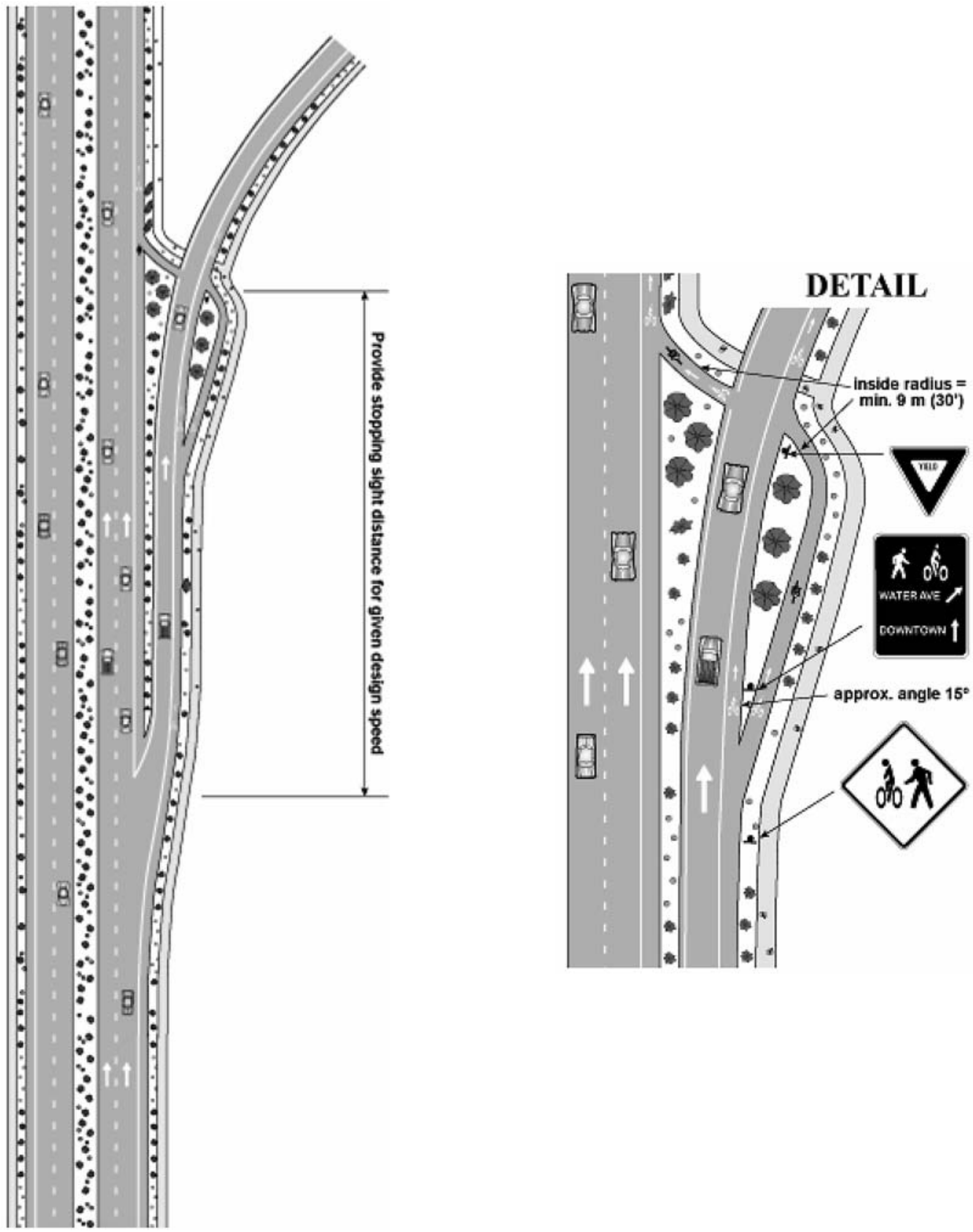


bicyclists are anticipated, a storage space of 3.0 m (10 ft) or more is preferred. This strategy is related to Strategy 9.1 A3—Construct Pedestrian Refuge Islands and Raised Medians in *NCHRP Report 500, Volume 10: Guide for Reducing Collisions Involving Pedestrians.*

AASHTO (1999) recommends that refuge islands be considered for use at the intersection of a shared use path and a roadway if one or more of the following apply:

- High volumes of vehicular traffic and/or speeds create unacceptable conditions for bicyclists.

EXHIBIT V-27
Bicycle Crossing of Interchange Entrance Ramp where a Bicycle Lane Becomes a Separated Path (Oregon DOT, 1995)



- Roadway width is excessive given the available crossing time.
- Crossing will be used by a number of people who cross more slowly (i.e., elderly, children, and persons with disabilities).

Exhibit V-28 provides example specifications for a refuge area at a path/roadway intersection.

EXHIBIT V-28
Specifications for a Refuge Island at a Path/Roadway Intersection (AASHTO, 1999)

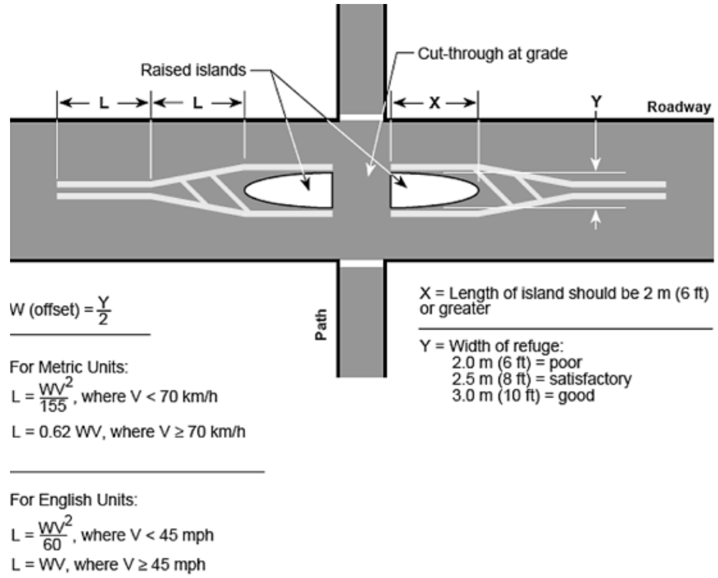


EXHIBIT V-29
Strategy Attributes for Improving the Geometry (T)

Attribute	Description
Technical Attributes	
Target	When bicycle safety concerns cannot be sufficiently addressed through traffic control (i.e., signing and pavement markings), modifications to the geometrics should be considered.
Expected Effectiveness	No accident studies have been performed that prove reducing the crossing distance at an intersection is a safety benefit for bicyclists. However, based upon exposure time, it is reasonable to expect that such a treatment improves bicycle safety, and research by Landis et al. (2003) on intersection level of service for bicyclists indicates that bicyclists feel safer crossing shorter distances. Concerning the expected safety benefits of realigning the roadway, a group of experts concluded from a review of the literature that realigning intersection approaches to reduce or eliminate intersection skew improves motor vehicle safety at unsignalized intersections along two-lane rural highways (Harwood et al., 2000). Skew angle is less of a safety concern at signalized intersections since the traffic signal separates most movements from conflicting approaches. The expert panel concluded the safety effectiveness of realignment is as follows for total motor vehicle crashes: AMF = exp (0.0040 SKEW) For three-legged intersections and AMF = exp (0.0054 SKEW) For four-legged intersections where: AMF = Accident modification factor SKEW = Intersection skew angle (degrees), expressed as the absolute value of the difference between 90 degrees and the actual intersection angle.

EXHIBIT V-29 (Continued)
Strategy Attributes for Improving the Geometry (T)

Attribute	Description
Technical Attributes	
	Multiplying the AMF by the proportion of bicycle/motor vehicle accidents at an intersection would give an indication of the expected number of bicycle/motor vehicle accidents that would be reduced due to this treatment. Interchange areas are high conflict locations for bicyclists because of the merging and weaving that occurs with motor vehicle traffic. No accident studies have been conducted on the safety benefits of modifying the geometrics near on- and off-ramps for bicyclists. Uniformly applying the optional treatments would increase both driver and bicyclist expectancy, which in turn is expected to improve bicycle safety. Although no accident studies have investigated the safety effectiveness of raised medians on bicycle safety, raised medians have provided significantly lower pedestrian crash rates on multi-lane roads, compared to roads with no raised median (Zegeer et al., 2002). It is reasonable to expect that raised medians would also benefit bicyclists at path/highway crossings. Raised refuge islands can also serve to calm traffic (i.e., reduce motor vehicle speeds), which is beneficial for bicyclists.
Keys to Success	The key to successfully applying this strategy is to identify candidate locations at which crash patterns exist that may be remedied by one of these various geometric improvements. Some of the optional treatments for improving bicycle safety near interchange areas have the bicyclist taking a path that is not necessarily the shortest distance through the interchange area for the bicyclist. A key to successful implementation is not to significantly increase the travel distance for bicyclists. Raised refuge islands should be considered where there are a limited number of gaps in the traffic stream and at intersections with long crossing distances. For example, AASHTO (2004) recommends that a refuge island be considered when the crossing distance exceeds 18 m (60 ft). Holding rails can also be installed so bicyclists do not have to put their feet down, thus making it quicker to start again. Finally, crossing islands must be visible to the motorist. This can be accomplished either with lighting (or illumination) or through retroreflective signs, pavement markings, or other materials (e.g., retroreflective tape can be installed along hand rails located within the median island to improve visibility).
Potential Difficulties	Several potential difficulties related to reducing the crossing distance for bicyclists are that it could negatively impact the level of service of the intersection and depending upon how the reduced crossing distance is achieved, it may decrease the separation distance between motor vehicles and between motor vehicles and bicyclists, which could negatively impact safety. When realigning a skewed intersection approach, it is possible to create such a sharp horizontal curve that the curve itself becomes a safety concern. Thus, the designer should be careful to avoid trading one safety concern for another. Realignment may also negatively affect adjacent properties. Because some of the optional treatments for improving bicycle safety near interchange areas are not necessarily the shortest distance through the interchange area for the bicyclist, some bicyclists may deviate from the bicycle facility. If it is not designed properly, a refuge island near an intersection could potentially be hazardous for all road users (i.e., bicyclists, pedestrians, and motorists). Thus, the designer should be careful to avoid trading one safety concern for another. Exhibit V-28 provides general specifications for a refuge island.

EXHIBIT V-29 (Continued)
Strategy Attributes for Improving the Geometry (T)

Attribute	Description
Technical Attributes	
Appropriate Measures and Data	A key process measure is the number of intersections where geometric improvements were implemented to improve bicycle safety. Crash frequency and severity, by type, are key safety effectiveness measures. Separate analysis of crashes targeted by the improvement is desirable. The analysis should also investigate bicycle/motor vehicle crashes and strictly vehicular crashes separately. Crash frequency and severity data are needed. Both bicycle and traffic volume data are needed to represent exposure. Crash location data is also important, particularly in interchange areas.
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	Highway agencies should ensure that their design policies for new or reconstructed intersections incorporate these geometric considerations for bicyclists. Guidance should be provided on where one or more of these geometric considerations are appropriate.
Issues Affecting Implementation Time	Most of the options for modifying the geometry of an intersection to improve bicycle safety can be implemented in a relatively short time frame (i.e., 1 to 2 years). The exception is realignment of skewed intersections, which could potentially take as long as 4 years. At least 1 year is necessary to work out the details of intersection approach realignment and to communicate the plan to affected businesses and residents. Where relocation requires right-of-way acquisition or demolition of existing structures, an extensive project development process up to 4 years long may be required.
Costs Involved	The costs for this strategy will vary widely, depending upon the design. Reducing the crossing distance can be accomplished either through restriping the pavement markings or by reconstructing the intersection such that the physical distance between curbs is narrower. Obviously, restriping costs are minimal compared to the intersection reconstruction costs. Reducing or eliminating the skew angle of an intersection involves the realignment of at least one intersection approach. The cost of this type of construction project is usually high. Furthermore, additional right-of-way will generally need to be acquired. Costs for improvement to interchange areas should be relatively minimal, unless a separated path is provided. Costs for additional signing and pavement markings could be incurred. Costs for refuge islands and raised medians vary depending upon the design, site conditions, and the use of landscaping. Appendix 9 in *NCHRP Report 500, Volume 10: Guide for Reducing Collisions Involving Pedestrians* provides typical cost estimates.
Training and Other Personnel Needs	None identified.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy A6: Restrict Right Turn on Red (RTOR) Movements (E)

General Description

Throughout the United States motorists are permitted to make a right turn on red (RTOR) movement unless prohibited by a posted traffic sign. The only exception to this rule is within New York City, where RTOR is generally prohibited unless otherwise permitted at specific locations by posted traffic signs. State RTOR laws generally require that drivers come to a complete stop and yield to approaching traffic before making a RTOR maneuver. The national policy permitting RTOR was instituted primarily to reduce fuel consumption following the energy crisis of 1973. Additional benefits of the RTOR policy include reduced vehicle delays and tailpipe emissions (Retting et al., 2002).

Following the adoption of the national RTOR policy, significant increases in bicycle crashes at signalized intersections were reported (Preusser et al., 1982; Zador, 1984). The effects were more pronounced in urban and suburban areas than in rural areas that have fewer signalized intersections (Preusser et al., 1982). Preusser et al. (1982) also reported that in most cases bicyclists were approaching from the driver's right side and drivers frequently claimed they were looking to the left searching for a gap in traffic and never saw the bicyclists.

The primary purpose of this strategy is not to restrict RTOR at all signalized intersections in an area or local jurisdiction. Rather, the purpose is to restrict RTOR movements at certain signalized intersections throughout the entire day or during portions of the day (e.g., during periods of peak bicycle activity). At signalized intersections with a history of bicycle/motor vehicle crashes resulting from RTOR movements, an analysis of the time of day of the crashes may provide justification for restricting RTOR movements throughout the entire day or during specified hours of the day.

EXHIBIT V-30
Strategy Attributes for Restricting Right Turn on Red (RTOR) Movements (E)

Attribute	Description
Technical Attributes	
Target	This strategy is to be implemented at signalized intersections where a significant number of motorists have struck bicyclists while making a RTOR. The prohibition may be scheduled throughout the entire day or during specified hours. This strategy may be especially applicable to intersections located near schools.
Expected Effectiveness	Approximately 3 to 4 percent of all bicycle/motor vehicle crashes occur during a RTOR maneuver, and 6 percent of these crashes result in serious or fatal injuries (Tan, 1996). The expected number of bicycle/motor vehicle crashes that may be reduced by implementing this strategy is difficult to assess because it is an experimental treatment for improving bicycle safety. However, this strategy has been recommended for improving pedestrian safety based upon a field study by Retting et al. (2002). Similar to bicycle crashes, significant increases in pedestrian accidents at signalized intersections have been reported following the adoption of the national RTOR policy. Retting et al. (2002) report that traffic signs prohibiting RTOR during specified hours were very effective at increasing driver compliance with stop lines, reducing the number of drivers turning right on red without stopping, and reducing the number of pedestrians yielding

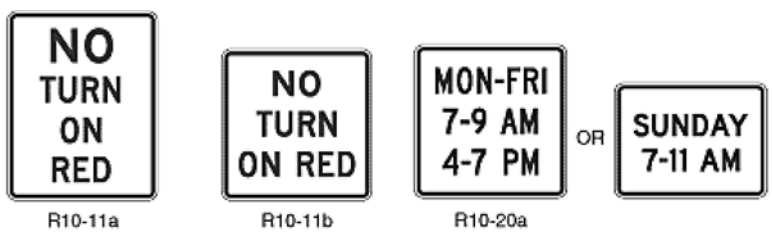
EXHIBIT V-30 (Continued)
Strategy Attributes for Restricting Right Turn on Red (RTOR) Movements (E)

Attribute	Description
Technical Attributes	
	the right-of-way to turning vehicles. It seems reasonable to expect that restricting RTOR movements, even only during specified hours of the day (i.e., during periods of peak bicycle activity), would reduce the likelihood of bicycle/motor vehicle crashes resulting from RTOR movements.
Keys to Success	Keys to success include (a) identifying signalized intersections where bicycle/motor vehicle crashes resulting from RTOR movements have occurred, (b) determining whether the restrictions should be throughout the entire day or only during specified hours of the day (e.g., periods of peak bicycle activity), and (c) consistent enforcement of the restrictions.
Potential Difficulties	Depending upon how this strategy is implemented and whether any potential PI&E programs might be released with this strategy, motorists may become disgruntled at any inconvenience (i.e., increased delay) that they experience if they personally do not view or encounter any bicyclists at the respective intersections during the periods of restricted movement. Enforcing the RTOR restrictions could also be difficult.
Appropriate Measures and Data	Key process measures include the number of signalized intersections where RTOR movements are restricted. Key safety effectiveness measures include (a) the frequency and severity of bicycle/motor vehicle crashes resulting from all right turn movements at signalized intersections, (b) the frequency and severity of bicycle/motor vehicle crashes resulting from RTOR movements at signalized intersections, and (c) the percentage of vehicles that comply with the RTOR restrictions. Exposure data is also critical for measuring safety effectiveness. In particular, bicycle exposure data (i.e., bicycles per hour that enter the respective intersections) during the periods of restricted movement is important, as well as motor vehicle counts (i.e., number of right-turning vehicles per hour and number of RTOR movements per hour). RTOR bicycle problems begin with wrong-way riding so the percentage of bicyclists riding in the wrong direction of travel (i.e., wrong-way riding) is also an important safety measure that should be collected.
Associated Needs	An accident analysis that investigates the time of day of bicycle/motor vehicle crashes that resulted from right-turn movements and RTOR movements may help to establish specific hours for the RTOR restrictions. In the absence of accident data, conflict studies could be performed at intersections to identify where this strategy may be applicable. Bicycle exposure data should also be gathered to determine periods of peak bicycle activity. A PI&E program may be released in part to educate bicyclists about the inherent dangers of wrong-way riding and to educate motorists about the primary purpose for the RTOR restrictions so that they may be more understanding of the RTOR restrictions and comply better with the restrictions.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	None Identified

EXHIBIT V-30 (Continued)
Strategy Attributes for Restricting Right Turn on Red (RTOR) Movements (E)

Attribute	Description
Organizational and Institutional Attributes	
Issues Affecting Implementation Time	This strategy can be implemented in a relatively short timeframe (i.e., 3-6 months). The only issues affecting the implementation time are conducting respective accident analyses/conflict studies and gathering exposure data (See Associated Needs section). It is assumed that the accident data are readily available in electronic format for analysis. Similarly, if a PI&E program was released in conjunction with this strategy, it could be developed in a short time period.
Costs Involved	Costs for implementing this strategy are relatively minimal. Associated costs would involve performing the accident analysis/conflict study and gathering exposure data. Gathering bicycle exposure data is often labor intensive and could require significant funds, depending upon the amount of data desired. Costs for a PI&E program may also be incurred. Finally, costs for supplying and maintaining the No Turn on Red signs and supplemental plaque (Exhibit V-31) showing the times of day that the restriction is in place will be incurred.

EXHIBIT V-31
No Turn on Red Signs and Supplemental Plaques (USDOT, 2003)



Attribute	Description
Training and Other Personnel Needs	The presence of law enforcement personnel may be required periodically to enforce and encourage higher compliance from motorists. Possibly in conjunction with a PI&E program, law enforcement personnel can also educate bicyclists who may be riding the wrong-way through these intersections on the inherent dangers of wrong-way riding.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy A7: Accommodate Bicyclists through Roundabouts (T)

When used and designed properly, roundabouts have been proven to significantly reduce motor vehicle crashes (Persaud et al., 2001). However, bicyclists do not experience the same safety benefits at roundabouts as motorists, although the results are mixed. Shen et al. (2000) concluded that bicycle accident rates at roundabouts are 15 times those of motor vehicles, and surveys taken from bicyclists indicate that bicyclists find roundabouts significantly more stressful to negotiate than other forms of intersections, particularly on roads with heavy traffic. A Danish accident study conducted on 48 Dutch roundabouts found that 66 percent of all injured users were bicyclists (Jorgensen & Rundkorsler, 1991). Alternatively, a separate 1994 Danish study used a sample of 201 roundabouts and concluded that while they did not benefit as significantly as motor vehicles, bicycles and mopeds experienced a 44 percent reduction in the number of casualties (Schoon and Minnen, 1994). In considering these European studies, it should be noted that compared to the United States, European countries have a proportionately higher number of bicyclists. It should also be noted that smaller, single-lane, low-speed roundabouts are likely safer for bicyclists than larger, multilane roundabouts.

Several recommended approaches for improving bicycle safety at roundabouts include (Robinson et al., 2000):

- Avoid bicycle lanes on the outer edge of the circulatory roadway. A 1992 German study focusing on bicycle safety at urban intersections found that including bike lanes or crosswalks on the outside of a "circular intersection" actually created more safety risk in an already dangerous environment than when bicycles simply shared the roadway with motor vehicles. It should be noted, however, that the intersections studied did lack some of the safety attributes of modern roundabouts (Schnüll et al., 1992). Even when bicycle lanes are provided on the outside edge of a roundabout, preliminary results of a Danish study suggest that 60 percent of bicyclists do not even use the bicycle lane (Herrstedt et al., 1993). It should be noted that the MUTCD states that bicycle lanes shall not be provided on the circular roadway of a roundabout intersection.
- On single lane roundabouts where vehicular traffic volumes are low and operating speeds are lower, allow bicyclists to mix with vehicular traffic without any separate facility outside the circulatory roadway.
- Speed is a fundamental risk factor in the safety of bicyclists. Design treatments that slow traffic such as tightening entry curvature and entry width, and radial alignment of the legs of a roundabout should improve bicycle safety. The necessity of a safe entry is illustrated by a 1986 study that found 86 percent of collisions involving bicycles and motor vehicles occurred between circulating bicyclists and motor vehicles entering the roundabout (Layfield and Maycock, 1986). Robinson et al. (2000) indicate that commuter bicyclist speeds can range from 19 to 24 km/h (12 to 15 mph) and designs that constrain the speeds of motor vehicles to similar values will minimize the relative speeds and improve safety.

EXHIBIT V-32
Strategy Attributes for Accommodating Bicyclists through Roundabouts (T)

Attribute	Description
Technical Attributes	
Target	This strategy should be considered at all roundabouts where bicyclists may be expected.
Expected Effectiveness	The use of modern day roundabouts is still in its infancy in the United States. As a result, the few safety evaluations of these facilities that have been conducted have focused on the safety impacts to motor vehicles, and for the most part, the negative impacts that roundabouts have on bicyclists have been identified but not studied. Thus, no accident studies have been conducted that estimate the safety benefit to bicyclists of implementing the recommended approaches to improving bicycle safety at roundabouts. However, these recommended approaches are in European policies where roundabouts have a

EXHIBIT V-32 (Continued)
Strategy Attributes for Accommodating Bicyclists through Roundabouts (T)

Attribute	Description
Technical Attributes	
	longer history of use so it is reasonable to expect that implementing these recommended approaches will improve bicycle safety at roundabouts in the United States.
Keys to Success	Because roundabouts are still a relatively new intersection treatment in the United States, new roundabouts are being constructed around the country. The key to success is to design these new roundabouts to accommodate bicyclists initially, rather than to modify the design at a later date to accommodate bicycle travel. Also, all traffic control devices should be in compliance with the MUTCD.
Potential Difficulties	It is difficult to ignore the safety benefits to motor vehicles that have been reported in the various safety evaluations. Persaud et al. (2001) reported reductions of 40 percent for all crash severities combined and 80 percent for all injury crashes, and reductions in the numbers of fatal and incapacitating injury crashes were estimated to be about 90 percent. Agencies may be willing to overlook the safety disbenefits to bicyclists in exchange for the safety benefits to motorists.
Appropriate Measures and Data	A key process measure is the number of roundabouts under the jurisdiction of the highway agency. Crash frequency and severity, by type, are key safety effectiveness measures, and location data are important to diagnosis a safety problem (e.g., did the crash occur on the approach to the roundabout, at the entry, or within the circulatory roadway). Crash frequency and severity data are needed. Bicycle and motor vehicle volume data are needed to represent exposure. Speed is also a fundamental risk factor in the safety of bicyclists, especially at roundabouts, so it is an important safety measure to collect vehicular speed data on approach and entry, as well as within the circulatory roadway.
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	Related to the potential difficulties, highway agencies should establish a policy to consider bicyclists during the design of every roundabout.
Issues Affecting Implementation Time	Because roundabouts are currently being constructed, these recommended approaches to improving bicycle safety at roundabouts could be considered during the design process and should have minimal impact on completing the final design of a roundabout.
Costs Involved	Costs for accommodating bicyclists at roundabouts are minimal in most cases.
Training and Other Personnel Needs	Training regarding use of this strategy should be provided in highway agency courses covering the use and design of roundabouts.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy A8: Provide an Overpass or Underpass (T)

General Description

At path/roadway intersections, an overpass or underpass allows for uninterrupted flow for bicyclists and completely eliminates exposure to vehicular traffic. These grade-separated crossings can improve safety and are desirable at some locations. However, because grade-separated crossings can be quite expensive, may be considered unattractive, may become sites of crime or vandalism, and may even decrease safety if not appropriately located and designed, these types of facilities are primarily used as measures of last resort (AASHTO, 2004; Zegeer et al., 2004). The AASHTO *Bicycle Guide* (1999) provides guidance on the design of overpasses and underpasses. This strategy is related to Strategy 9.1 A5—Install Overpasses/Underpasses in *NCHRP Report 500, Volume 10: Guide for Reducing Collisions Involving Pedestrians.*

EXHIBIT V-33
Strategy Attributes for Providing an Overpass or Underpass (T)

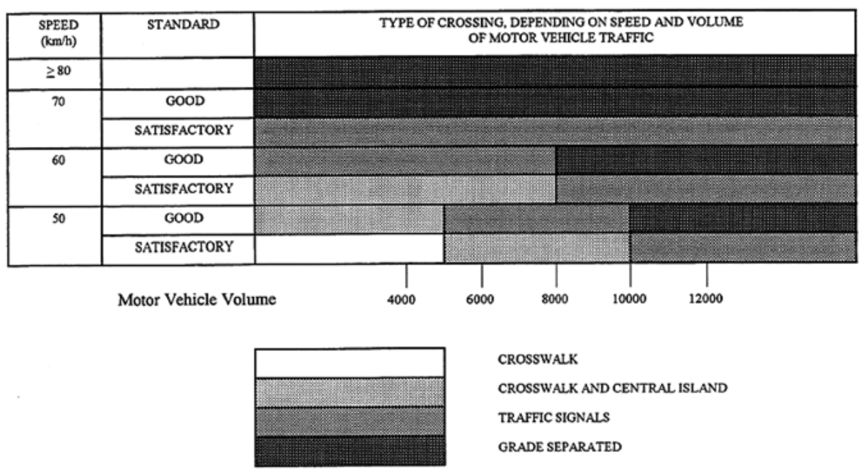
Attribute	Description
Technical Attributes	
Target	This strategy primarily focuses on path/roadway intersections, particularly at intersections of freeways or other high-speed, high-volume arterial streets.
Expected Effectiveness	The effectiveness of this strategy depends largely upon the likelihood that bicyclists will utilize the facility to cross the street, which is determined largely by convenience. If the grade-separated crossing is placed within a reasonable distance of the desired route/path of the bicyclists, it will likely be highly utilized. If bicyclists have to go out of their way to access the grade-separated crossing, it will be underutilized. One agency suggests that an overpass or underpass should be at least 600 ft from the nearest alternative “safe” crossing (Edwards and Kelcey, 2002). A safe crossing is defined as a location where a traffic control device stops vehicles to create adequate gaps to cross.
Keys to Success	One key to success is establishing a policy that may be used to determine the need for a grade-separated crossing. For example, Exhibit V-34 illustrates guidelines established by the Minnesota DOT to help determine the need for grade-separated crossings. Several other factors that should be considered in determining the need for grade separation include (Minnesota DOT, 1996): • Traffic volume and traffic mix • Motor vehicle operating speeds • Number of lanes to be crossed (i.e., crossing distance) • Sight distance • Design bicyclist • Approach grade • Destinations • Design of turning movements • Primary path function

EXHIBIT V-33 (Continued)
Strategy Attributes for Providing an Overpass or Underpass (T)

Attribute	Description
Technical Attributes	

- Approaching path design
- Impact of bicycle traffic on vehicular traffic

EXHIBIT V-34
Choice of Intersection Type (Minnesota DOT, 1996)



Another key to success of grade-separated crossings is they must be well-designed. Several attributes of well-designed grade-separated crossings include (AASHTO, 2004):

- The facility is located where it is needed and will actually be used.
- Crossing structures are built with adequate widths.
- The design is accessible for all users (i.e., meets ADA requirements).
- Barriers/railings are provided to add an increased sense of safety.

The facility is well-lit to provide an increased level of security.

Potential Difficulties — Potential difficulties include ensuring that bicyclists will utilize the facility. Also nearby residents may find the structure “ugly” and may complain about loss of privacy (Zegeer et al., 2004).

Grade-separated structures often require a considerable amount of right of way.

Underpasses can have drainage and associated debris problems if not properly designed and maintained. Crime, vandalism, and graffiti can also cause problems.

Appropriate Measures and Data — A key process measure is the number of grade-separated crossings at path/roadway intersections.

EXHIBIT V-33 (Continued)
Strategy Attributes for Providing an Overpass or Underpass (T)

Attribute	Description
Technical Attributes	
	Crash frequency and severity, by type, are key safety effectiveness measures. Grade-separated crossings can be used by all shared use path users (i.e., bicyclists, pedestrians, in-line skaters, etc). Accident analysis should include all types of trail users. Crash frequency and severity data are needed. Both bicycle and traffic volume data are needed to represent exposure. The impact on traffic operations (i.e., level of service of the crossing) should also be evaluated. A final measure is the percentage of bicyclists (and other shared path users) who use the facility compared to those that cross at street level.
Associated Needs	Grade-separated crossings must meet ADA requirements. Grade-separated crossings should also be able to accommodate maintenance and emergency vehicles.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	Agencies should establish a policy that may be used to determine the need for a grade-separated crossing.
Issues Affecting Implementation Time	Finding adequate funds to construct an overpass or an underpass may impact implementation time. Acquisition of additional right of way may be required which could significantly impact the implementation time, and significant time will be required to design the structure.
Costs Involved	The cost for an overpass or underpass can range from $500,000 to $4 million, depending on the site characteristics and right of way acquisition required (Zegeer et al., 2004).
Training and Other Personnel Needs	None identified.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Objective B—Reduce Bicycle Crashes along Roadways

Strategy B1: Provide Safe Roadway Facilities for Parallel Travel (T)

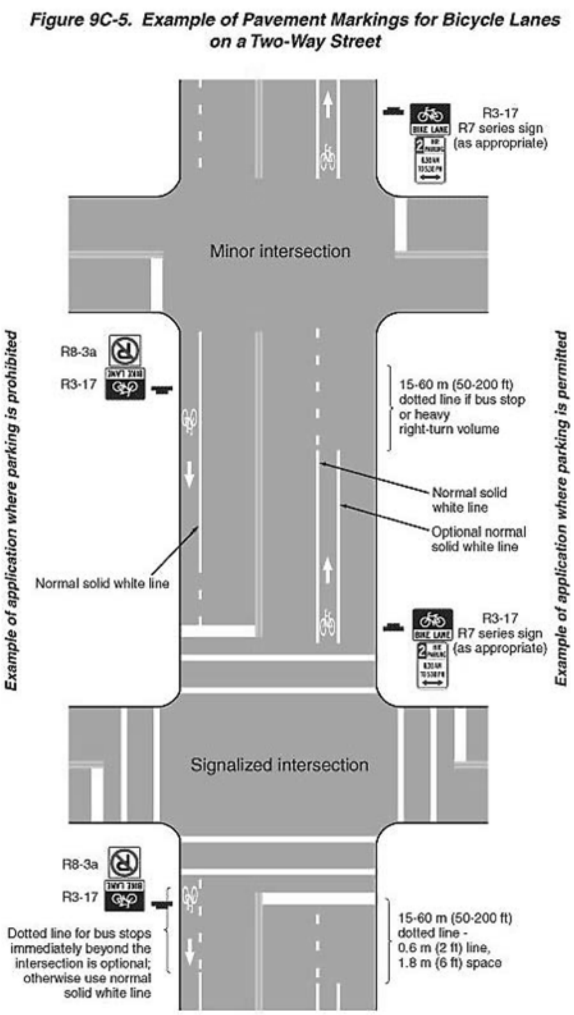
As discussed in Section III, 35.5 percent of bicyclist crashes with motor vehicles occur when travel directions are parallel. Roadway facilities that better identify appropriate travel areas for all road users and their expected behavior may provide a safer environment for bicyclist travel along parallel paths and help reduce crashes.

Bicycle Lane Striping

Striped bicycle lanes provide marked areas for bicyclists to travel along roadways and provide for more predictable movements for both bicyclists and motorists. Striped bike lanes can be incorporated into a roadway when it is desirable to delineate which available road space is for exclusive or preferential use by bicyclists.

The AASHTO *Bicycle Guide* (1999) provides detail for installation of striped bicycle lanes. Bike lanes are usually along the right edge of the roadway but may be placed to the left of parking or right-turn lanes. Marked bicycle lanes on roadways should be one-way only and carry bicycle traffic in the same direction as adjacent motor vehicle traffic. Bike lane markings can reduce the risk of "dooring" (i.e., bicyclists being struck by opening car doors) when the lane runs along a parking lane, although placement of the lane markings is critical for achieving this outcome. Bicycle lanes are often appropriate where most bicyclists on the route are less experienced (Wilkinson et al., 1994).

EXHIBIT V-35
MUTCD Example of Striped Bicycle Lanes (http://mutcd.fhwa.dot.gov/HTM/2003r1/part9/fig9c-05_longdesc.htm)



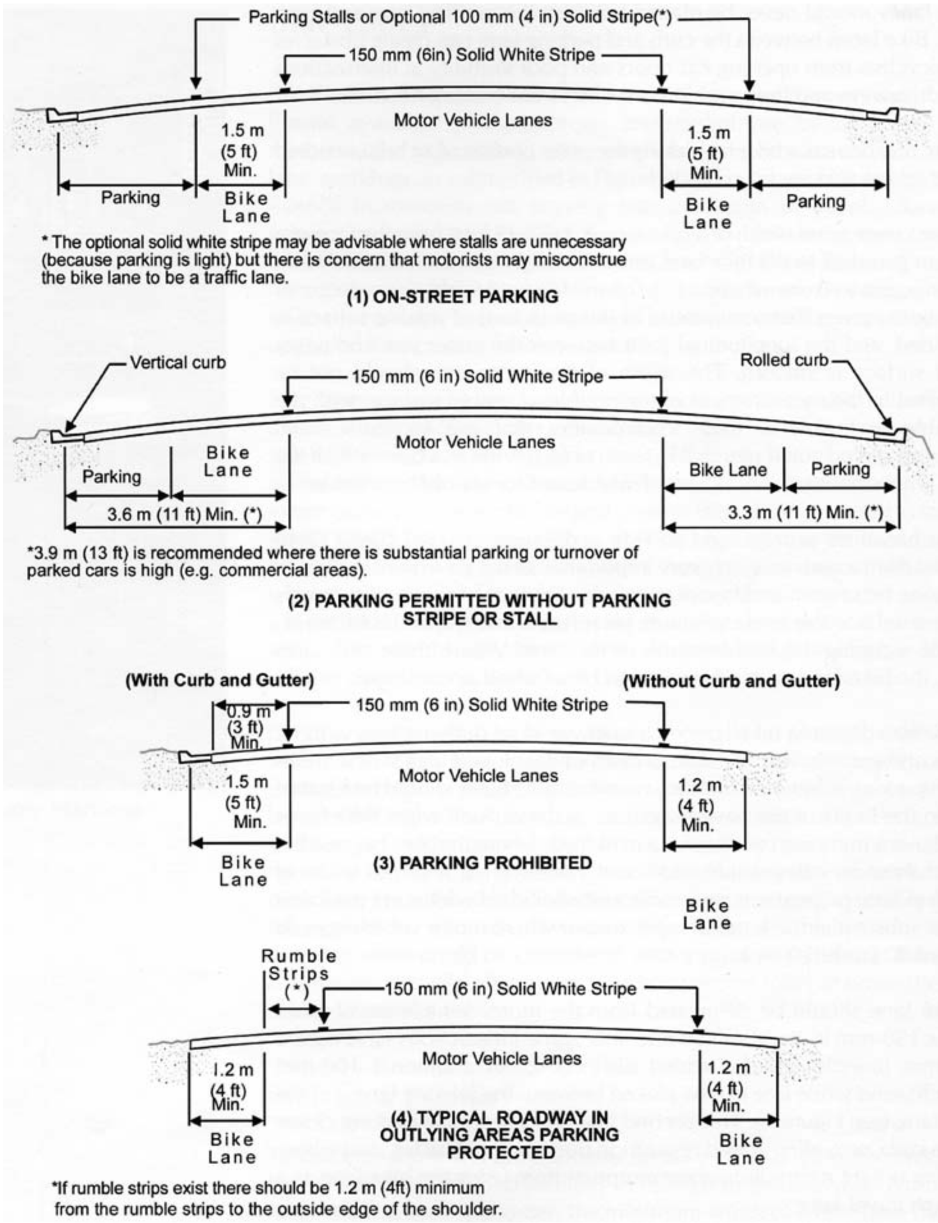
Most studies present evidence that bicycle lanes may provide protection against bicycle/motor vehicle collisions. Evidence also shows that riding with the flow of vehicular traffic reduces bicyclists' chances of collision with a motor vehicle. Locations with bicycle lanes have lower rates of wrong-way riding (Hunter et al., 1998). Most crashes associated with marked bike lanes are concentrated where the marking ends, typically at approaches to intersections, and bicyclists must enter mixed traffic, or at locations where automobiles entering the roadway cross the marked bike lane. Such crashes may be reduced by application of other treatments discussed in this report, including intersection and driveway treatments.

Striped bicycle lane design can be quite challenging in situations where the existing urban traffic patterns are complex and cross-sections are already constrained by heavy traffic volumes. Examples of different lane cross sections based on different roadway characteristics are shown in Exhibit V-36.

Examples include the following:

- Oakland, CA—Since 1999, Oakland has installed nearly 93 mi of bicycle lanes. Many of these individual projects are described on their website: http://www.oaklandpw.com/bicycling/bikelanes.htm.

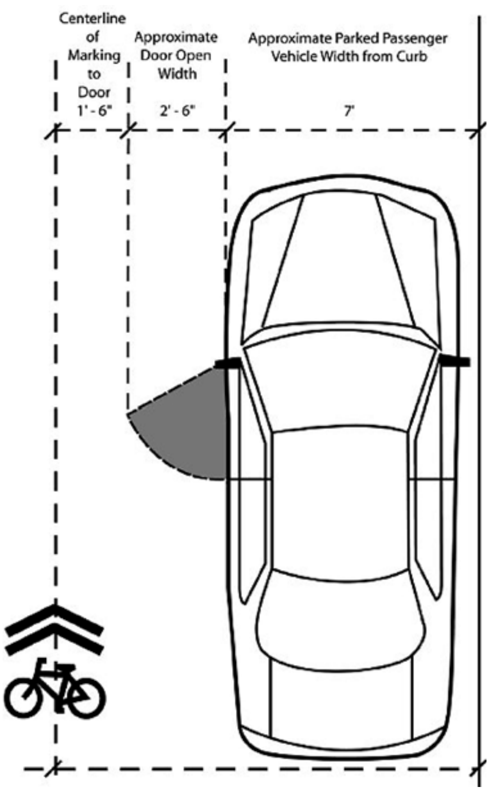
EXHIBIT V-36
Example of Roadway Cross Sections with Bicycle Lanes (AASHTO, 1999)



- Phoenix, AZ—In 1987, Phoenix began implementing an aggressive program to install over 700 mi of striped bicycle lanes. A net decrease in the rate of bicycle/motor vehicle crashes has been observed, although the number of bicyclist fatalities has remained constant. A case study describing Phoenix's experience is included in the BikeSafe Countermeasure Selection System (http://www.bicyclinginfo.org/bikesafe).

EXHIBIT V-37
Chevron Shared Lane Marking in San Francisco (Deirdre Weinberg, San Francisco Metropolitan Transportation Agency, 2004)

EXHIBIT V-38
San Francisco's Standard Shared Lane Marking and Placement (Burk and Sallaberry, 2004)



Additional information on bicycle lane striping may be found at:

- Pedestrian and Bicycle Information Center—http://www.bicyclinginfo.org/de/onstreet.htm#bike
- Chicago, IL—http://www.bicyclinginfo.org/de/bikelaneguide.htm (*Bike Lane Design Guide*) [Note: some of the designs in the Chicago *Bike Lane Design Guide* are not consistent with current MUTCD standards.]
- City of San Francisco, CA—http://sfgov.org/bac/anlreport1001.htm
- Florida Department of Transportation—http://www11.myflorida.com/safety/ped_bike/handbooks_and_research/bhchpt4.pdf

Shared Lane Marking

Shared lane markings are a promising experimental method for providing parallel travel facilities. Similar in concept to striped bicycle lanes, shared lane markings consist of markings placed in the area of desired bicyclist travel. The markings do not indicate a separated bicycle lane, but instead direct bicyclists to travel outside the car door zone and improve awareness of bicyclists and motorists that they are sharing part of the roadway environment. Shared lane markings have the advantage over striped bike lanes of also reducing wrong-way riding and car door crashes. They are intended for use primarily on roadways where traffic lanes are too narrow to be safely shared side-by-side by bicyclists and motor vehicles.

Example:

San Francisco, CA—San Francisco conducted an extensive study of different shared lane markings, and developed recommendations that are now included in California's MUTCD for use on streets where there are parallel on-street functions. More information about San Francisco's program can be found at: http://www.bicycle.sfgov.org/site/dptbike_index.asp?id=22747.

Information about shared lanes in general, including signed shared lanes, may be found at http://www.bicyclinginfo.org/de/onstreet.htm#signed.

Paved Shoulder

Paved shoulders are very similar to bike lanes as a bicycle facility. The pavement edge line for the paved shoulder provides separated space for the bicyclist much like a bike lane. The AASHTO *Bicycle Guide* notes that in rural areas "adding or improving paved shoulders often can be the best way to accommodate bicyclists," and shoulders have the additional attraction of providing a variety of benefits to motorists and other road users as well.

Widths are a function of motor vehicle speeds, volume, percentage of truck and bus traffic, etc. If the paved shoulder is less than 1.2 m (4 ft) in width it should not be designated or marked as a bicycle facility. Widths should be increased with higher bicycle volumes, motor vehicle speeds above 80 km/h (50 mph), or higher percentage of truck and bus traffic. Further guidance on the appropriate width of shoulders to accommodate bicyclists on roadways in these situations can be found in FHWA's *Selecting Roadway Design Treatments to Accommodate Bicyclists.* Paved shoulders tend to result in fewer erratic motor vehicle driver maneuvers, more predictable bicyclist riding behavior, and enhanced comfort levels for both motorists and bicyclists (Harkey et al., 1996).

Example:

Wisconsin DOT has a policy of providing a 0.9 m (3 ft) paved shoulder on all highways with an average daily traffic in excess of 1,000 vehicles, and this is widened to 1.5 m (5 ft) if a moderate number of bicyclists regularly use the road (Wisconsin DOT, 2003).

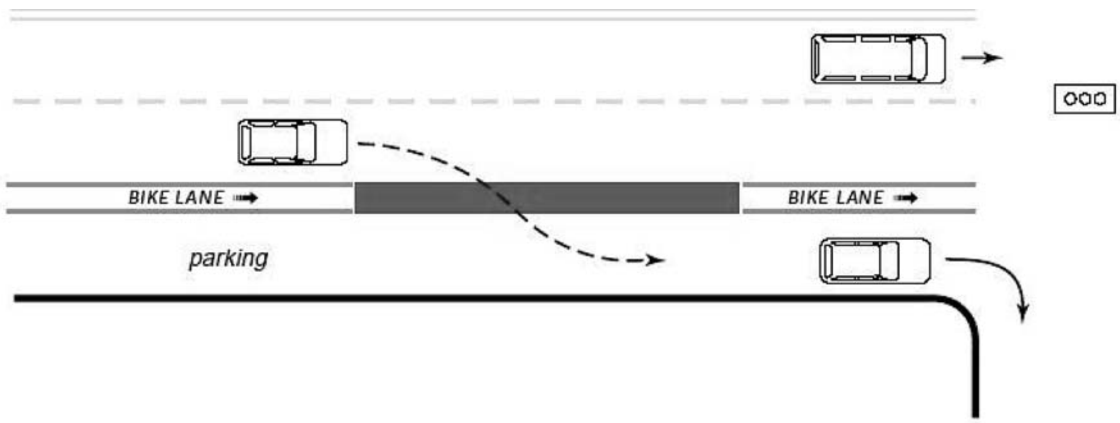
For more information, see the following resources:

- Oregon's ped-bike program's discussion of paved highway shoulders: (http://www.odot.state.or.us/techserv/bikewalk/whyhave.htm)
- http://www.bicyclinginfo.org/de/onstreet.htm (Includes discussion of both paved shoulders and wide outside lanes, as well as a comparison of striped bike lanes to paved or wide shoulders.)

Colored Pavement Marking

Colored pavements (e.g., green bike lanes) or different paving materials have been used in certain situations to distinguish bike lanes from the motor vehicle lanes. Use of colored bike lanes is being considered but is not yet an accepted MUTCD standard. Colored pavement markings have mostly been applied and studied at intersections and other high-conflict areas where motor vehicles are more likely to enter the bicycle lane. A description of colored bicycle lanes for use at intersections is also included with *Strategy A4—Improve Pavement Markings at Intersections* in this guide. Colored bicycle lanes have been used to visually narrow the roadway while also maintaining a preferential area for bicyclist usage. Colored pavement may be appropriate where a wide roadway results in high traffic speeds, but certain forms of traffic calming raise concerns about emergency vehicle access.

EXHIBIT V-39
Colored Pavement Placement at High-risk Roadway Location



Colored bike lanes have been a feature of bicycle infrastructure in the Netherlands (red), Denmark (blue), France (green), and many other countries for many years. In the United Kingdom, both red and green pigments are used to delineate bike lanes and bike boxes. However, in the United States their use has been limited to a few experiments in just a handful of locations. The most extensive trial took place in Portland, Oregon, where a number of critical intersections had blue bike lanes marked through them, and the results were carefully monitored.

For more information about colored lanes and the Portland study, visit http://www.trans.ci.portland.or.us/bicycles/bluebike.htm.

EXHIBIT V-40
Strategy Attributes for Providing Marked Roadway Facilities (T)

Attribute	Description
Technical Attributes	
Targets	This strategy targets both bicyclists and motorists by providing multiple cues that indicate preferential areas for each to travel along roadways.
Expected Effectiveness	Marked roadway improvements such as striped bicycle lanes and other treatments suggest a protective effect for certain types of bicycle/motor vehicle collisions (Lott and Lott, 1976). *Striped Bike Lane* Bike lanes have been found to provide more consistent separation between bicyclists and passing motorists than shared travel lanes. The presence of the bike lane stripe has also been shown from research to result in fewer erratic motor vehicle driver maneuvers, more predictable bicyclist riding behavior, and enhanced comfort levels for both motorists and bicyclists (Harkey et al., 1996). The extra space created for bicyclists is also a benefit for

EXHIBIT V-40 (Continued)
Strategy Attributes for Providing Marked Roadway Facilities (T)

Attribute	Description
Technical Attributes	
	bicyclists on congested roadways where bicyclists may be able to pass motor vehicles on the right. *Shared Lane Markings* Shared lane markings have resulted in a 203 mm (8 in) increase in the distance of bicyclists from parked cars. The markings also resulted in an increase of over 0.6 m (2 ft) between bicyclists and passing motorists. Markings also reduce the number of bicyclists who ride on sidewalks, as well as resulting in an 80 percent reduction in wrong-way riding (Burk and Sallaberry, 2004). *Wide Curb Lanes* Wide curb lanes provide an area sufficiently wide for both motor vehicles and bicyclists to use the lane. Research (Harkey et al., 1996) has shown that paved shoulders tend to result in fewer erratic motor vehicle driver maneuvers, more predictable bicyclist riding behavior, and enhanced comfort levels for both motorists and bicyclists. *Colored Pavement Marking* Colored pavement markings are expected to increase the visibility of bicyclists by explicitly defining the bicyclist right-of-way. In Portland's painted lane experiment, significantly more motorists yielded to bicyclists and slowed or stopped before entering colored pavement areas.
Keys to Success	Where bicycle lanes exist, riding should be restricted to the direction of motor vehicle travel. Adequate facility lane width should be provided to accommodate bicyclists. Information through signage and/or pavement marking should be provided to encourage desired behavior and guide users to the facilities. Custom or specially developed signs may be necessary for new facilities.

EXHIBIT V-41
Signs Developed for Portland's Colored Lanes
(http://www.trans.ci.portland.or.us/bicycles/Bluelane.pdf)

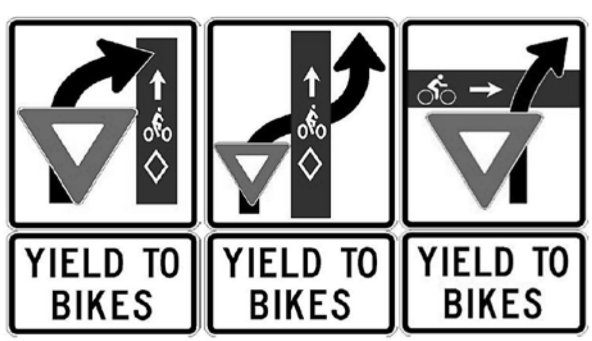


EXHIBIT V-40 (Continued)
Strategy Attributes for Providing Marked Roadway Facilities (T)

Attribute	Description
Technical Attributes	
	Adequate space between the bike lane and parked cars should be provided so that open doors do not create a hazard for bicyclists. Termination of bike lanes that place bicyclists in a vulnerable situation should be avoided. Finally, it is important to determine if special signs or markings are necessary for situations such as a high-volume of bike left turns on a busy roadway.
Potential Difficulties	Although treatments included here have been studied and shown favorable results, not all are currently included in the MUTCD. The MUTCD is regularly revised, and most of these treatments are under consideration. The level of a bicyclist's experience influences facility preferences. There is rarely one pavement treatment that satisfies all users. Wide curb lanes are not generally as effective as striped bike lanes and marked shared lanes at reducing wrong-way riding. The cost of maintaining stripes, shared lane markings, and colored bicycle lanes may be high, but proper selection of paint or colored surface material can minimize these costs. Proper placement of on-road bicycle facilities requires balancing user needs with right-of-way limitations. Placement of bicycle lanes on roads with parallel parking, in particular, should occur so that impacts with car doors are unlikely; this is accomplished by placing the lane markings outside the expected door opening area. There may be resistance to establishing bicycle lanes from a portion of the community. This resistance may be based on perceptions of erratic bicyclist behavior, and might be overcome with an effective PI&E program.
Appropriate Measures and Data	Comparing before and after data about bicyclist exposure or usage and crash or injury data would provide the most comprehensive evaluation of roadway facilities for bicyclists. However, useful exposure data is usually unavailable, leaving only crash or injury data for evaluation.
Associated Needs	Although many bicyclists and motor vehicle operators understand how to ride or drive on roads with striped bicycle lanes, installation of other on-road bicycle facilities should be accompanied by public information campaigns to clarify how they should behave with the new facilities.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	The needs of bicyclists and motorists must be balanced when considering any changes to roadways. Factors such as lane widths, operating space, parking, vehicle speeds, etc. need to be completely examined so that the most appropriate alternative can be selected.
Issues Affecting Implementation Time	Facilities that consist of adding paint to the roadway can be implemented within a very short timeframe. Paved shoulders require significantly more time to plan and construct.

EXHIBIT V-40 (Continued)
Strategy Attributes for Providing Marked Roadway Facilities (T)

Attribute	Description
Organizational and Institutional Attributes	
Costs Involved	The BikeCost tool (http://www.bicyclinginfo.org/bikecost) provides an online estimation calculator of approximate cost for many bicycle facilities, including marked roadway facilities. • The cost of installing a bicycle lane is approximately $3,100 to $31,000 per kilometer ($5,000 to $50,000 per mile), depending on the condition of the pavement, the need to remove and repaint the lane lines, the need to adjust signalization, and other factors. It is most cost efficient to create bike lanes during street reconstruction, street resurfacing, or at the time of original construction. • Shared lane markings have significantly lower initial and maintenance costs compared to striped bicycle lanes. • Paved shoulder costs can be quite variable. Using data from Iowa DOT average contract prices for calendar year 2000, a minimum design width of 1.2 m (4 ft) of paved shoulder width to accommodate bicycle traffic was estimated at $44,000 per kilometer ($71,000 per mile) (Souleyrette et al., 2001). • Painted bicycle lanes cost approximately $3,700 per kilometer ($6,000 per mile) in both directions. The cost of widening and resurfacing a section of roadway to make painting appropriate varies depending on current conditions, but a minimum cost estimate is at least $93,200 per kilometer ($150,000 per mile).
Training and Other Personnel Needs	None identified.
Legislative Needs	The use of any treatment that is not contained in the MUTCD requires the approval of the FHWA.
Other Key Attributes	
Wide Curb Lane Alternative	Wide curb lanes are an alternative to marked roadway facilities such as bicycle lanes and shared lane markings. They are intended to create on-street facilities for bicyclists by creating a lane that is wide enough so motor vehicles and bicycles have adequate room to share the lane during overtaking. Advocates of wide curb lanes believe that they encourage bicyclists to operate more like motor vehicles and thus lead to more correct positioning at intersections, particularly for left-turn maneuvers. A wide curb lane is the lane nearest the curb that is wider than a standard lane and provides extra space so that the lane may be shared by motor vehicles and bicyclists. Wide curb lanes can be placed on roads with or without curbs. Wide curb lanes may be present on two-lane or multi-lane roads. The desired width is 4.3 m (14 ft) for the lane, not including the gutter plan area. Wider lanes may result in the operation of two motor vehicles side-by-side in the lane, and narrower widths may not provide adequate space for the bicyclist and motor vehicle to operate side-by-side. In addition, the usable lane width is reduced by drainage grates, raised reflectors, or on-street parking, so lane width should be increased to accommodate those impediments. Because wide curb lanes are a shared-lane countermeasure, they are not marked or signed like a bicycle lane. As a result, bicyclists may not know of their existence or utility as a bicycle facility.

EXHIBIT V-40 (Continued)
Strategy Attributes for Providing Marked Roadway Facilities (T)

Attribute	Description
Other Key Attributes	
	Shared lane markings may supplement wide curb lanes. These markings would provide a relatively low-cost approach to help identify the facility for bicyclists. Shared lane markings may also encourage proper placement of the bicyclist within the wide curb lane and will encourage bicyclists to travel in the same direction as motor vehicle traffic.
Width of Bicycle Lanes	Minimum and maximum design widths for bicycle lanes should be carefully examined. For example, bicycle lane widths of 1.8 m (6 ft) maximum may be desirable when one or a combination of the following conditions exists: • traffic volumes and speeds are high; • adjacent parking use and turnover is high; • catch basin grates, gutter joints, and other features in the bicycle lane may present an obstacle to cyclists; • steep grades exist; • truck volumes are high; or • bicycle volumes are high. Also, bicycle lane widths of 1.2 m (4 ft) minimum may be acceptable when: • physical constraints exist for a segment of less than 1.6 km (1 mi) that links to existing bikeways on both ends, • implemented in conjunction with traffic calming devices (see *Strategy C1—Implement Traffic Calming Techniques*), • adjacent to parking with [very] low use and turnover, or • adjacent to an uncurbed street shoulder.

Strategy B2: Provide Contraflow Bicycle Lanes (T)

Contraflow Bicycle Lanes

A contraflow bicycle lane establishes a two-way street for bicyclists on a street that only allows one-way motor vehicle traffic. Contraflow lanes allow bicyclists to travel in the opposite direction from motor vehicle traffic on the same roadway. Bicyclists are generally expected to follow established rules-of-the-road such as riding in the same direction as motor vehicle traffic. However, there are certain situations where the placement of a bicycle lane counter to the normal flow of traffic can increase safety or improve access for bicyclists. Some one-way streets, particularly in hilly or downtown areas, may provide benefits to bicyclists if a contraflow bike lane is designated to allow bicyclists to ride against the flow of traffic.

It should be made clear that there are safety concerns associated with wrong-way riding, as this places bicycles in a position where motorists do not expect to see them. However, there is precedent for opposite direction riding that emanates from Europe, where bicyclists are often allowed to ride in the opposite direction on one-way streets, usually with slow motor vehicle traffic. The contraflow bike lane is a specific bicycle facility that can be used in special situations and is intended to reduce the number of conflicts between bicycles and motor vehicles. The facility also would be intended to save time for bicyclists having to travel an extra distance if they rode with traffic. It may also alleviate riding on a high speed, high volume route.

EXHIBIT V-42
Contraflow lane application in Cambridge, MA
(Photo by Cara Seiderman)

Examples of contraflow bike lanes can be found in cities in the United States with large numbers of bicyclists, including Cambridge, Massachusetts; Boulder, Colorado; Madison, Wisconsin; and Eugene, Oregon.

The Madison contraflow lane—University Avenue—runs through the heart of the University of Wisconsin campus and carries heavy flows of bicyclists and other road users. Because of the high demand for bicycle travel in both directions, the road was rebuilt with a bus lane, bike lane, and three travel lanes in one direction and a bike lane only (separated by a raised median) in the other direction.

For more information about contraflow bicycle lanes:

BikeSafe Countermeasure Selection System includes a number of case studies of contraflow lanes: (http://www.bicyclinginfo.org/bikesafe)

Portland, Oregon's Bicycle Design and Engineering Guidelines (http://www.trans.ci.portland.or.us/designreferences/bicycle/appenda3.htm)

San Francisco Bay Area Metropolitan Transportation Commission's Bicycle and Pedestrian Safety Toolbox (http://www.bayareatrafficsignals.org/toolbox/Tools/ContraFlowBike.html)

EXHIBIT V-43
Contraflow Lanes may Require Specific Signs
(BikeSafe—www.bicyclinginfo.org/bikesafe)

EXHIBIT V-44
Strategy Attributes for Providing Contraflow Bicycle Lanes (T)

Attribute	Description
Technical Attributes	
Targets	Contraflow bicycle lanes are targeted to ensure that potential conflicts between motor vehicles and bicyclists are minimized. They target bicyclists' behavior and sense of security and motorists' behavior.
Expected Effectiveness	Contraflow bicycle facilities are generally recommended in areas with numerous one-way streets or where following traffic flow would result in difficulty for bicyclists. They provide facilities that bicyclists generally consider safer, encouraging more use.
Keys to Success	Portland, Oregon's Bicycle Design and Engineering Guidelines (http://www.trans.ci.portland.or.us/designreferences/bicycle/appenda3.htm) recommend using contraflow bicycle lanes only under the following conditions: • The contraflow bicycle lane provides a substantial savings in out-of-direction travel compared to the route motor vehicles must follow; • The contraflow bicycle lane is short and provides direct access to a high-use destination point; • Safety is improved because of reduced conflicts; • There are no or very few intersecting driveways, alleys, or streets on the side of the proposed contraflow lane; • Bicyclists can safely and conveniently reenter the traffic stream at either end of the section; • A substantial number of bicyclists are already using the street; and • There is sufficient street width to accommodate a full-dimension bicycle lane. The Portland guide further recommends the following special treatments to ensure success of contraflow lanes (note that these are requirements for Portland, but might alternatively be considered as recommended practices in other communities. Other locations may recognize acceptable exceptions to these regulations): • The contraflow bicycle lane must be placed on the right side of the street (to drivers' left) and must be separated from oncoming traffic by a double yellow line. This indicates that the bicyclists are riding on the street legally, in a dedicated travel lane. • Any intersecting alleys, major driveways, and streets must have signs indicating to motorists that they should expect two-way bicycle traffic. • Existing traffic signals must be fitted with special signals for bicyclists, with loop detectors or push-buttons. The push-buttons must be placed so they can be easily reached by bicyclists, without having to dismount. • It is preferable to place a separate bicycle lane in the direction of motor vehicle traffic, striped as a normal bicycle lane. Where the roadway width does not allow this, bicyclists will have to share the road with traffic. In this situation, striping the contraflow bicycle lane should take precedence, otherwise some bicyclists will be tempted to ride illegally, against traffic. The BikeSafe Bicycle Countermeasures Selection System (http://www.bicyclinginfo.org/bikesafe) recommends that pavement markings and signs should be thought through

EXHIBIT V-44 (Continued)
Strategy Attributes for Providing Contraflow Bicycle Lanes (T)

Attribute	Description
Technical Attributes	
	carefully in the design, rather than following a standard guideline. It is preferable to implement the lane when longer-lasting pavement marking materials can be installed (thermoplastic or in-lay tape), otherwise a strict maintenance program to keep paint highly visible will be required. Bicycle symbols and arrows should be placed at frequent intervals (far more frequently than standard AASHTO recommendations). Consideration should be given to adding color (blue is most visible) in the lane. Signs should be installed wherever motorists would be approaching the street (at the beginning of the intersection and at any intersecting roads or major driveways). Proper coordination between on-street parking and contraflow lanes is necessary. Lanes should be placed so that both bicyclists and motorists leaving parking spaces are expecting potential conflicts and can see each other. When parking is adjacent to the contraflow lane, drivers exiting a parking space cannot see bicyclists until they are about halfway into the contraflow lane. It is therefore recommended that parking not be adjacent to the contraflow lane (i.e., on the left side of the road for the motorists.)
Potential Difficulties	Special attention must be paid to the treatment given contraflow lanes at intersections, because bicyclists will be traveling on the wrong side of the street through the intersection. Similarly, bicyclists turning left from contraflow lanes will encounter oncoming traffic unless traffic control devices stop motor vehicles, including those approaching from intersecting lanes. Motorists approaching contraflow lanes may not notice approaching bicyclists because the motorist is expecting and looking for traffic from the other direction. Contraflow lanes require signs specifically for bicyclists, because signs posted for motorists face the opposite direction of bicycle travel. There is also a lack of empirical evidence about the safety and other benefits of contraflow lanes. Anecdotal reports from Cambridge, Massachusetts, indicate no negative safety effects. Future research should examine safety benefits and specific issues such as nighttime use (i.e., whether auto headlights affect the bicyclist). The use of sidewalks as contraflow lanes should be avoided (see “Other Key Attributes” below).
Appropriate Measures and Data	Comparing before and after data about bicyclist exposure or usage, and crash or injury data would provide the most comprehensive evaluation of roadway facilities for bicyclists. However, useful exposure data is usually unavailable, leaving only crash or injury data for evaluation.
Associated Needs	Treatments that are new to a community are more likely to succeed with a PI&E program to educate both bicyclists and motorists of their intended purpose and use.
Organizational and Institutional Attributes	
Organizational, Institutional and Policy Issues	None identified.
Issues Affecting Implementation Time	This strategy may require time to plan and construct new facilities. In addition, public involvement in the planning phases of this strategy will improve acceptance and compliance with the new facilities.

EXHIBIT V-44 (Continued)
Strategy Attributes for Providing Contraflow Bicycle Lanes (T)

Attribute	Description
Organizational and Institutional Attributes	
Costs Involved	The cost of installing bike lane markings (such as for contraflow lanes) is approximately \$3,100 to \$31,000 per kilometer (\$5,000 to \$50,000 per mile), depending on the condition of the pavement, the need to remove and repaint the lane lines, the need to adjust signalization, and other factors. It is most cost efficient to create bike lanes during street reconstruction, street resurfacing, or at the time of original construction.
Training and Other Personnel Needs	None identified.
Legislative Needs	None identified.
Other Key Attributes	
Potential Use of Sidewalks	Sidewalks should not be used as bicycle facilities. Some early bikeways used sidewalks for both pedestrians and bicyclists. While in rare instances this type of facility may be necessary, or desirable for use by small children, in most cases it should be avoided. In instances where it cannot be avoided, carefully considered and prepared education for the children should be a component of the use (http://www.odot.state.or.us/techserv/bikewalk/planimag/II1c.htm). Sidewalks are not suited for bicycling for several reasons: • Bicyclists face conflicts with pedestrians. • There may be conflicts with utility poles, sign posts, benches, etc. • Bicyclists face conflicts at driveways, alleys, and intersections: a bicyclist on a sidewalk emerges onto driveways and alleys unexpectedly and is generally not visible to motorists. This is especially true of bicyclists who ride opposing adjacent motor vehicle traffic; drivers do not expect a vehicle coming from this direction. • Bicyclists are put into awkward situations at intersections where they cannot safely act like a vehicle but are not in the pedestrian flow either, which creates confusion for other road users. Where constraints do not allow full-width bikeways, solutions should be sought to accommodate both modes (e.g. narrowing travel lanes or reducing on-street parking). In some urban situations, preference may be given to accommodating pedestrians. Sidewalks should not be signed for bicycle use—the choice should be left to the users.

Strategy B3: Improve Bicyclists' Visibility (T)

Lighting

Improved roadway lighting may help to reduce crashes that occur under less than optimal light conditions. Intersections may warrant higher lighting levels than roadway segments. Good lighting on roadways, bridges, tunnels, and multi-use paths is also important for personal security. Sufficient roadway illumination also helps nighttime bicyclists see surface conditions and obstacles or people in the path of travel.

Bicyclists, particularly commuters, may have to ride during early dawn hours or during twilight or darkness, particularly in the winter months. Although bicyclists riding during dark conditions are generally required to have appropriate lighting on their vehicles or persons, requirements vary from state to state, and bicyclists can still be vulnerable to not being seen by motor vehicle operators. Conspicuity, making the bicyclist more conspicuous with lights and retroreflective material, is a behavioral treatment that is discussed in Strategy F2.

Lighting is a complex treatment requiring thoughtful analysis. Not only are there safety and security issues for bicyclists, pedestrians, and motorists, but potential light pollution, long-term energy costs, and aesthetics also become factors. With good design, lighting can enhance safety of the bicycling as well as pedestrian environment and improve the ambience of areas of nighttime activity.

Virtually all research on lighting has focused on motor vehicles, with much of that research related to highways. More research is needed on the safety and mobility benefits of lighting improvements to bicyclists.

Examples include the following:

For more information about improving lighting conditions for bicyclists, the Wisconsin Bicycle Facility Design Handbook provides guidance for path illumination (p. 4–35 to 4–37 available from: http://www.dot.wisconsin.gov/projects/state/docs/bike-facility.pdf). For in-depth roadway lighting specifications, see American National Standard Practice for Roadway Lighting ANSI IESNA RP-8 (available from the Illuminating Engineering Society).

The Florida Department of Transportation provides some guidance on the lighting of bicycle facilities at: http://www.dot.state.fl.us/safety/ped_bike/handbooks_and_research/bhchpt4.pdf.

EXHIBIT V-45
Strategy Attributes for Improving Bicyclists' Visibility (T)

Attribute	Description
Technical Attributes	
Targets	Improved lighting targets both bicyclists and motor vehicle drivers. Better lighting allows bicyclists to see the roadway and debris or potential obstructions. It also makes bicyclists more visible to drivers in low light conditions.
Expected Effectiveness	Improved lighting is expected to change conditions to reduce bicycle/motor vehicle crashes. • Optimize visibility of bicyclists (and pedestrians) during low-light conditions, particularly in locations where high numbers of bicyclists may be expected such as commuter routes, routes to and from universities, intersections, and intersections with multi-use trails. • Improve personal security of bicyclists and make roadway safer for all users. Data from 5 years of North Carolina bicycle/motor vehicle crashes indicate that about one-quarter of reported collisions and more than one-half of bicyclist fatalities occurred during non-daylight conditions, probably far exceeding the proportion of riding that occurs under these conditions (http://www.pedbikeinfo.org/pbcat/bike_main.htm).

EXHIBIT V-45 (Continued)
Strategy Attributes for Improving Bicyclists' Visibility (T)

Attribute	Description
Technical Attributes	
	Similarly, estimates from Florida State University (http://www.safety.fsu.edu/ bicyclemanual.html#accidents) indicate that "nearly 60 percent of all adult fatal bicycle accidents in Florida occur during twilight and night hours even though less than 3 percent of bicycle riding takes place during that time period."
Keys to Success	The AASHTO *Bicycle Guide* recommends using average maintained illumination levels of between 5 and 22 lux. Additional research is needed on the safety and mobility benefits of lighting improvements to bicyclists.
Potential Difficulties	Lighting decisions should include consideration of potential light pollution, long-term energy costs, and aesthetics. With good design, lighting can enhance safety of the bicycling as well as pedestrian environment and improve the ambience of areas of nighttime activity. Other difficulties may include acquiring adequate funding to install new lighting with new construction projects.
Appropriate Measures and Data	In addition to standard measures of crash frequency and severity, a key measure is whether the new installations bring lighting levels up to recommended levels.
Associated Needs	• Install lighting on both sides of wide roadways for most effective illumination. • Provide generally uniform illumination avoiding hot spots, glare, and deep shadows; some intersections may warrant additional illumination. • Consider rural locations for lighting improvements if nighttime or twilight crashes are a problem.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	It is important for state and local agencies to establish policies for lighting of bicycle facilities, as well as a procedure for identifying and implementing needed lighting improvements. Most state DOTs have policies that limit or prohibit payment for lighting as part of road construction projects, leaving funding for lighting as a local contribution.
Issues Affecting Implementation Time	This strategy does not require a long development process. Lighting improvements can typically be implemented in less than 6 months. Availability of funding for lighting improvements is a key issue affecting implementation time. Also, local governments often prefer more expensive, decorative lighting instead of the standard lighting recommended by many state standards. Resolving these issues, including who pays for various aspects of the improvements, can delay lighting project completion.
Costs Involved	Cost varies depending on fixture type, design, local conditions, and utility agreements.
Training and Other Personnel Needs	Lighting improvements can be made by agency personnel or by private contract. In both instances, experienced personnel are needed to design and install lighting improvements. Monitoring and maintenance programs are also needed, including night inspections.

EXHIBIT V-45 (Continued)
Strategy Attributes for Improving Bicyclists' Visibility (T)

Attribute	Description
Organizational and Institutional Attributes	
Legislative Needs	Local legislative bodies (city and county governing boards) may establish policies that require adequate lighting for bicyclists and pedestrians in all new developments. This may reduce the direct governmental costs incurred to install adequate lighting.
Other Key Attributes	
Behavior	Another lighting issue to consider is the use of lights and reflectors by bicyclists. This topic is discussed in *Strategy F2-Increase Rider and Bicycle Conspicuity.* Generally, when riding at night, bicyclists are required to have front and rear lights (or rear reflectors)-both to aid in their detection and to help them see what's in front of them. The Oregon DOT has an easy-to-understand section of its manual that addresses the equipment needs of bicyclists, including lights (http://www.odot.state.or.us/techserv/bikewalk/planimag/bicycle.htm#equipment).
Lighting Option	The type of lighting (mercury vapor, incandescent, or high pressure sodium) should be selected based on the needs for a given roadway.

Strategy B4: Improve Roadway Signage (T)

Signs are placed along roadways to provide regulation, warning, and guidance information to road users, including bicyclists. This strategy focuses on providing additional regulatory and directional signs to improve bicycle safety and behavior along roadways. The AASHTO *Bicycle Guide* (1999) and MUTCD (2003) should be consulted concerning bicycle-related signs.

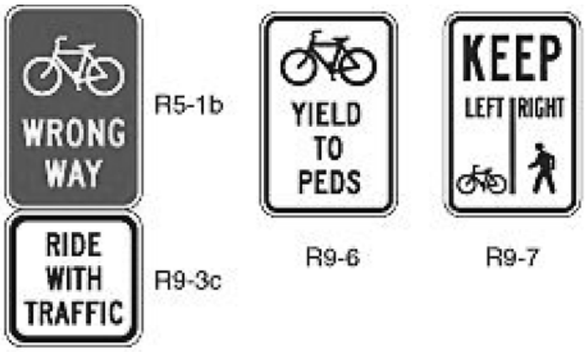
Shared Roadway Signage

The intent of shared roadway signage is to let bicyclists and motorists know what to expect along the roadway, thus improving the chances that they will react and behave appropriately. These signs reinforce that bicyclists have a legal right to use the roadway. The safety effectiveness of shared roadway signs has not been evaluated, and their overall use is thought to be decreasing. Some experts now feel that they are only appropriate in "pinch point" locations where roadway facilities may not fully accommodate both bicyclists and motorists.

EXHIBIT V-46
Share the Road Sign (USDOT, 2003)

Shared roadway signs typically consist of yellow warning signs with the legend "Share the Road" and a bicycle and car logo (Exhibit V-46). Similar messages may be used, including "Cars Share the Road," to specifically indicate that motor vehicles

EXHIBIT V-47
Special Bicycle Signs may be Needed for Unusual Circumstances (MUTCD) (http://mutcd.fhwa.dot.gov/HTM/2003/part9/fig9b-02_longdesc.htm)



should accommodate bicyclists in the roadway. These signs are typically placed along roads with significant bicycle traffic but relatively hazardous conditions for riding, such as narrow travel lanes with no shoulder, roads or streets with poor sight distance, or a bridge crossing with no accommodation for bicycles.

Special Bicycle-Related Signage

As with shared roadway signage, special bicycle-related signage conveys important information intended to provide information to bicyclists and motorists so they know what to expect, and thus improve the chances that they will react and behave appropriately. Examples of special bicycle-related signs include the use of "No Parking in Bike Lane" signs, intended to keep bike lane spaces clear for cyclists, "Bikes Wrong Way" signs, special warnings to alert motorists and bicyclists about specific approaching conditions that might present a dangerous environment, and specific regulatory signs. Regulatory signs, such as "Stop," "Yield," or turn restrictions require driver actions and are enforceable. "No Turn on Red" signs can improve safety for bicyclists (and pedestrians). Problems often occur at RTOR locations as motorists look to the left for a gap in traffic, especially if bicyclists are riding the wrong way either in the street or on the sidewalk.

Care should always be exercised when placing non-standard signs. Proliferation of special bicycle-related signs may limit their impact as well as decrease the effectiveness of other signs.

For more information about special bicycle-related signage, the Pedestrian and Bicycle Information Center's bicycle signs and markings information page contains links and examples of most established sign types: http://www.bicyclinginfo.org/de/signs_markings.htm.

The MUTCD (2003) defines national standards for signs relating to bicyclists along roadways (http://mutcd.fhwa.dot.gov/HTM/2003r1/part9/part9-toc.htm).

Bicycle Route Signage

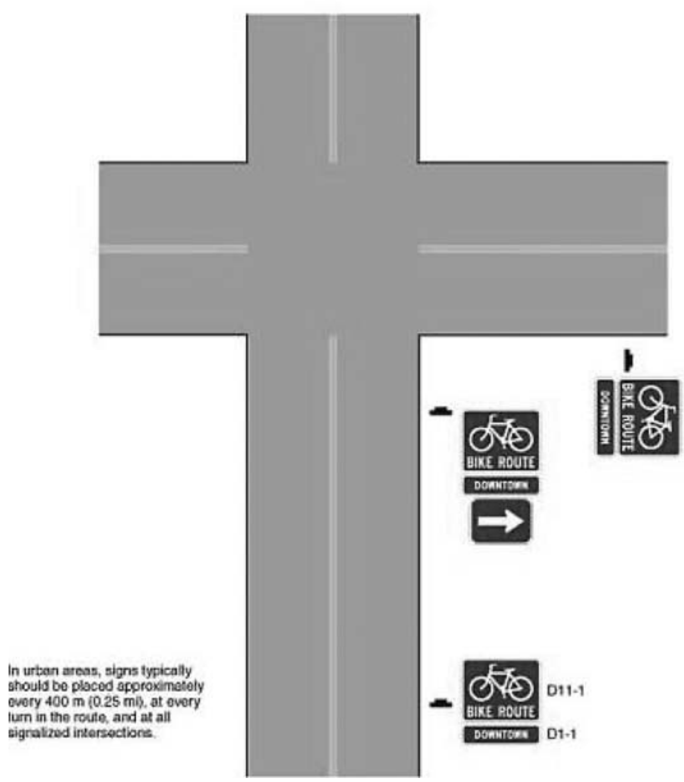
By providing bicycle route signs that identify official bicycle routes and provide additional information about the route, bicyclist travel can be directed to areas that have better facilities, as well as provide both bicyclists and motorists additional information about their expected behavior. Typical bicycle route signage identifies that a roadway is part of a bicycle route and then identifies the primary destination served by the route. Bicycle routes can consist of local routes, as well as regional routes. They often are used where a local community has identified a system of preferred bicycle routes.

EXHIBIT V-48
MUTCD Standard Bicycle Route Signs
(http://mutcd.fhwa.dot.gov/HTM/2003r1/part9/fig9b-04_longdesc.htm)

Placement of bicycle route signs is important for achieving successful compliance with the bicycle routes, as well as providing a more welcoming environment for bicyclists. They also increase motor vehicle operator expectations of encountering bicyclists along the route, which increases the potential that a motorist will detect, recognize, and avoid potential collisions with a bicyclist.

EXHIBIT V-49
MUTCD Recommended Placement of Bicycle Route Signs
(http://mutcd.fhwa.dot.gov/HTM/2003r1/part9/fig9b-06_longdesc.htm)

Figure 9B-6. Example of Signing for an On-Roadway Bicycle Route



Creating bicycle routes is an inexpensive but visible way to improve the bicycling environment by taking advantage of the existing bicycle facility network. Although evaluation of the existing environment and careful planning should be conducted before establishing bicycle routes, the bicycle routes and signs can be changed with relative ease. This is important when experimenting with route ideas and approaches. Unlike moving a poorly sited bicycle bridge, for instance, it is relatively easy to remove signs and then install them in a different location.

Bicycle route systems may function as a means of identifying potential sites for other types of improvements in order to complete a functional network. For instance, building a bike bridge at a particular location can help complete a route through one part of town; striping bike lanes can help make it work in another.

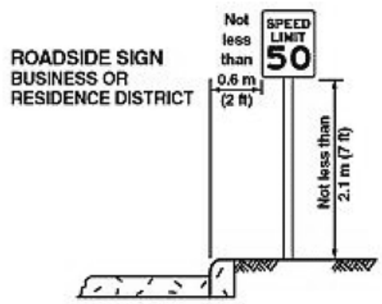
EXHIBIT V-50
Strategy Attributes for Improving Roadway Signage (T)

Attribute	Description
Technical Attributes	
Targets	Bicycle-related signs are primarily targeted towards providing information and affecting the behavior of bicyclists, although motorists may also benefit from having access to the information contained in the signs. Some signs, particularly “Cars Share the Road” signs, are targeted specifically at motor vehicle operators.
Expected Effectiveness	Roadway bicycle-related signs are effective at communicating information and regulations about how both bicyclists and motorists should operate in the roadway. They are important for safety improvement, helping bicyclists avoid unsafe conditions or navigate unfamiliar locations.
Keys to Success	Success of many roadway signs for bicyclists is dependent upon proper installation and designation at intersections, where bicyclists and motorists first encounter the roadway facility, or in other locations where roadway conditions change. Information about signage at intersections is found in *Strategy A3—Improve Signing* of this guide. FHWA has an extensive web site about the MUTCD that includes answers to many commonly asked questions about the manual, including one that confirms its status as the national standard for traffic control: “all traffic control devices nationwide must conform to the MUTCD. There are no exceptions” (http://mutcd.fhwa.dot.gov). In addition to the MUTCD, many States supplement the national manual with additional optional signs and markings, or complete Uniform Traffic Control Devices manuals. As an example, the Oregon DOT has a chapter in its bicycle plan detailing which signs and markings should be used in conjunction with bicycle facilities (www.odot.state.or.us/techserv/bikewalk/planimag/II8a.htm). Roadway signs that serve both bicyclists and motorists should be placed and mounted in accordance with standard MUTCD guidance for sign placement, available at http://mutcd.fhwa.dot.gov/HTM/2003r1/part2/part2-toc.htm.

EXHIBIT V-50 (Continued)
Strategy Attributes for Improving Roadway Signage (T)

Attribute	Description
Technical Attributes	

EXHIBIT V-51
MUTCD Guidance for General Placement of Signs
(http://mutcd.fhwa.dot.gov/HTM/2003r1/part2/fig2a-01_longdesc.htm)



Attribute	Description
Potential Difficulties	Care should be taken not to overuse traffic signs. If used in excess, regulatory and warning signs tend to lose their effectiveness. The ease of signing for bicycle routes can also mean that bicyclists may not view the effort as a major commitment to bicycling.
Appropriate Measures and Data	A key process measure is the number and interval of roadway signs. Crash frequency and severity, by type, are key safety effectiveness measures.
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Roadway signs for bicyclists should comply with community policy and desires. Agencies should ensure that bicycle-related signs reflect the community's established or planned bicycle facilities.
Issues Affecting Implementation Time	This strategy does not require a long development process. Signing improvements can typically be implemented in 3 months or less.
Costs Involved	Costs to implement signing are relatively low. An agency's maintenance costs may increase.
Training and Other Personnel Needs	Training regarding use of this strategy should be provided in courses covering the MUTCD and the use of traffic control devices.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy B5: Provide Bicycle-Tolerable Shoulder Rumble Strips (T)

General Description

Bicycle-tolerable shoulder rumble strips are rumble strip configurations that decrease the level of vibration experienced by bicyclists when traversing rumble strips, while at the same time providing an adequate amount of stimuli to alert inattentive/drowsy motorists. Highway shoulder rumble strips have proven to be an effective measure in reducing run-off-the-road (ROR) crashes on urban and rural freeways. (See Strategy 15.1 A1—Shoulder Rumble Strips in *NCHRP Report 500, Volume 6: Guide for Addressing Run-Off-Road Collisions* and Strategy 15.2 A4—Install Shoulder Rumble Strips in *NCHRP Report 500, Volume 7: Guide for Reducing Collisions on Horizontal Curves.*) ROR crashes may be reduced by as much as 20 percent to 50 percent when rumble strips are installed. As the use and benefits of shoulder rumble strips are extended to non-freeway facilities, bicyclists will encounter rumble strips more frequently. Bicyclists are concerned about maneuverability problems while traversing rumble strips because they can be very uncomfortable to ride over and may cause loss of control of the bicycle.

The incompatibilities between shoulder rumble strips and bicycle use are a major concern and much research has been performed on this issue. The three most comprehensive studies on the effects rumble strips have on bicyclists were conducted in Pennsylvania, California, and Colorado by Elefteriadou et al. (2000), Bucko and Khorashadi (2001), and Outcalt (2001), respectively. Each study included bicycle and motor vehicle testing of various rumble strip designs. In general, the rumble strips that provided the greatest amount of stimuli (i.e., noise and vibration) to alert an inattentive or drowsy driver were also the most uncomfortable for the bicyclists to traverse. Likewise, the rumble strips that were the most comfortable for the bicyclists generated the least amount of stimuli in a motor vehicle to alert an inattentive or drowsy driver. In all three studies, compromises were made when selecting the rumble strip design most compatible for both types of road users. Exhibit V-52 provides the recommended configurations from the respective studies as the most compatible for both motorists and bicyclists.

None of these bicycle-tolerable rumble strip configurations should necessarily be considered “comfortable” for a bicyclist to ride over for a considerable length of time. Rather, these rumble strip patterns cause less discomfort and allow for better control of the bicycle when encountered as compared to other rumble strip patterns designed strictly with the motorist in mind.

Placement of rumble strips within the right of way is also important for the safety of bicyclists. If placed improperly, rumble strips can render a shoulder unusable for bicycling. The AASHTO *Bicycle Guide* recommends that rumble strips not be used on routes used by bicyclists unless a minimum of 1.2 m (4 ft) of rideable surface remains for the bicyclist (1.5 m [5 ft] from a curb or guardrail). Other rumble strip policies that have been instituted in an effort to balance the needs of motorists and bicyclists include:

- Using rumble strips exclusively on limited access or controlled access facilities
- Using a textured white fog line (Oregon) rather than rumble strips

EXHIBIT V-52
Bicycle-Tolerable Rumble Strip Dimensions

State	Groove Width (Parallel to traveled way)	Groove Depth	Groove Spacing	Comments
Pennsylvania (Elefteriadou et at., 2000)	127 mm	10 mm	178 mm between grooves	Non-freeway facilities with operating speeds near 88 km/h.
	127 mm	10 mm	152 mm between grooves	Non-freeway facilities with operating speeds near 72 km/h.
California (Bucko and Khorashadi, 2001)	50 mm	25 mm	200 mm on centers	None
	125 mm	8 ± 1.5 mm	300 mm on centers	None
	Allows for installation of raised/inverted profile thermoplastic in areas where shoulders are less than 1.5 m			
Colorado (Outcalt, 2001)	127 mm	10 ± 3 mm	305 mm on centers	Recommend gap pattern of 14.6 m of rumble strip followed by 3.6 m of gap.

- Leaving gaps between the rumble strips to allow bicyclists to cross them if necessary (e.g., 3.7 m [12 ft] gaps every 12.2 or 18.3 m [40 or 60 ft]) (Moeur, 2000)

Research is underway in National Cooperative Highway Research Program (NCHRP) Project 17-32 to develop further guidance for the design and application of shoulder and centerline rumble strips as an effective motor vehicle crash reduction measure, while minimizing adverse operational effects for motorcyclists, bicyclists, and nearby residents. This research will provide additional guidance related to the installation of rumble strips while taking into consideration the concerns of bicyclists.

Additional information on rumble strips can be found at FHWA's resource site about rumble strips at http://safety.fhwa.dot.gov/fourthlevel/pro_res_rumble.library.htm.

It should be noted that this strategy focuses on the impact of bicycle-tolerable rumble strips on bicycle safety. The primary purpose of rumble strips, however, is to improve motorist safety. The reader should refer to Strategy 15.1 A1—Shoulder Rumble Strips in *NCHRP Report 500, Volume 6: Guide for Addressing Run-Off-Road Collisions* and Strategy 15.2 A4—Install Shoulder Rumble Strips in *NCHRP Report 500, Volume 7: Guide for Reducing Collisions on Horizontal Curves* for more detailed information related to rumble strips and their impact on vehicular safety.

EXHIBIT V-53
Strategy Attributes for Bicycle-tolerable Rumble Strips (T)

Attribute	Description
Technical Attributes	
Targets	Bicycle-tolerable rumble strips are intended to provide a safer environment for bicyclists when rumble strips are present along a roadway. They are not intended to change the behavior of bicyclists.
Expected Effectiveness	Bicycle-tolerable rumble strip patterns have been recommended to accomplish the intended goal of providing rumble strips to benefit motorists without generating excessive vibration for bicyclists who ride over the rumble strips. The actual safety effectiveness of this treatment is difficult to assess because most agencies do not have data on bicycle-only crashes or loss-of-control bicycle injuries related to rumble strip encounters. However, by installing bicycle-tolerable rumble strips (which have been intentionally designed with the bicyclist in mind) rather than rumble strip patterns that have been designed strictly based upon motorists' needs, it can be expected that bicyclists will experience less vibration when they encounter the bicycle-tolerable rumble strips, resulting in less discomfort and more control over their bicycles, reducing the risk to bicyclists. If bicyclists know that bicycle-tolerable rumble strips are installed along a route, the bicyclists may be more willing to ride along the shoulder, rather than in the travel lane, thus reducing the exposure to motor vehicle traffic.
Keys to Success	Rumble strip policies that take bicyclists into consideration should be adopted. Shoulder width requirements for installation of rumble strips are very much related to bicycle use. An *FHWA Technical Advisory* (2001) recommends a minimum shoulder width of 1.8 m (6 ft) where rumble strips are to be installed, but it should also be noted that some agencies require as little as 1.2 m (4 ft) of paved shoulder before rumble strips will be installed. The *FHWA Technical Advisory* also indicates that a minimum of 1.2 m (4 ft) of shoulder width be given outside of the rumble strips where bicyclists are present. This recommendation is consistent with AASHTO (1999) policy which states that rumble strips are not recommended where shoulders are used by bicyclists unless there is (a) a minimum clear path of 0.3 m (1 ft) from the rumble strip to the traveled way, (b) 1.2 m (4 ft) from the rumble strip to the outside edge of paved shoulder, or (c) 1.5 m (5 ft) to adjacent guardrail, curb, or other obstacle. Exhibit V-52 provides information on groove width, depth, and spacing of bicycle-tolerable rumble strips. Two other dimensions associated with rumble strips that are critical to their impact on bicyclists are the transverse width (i.e., perpendicular to the traveled way) of the rumble strip and the distance the rumble strips are offset from the edge line. Most state policies specify the transverse width to be between 305 and 406 mm (12 and 16 in) (Elefteriadou et al., 2000), and most state policies specify that the rumble strips be offset from the edge line by 152 to 305 mm (6 to 12 in). These two dimensions affect the clear path available for bicyclists.
Potential Difficulties	Some bicycle groups may be totally against adopting a bicycle-tolerable rumble strip pattern, citing that all rumble strip patterns cause some discomfort and increase the risk for loss of control of bicycles. Rather than adopting a bicycle-tolerable rumble strip pattern, these bicycle groups may take the position that no rumble strips should be installed along routes where bicyclists may be expected to ride.
Appropriate Measures and Data	Appropriate process measures may include the number of shoulder miles or lane miles where bicycle-tolerable rumble strips are installed. This could be compared to the number of shoulder miles or lane miles of rumble strip installations with dimensions other than those specified to be bicycle-tolerable.

EXHIBIT V-53 (Continued)
Strategy Attributes for Bicycle-tolerable Rumble Strips (T)

Attribute	Description
	Appropriate measures used to evaluate the safety effectiveness of the bicycle-tolerable rumble strips include data on bicycle-only crashes or loss-of-control bicycle injuries related to rumble strip encounters. Vibration levels experienced by bicyclists while traversing the rumble strip pattern can be used as a surrogate measure to evaluate the tolerability of rumble strip patterns. Rumble strip patterns that generate lower levels of vibrations for bicyclists are more tolerable for bicyclists.
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	An agency should have a written rumble strip policy that takes bicyclists into consideration.
Issues Affecting Implementation Time	Rumble strip programs can be implemented quickly (i.e., within a year of an agency deciding to proceed). They can be implemented as components of both new construction and rehabilitation projects.
Costs Involved	Costs for installing rumble strips are minimal. An average cost of approximately $0.82 per meter ($0.25 per foot) or $1,640 per kilometer ($2,640 per mile) for the installation of milled-in rumble strips on the shoulders on both sides of two-lane roads has been reported. Incremental costs would be even less for rumble strips being implemented concurrently with reconstruction or resurfacing of a highway.
Training and Other Personnel Needs	None identified.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Information on Organizations Currently Implementing this Strategy

Appendix 7 illustrates the policy developed by the Pennsylvania Department of Transportation to guide the installation of bicycle-tolerable shoulder rumble strips.

The Washington Department of Transportation developed a shoulder rumble strip installation policy that includes required coordination with the WSDOT Bicycle/Pedestrian Advisory Committee. More information is available at: http://www.wsdot.wa.gov/publications/folio/Rumble_Strips.pdf.

Objective C—Reduce Motor Vehicle Speeds

Strategy C1: Implement Traffic Calming Techniques (P)

General Description

Traffic calming refers to traffic management techniques and engineering measures intended to enhance the safety of road users and, in many cases, improve the livability of a community.

The goals of traffic calming are to reduce motor vehicle speeds, traffic volume, or both. Reducing motor vehicle speeds has the potential to reduce both the frequency and severity of bicycle/motor vehicle crashes, and reductions in vehicular volumes ultimately decrease bicycle exposure to motor vehicle traffic.

Several of the companion guides provide detailed information on traffic calming techniques intended to reduce motor vehicle speeds. The reader is referred to these guides for more detailed information on implementing traffic calming techniques. In particular, the reader is directed to the following objectives and strategies in the respective guides:

- *NCHRP Report 500, Volume 10: A Guide for Reducing Collisions Involving Pedestrians*
  - Objective 9.1 C—Reduce Vehicle Speed
    - Strategy 9.1 C1—Implement road narrowing measures
    - Strategy 9.1 C2—Install traffic calming—road sections
    - Strategy 9.1 C3—Install traffic calming—intersections
- *NCHRP Report 500, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*
  - Objective 17.1 H—Reduce operating speeds on specific intersection approaches
    - Strategy 17.1 H2—Provide traffic calming on intersection approaches through a combination of geometrics and traffic control devices

The remainder of this section presents issues specifically related to traffic calming and bicycles.

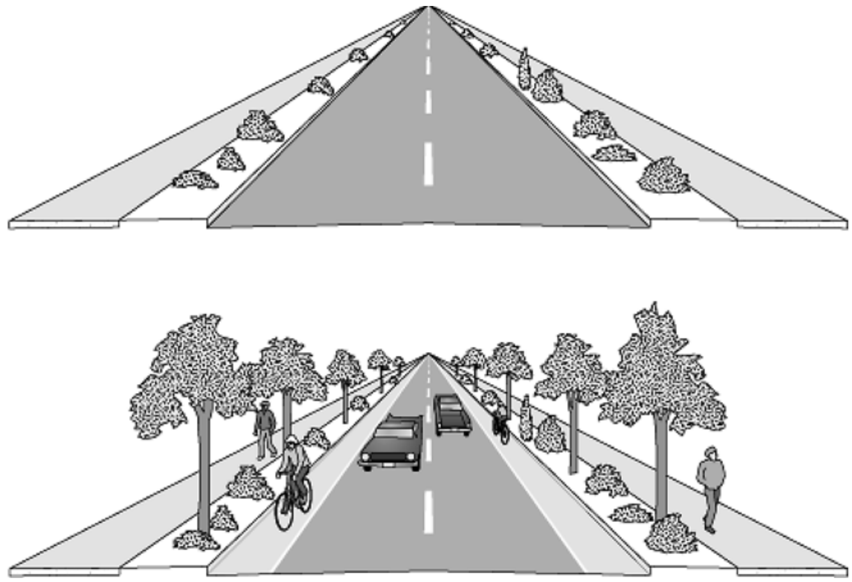
In 1994, FHWA published the *National Bicycling and Walking Study, FHWA Case Study No. 19: Traffic Calming, Auto-Restricted Zones and Other Traffic Management Techniques—Their Effects on Bicycling and Pedestrians* (USDOT, 1994a). Several of the more relevant findings from this case study are as follows:

- European experience clearly shows bicycle use often increases after traffic calming projects are completed. This could, in part, be explained by the fact that traffic calming projects are often designed to prioritize bicycle transportation.
- One European study reported a doubling of bicycle use and an increase in bicycle crashes after the completion of a traffic calming project. Although the frequency of bicycle crashes had risen, the crashes were primarily non-injury crashes.
- The city of Palo Alto (California) has installed traffic calming measures and created a priority street for bicycles (i.e., a bicycle boulevard). The purpose of a bicycle boulevard is to provide (a) a throughway where bicyclists have priority over vehicular traffic, (b) a direct route that reduces travel time for bicyclists, (c) a route that reduces conflicts between bicyclists and motor vehicles, and (d) a facility that promotes and facilitates the use of bicycles as an alternative mode for all purposes of travel.

Traffic calming engineering measures intended to reduce vehicle speeds can be divided into three categories: vertical, horizontal, and narrowing. Exhibit V-54 shows an example of incorporating a bicycle lane within the roadway cross section, resulting in narrower lane widths. Drivers see only the travel lanes as available road space, so the roadway appears narrower than it is (Oregon DOT, 1998).

Bicyclists may experience problems in traffic calmed streets where they have to use the same space as motor vehicles, in particular with humps and other vertical measures (Van Schagen, 2003). In these situations, bicyclists' comfort and safety can be improved by

EXHIBIT V-54
Trees and Colored Bike Lanes Make a Roadway Appear Narrow (Oregon DOT, 1998)



concentrating the vertical elements in the center of the street, leaving space at both sides, so bicyclists can avoid the traffic calming device, or by designing the traffic calming measures with the bicyclists in mind (e.g., designing speed humps that are more tolerable for bicyclists). Vertical measures in streets that are built on a slope should be avoided at all times. Horizontal measures such as road narrowing can also leave separate space for bicyclists so they can pass through in a straight line.

For more information on traffic calming as it relates to bicycles, Lesson 11 of the *FHWA Course on Bicycle and Pedestrian Transportation* pertains to traffic calming (see http://www.walkinginfo.org/training/fhwa-training.cfm).

Strategy C2: Implement Speed Enforcement (T)

General Description

The intent of this strategy is to reduce motor vehicle speeds through speed enforcement programs. Reducing motor vehicle speeds through speed enforcement has the potential to reduce the frequency and severity of bicycle/motor vehicle crashes. Most highway agencies implement some form of speed enforcement programs in cooperation with local law enforcement agencies.

The keys to a successful speed enforcement program are selecting targeted locations and public awareness. A review of recent speed studies and crash data will aid in selecting specific locations for enforcement activities. Input from officers who regularly patrol the streets will be useful in selecting target locations, and input from the general public, including bicycle clubs or local bicyclists, can also be sought. Media attention is also critical in raising public awareness of the program and need for the program. Finally, enforcement activities should be conducted during hours of the day when speeding is most prevalent at the targeted locations.

Several of the companion guides provide detailed information on speed enforcement programs intended to reduce motor vehicle speeds. The reader is referred to these guides for more detailed information on implementing speed enforcement. In particular, the reader is directed to the following objectives and strategies in the respective guides:

- *NCHRP Report 500, Volume 1: A Guide for Addressing Aggressive-Driving Collisions*
  - Objective 4.1 A—Deter aggressive driving in specific populations, including those with a history of such behavior, and at specific locations
    - Strategy 4.1 A1—Target enforcement
- *NCHRP Report 500, Volume 5: A Guide for Addressing Unsignalized Intersection Collisions*
  - Objective 17.1 H—Reduce operating speeds on specific intersection approaches
    - Strategy 17.1 H1—Provide targeted speed enforcement
- NCHRP Report 500, *Volume #TBA: A Guide for Reducing Speeding-Related Crashes on High-Speed Roadways*
  - Objective C—Improve efficiency and effectiveness of speed enforcement efforts
    - Strategy C1—Use targeted conventional speed enforcement programs at locations known to have speeding-related crashes

Objective D—Reduce Bicycle Crashes at Midblock Crossings

Strategy D1: Improve Driveway Intersections (T)

EXHIBIT V-55
Unsafe Driveway Intersections may Lengthen Conflict Areas Between Bicyclists and Motor Vehicles (Dan Burden, http://www.pedbikeimages.org)

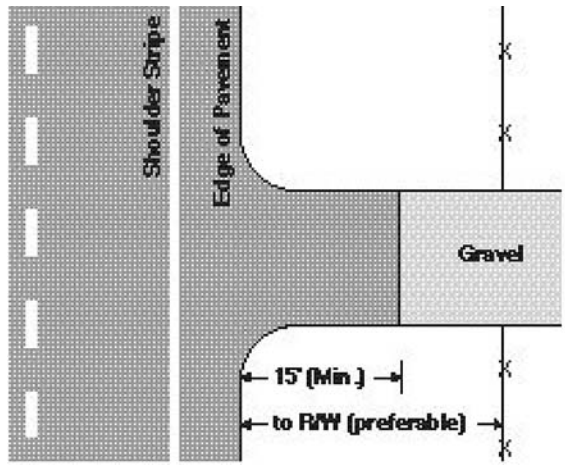
Driveway improvements are intended to modify the intersection of driveways and roadways to minimize potential conflicts between bicyclists and motor vehicles. The design of connections to the street network has a considerable impact on bicyclist safety and access because a significant portion of bicycle/motor vehicle crashes (approximately 20 percent) occur when either bicyclists or motorists ride or drive out from a driveway without properly yielding to oncoming traffic. Every driveway connection is a potential conflict point for motorists, bicyclists, and pedestrians and should be designed to minimize unsafe conflicts.

Examples of driveway intersection improvements include:

- Tighter turn radii at driveways that slow vehicle speeds. Curb cuts should have sufficient flare, however, for bicyclists to complete turns into the driveway or into the nearest lane without "swinging wide" into the adjacent lane.
- On streets with sidewalks, the walkway should continue at grade across the driveway to provide for clear pedestrian movement and make it clear to motorists and bicyclists that pedestrians have the right-of-way.

- Paved driveway approach aprons may be better suited for intersections with unpaved streets and driveways so that gravel and debris can be contained and prevented from accumulating in the bikeways, where it can lead to unsafe riding conditions at the driveway intersection. Although 4.6 m (15 ft) is a typical minimum length for the paved apron, to better reduce transfer of gravel and debris from the unpaved portion into the bicycle lane, longer paved aprons should be considered. Driveway aprons should also not have deep “lips” or grooves that may disrupt bicycle tires.
- Driveway right-of-ways should also be kept cleared of foliage, signs, and other objects that obscure visibility.

EXHIBIT V-56
Paved Driveway Aprons Help Keep Gravel from the Bikeway
(Portland, http://www.trans.ci.portland.or.us/designreferences/bicycle/appenda1.htm)



- Pavement markings may improve conditions for bicyclists at driveway intersections; although skip-striping is typically intended to provide information to motorists about an approaching intersection with a right-turn lane, it might also be considered as a means of informing bicyclists that drivers might turn into the driveway.

Because every driveway intersection is a potential conflict location, reducing the number of driveways through driveway consolidation or other measures should also be considered, particularly for arterials and collector roads. See *Strategy D2—Implement Access Management* for more discussion.

EXHIBIT V-57
Strategy Attributes for Improving Driveway Intersections (T)

Attribute	Description
Technical Attributes	
Targets	Driveway improvements target both bicyclists and motorists. Bicyclists benefit from safer mid-block driveway intersections, and motorists are encouraged to operate more safely as a result of improvements.
Expected Effectiveness	Approximately 20 percent of bicycle/motor vehicle crashes occur at driveway locations. This strategy is intended to improve conditions for bicyclists at driveway locations, and result in reduced bicyclist-involved crashes at those locations. This strategy is expected to result in the following types of improvements: • Provide good visibility for motorists and bicyclists accessing the roadway. • Slow motor vehicles entering / exiting the roadway and establish pedestrian right-of-way.

EXHIBIT V-57 (Continued)
Strategy Attributes for Improving Driveway Intersections (T)

Attribute	Description
Technical Attributes	
	• Reduce the chances of a bicycle-only fall or turning error when bicycles enter or leave the roadway. Driveway improvements also may improve conditions for pedestrians.
Keys to Success	It is best to properly design and consolidate driveways at the outset. Local regulations can require appropriate driveway design when driveways are repaired or modified, or when new driveways are built. Where there is a parking and/or bicycle lane, consideration should be given to designing curb radii tighter than modern guides recommend (e.g., older cities in the Northeast and in Europe frequently have radii of 0.6 to 1.5 m [2 to 5 ft]). More typically, in new construction, the appropriate turning radius is about 4.6 m (15 ft) and about 7.6 m (25 ft) for arterial streets with a substantial volume of turning buses and/or trucks. Tighter turning radii are particularly important where streets intersect at a skew. While the corner characterized by an acute angle may require a slightly larger radius to accommodate the turning movements, the corner with an obtuse angle should be kept very tight, to prevent high-speed turns. It is important to make sure that public maintenance vehicles, school buses, and emergency vehicles are accommodated.
Potential Difficulties	Several driveway designs may cause safety and access problems for pedestrians, including excessively wide or sloped driveways, driveways with large turning radii, multiple adjacent driveways, driveways that are not well defined, and driveways where motorist attention is focused on finding a gap in congested traffic. Local landscape ordinances and other driveway guidelines may be needed to establish clear zones for driveway rights-of-way and maintain roadway surfaces. Along corridors, driveway consolidation creates the need for u-turns, which can be hazardous along roadways with high speeds or ADTs. Large trucks and buses may ride over the curb at intersections with tight radii, creating a danger for pedestrians who are waiting to cross. Driveways without a level sidewalk landing may not comply with ADA pedestrian standards. See *Designing for Pedestrians with Disabilities,* http://www.walkinginfo.org/de/index.htm.
Appropriate Measures and Data	A key process measure is the number of driveways that receive improvements. Performance measures include the number of crashes involving bicyclists at driveways, and bicycle and motor vehicle volume data are needed to represent exposure.
Associated Needs	None identified.

EXHIBIT V-57 (Continued)
Strategy Attributes for Improving Driveway Intersections (T)

Attribute	Description
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Agencies may need to develop new or revised driveway design, construction, and access management policies.
Issues Affecting Implementation Time	Implementation time may be affected by the amount of public involvement and controversy surrounding the proposed program. This can occur during the planning, design, and funding acquisition processes.
Costs Involved	No additional costs are incurred when incorporated into original plan and construction. Costs for retrofitting changes vary depending on existing conditions and scope of work. For example, construction costs for reconstructing a tighter turning radius are approximately $2,000 to $20,000 per corner, depending on site conditions (e.g., drainage and utilities may need to be relocated).
Training and Other Personnel Needs	Because sidewalks also cross many driveways, training on ADA requirements may be needed for anyone involved in the design, construction, or maintenance of driveway areas.
Legislative Needs	Changes to driveway requirements may require updates to local development and construction regulations.
Other Key Attributes	
	None identified.

Strategy D2: Implement Access Management (T)

Managing the number, spacing, access, directional flow, and other aspects of driveway connections protects those traveling along the corridor from conflicts with those entering or leaving the corridor. Every driveway connection is a potential conflict point among motorists, bicyclists, and pedestrians. Access management strategies such as providing raised/non-traversable medians and limiting driveway access may be useful in promoting safe bicycle travel, particularly on arterial or major collector streets, since they help reduce the number of potential conflict points.

The principles of access management incorporate providing specialized roadways appropriate to their intended use. The trade-off is between providing direct access and promoting through movement. For example, the main purpose of freeways and arterials is to move through traffic, and access should be restricted to necessary interchanges. Local streets should generally serve all destinations, and access should not be limited. There are exceptions, however, if management is needed to reduce non-local traffic. Access management includes such measures as:

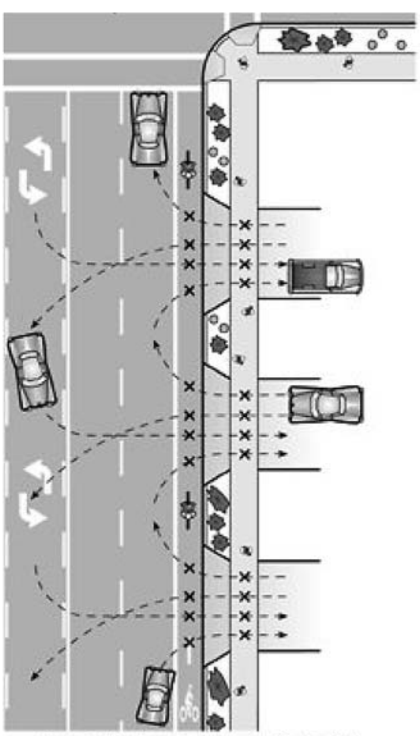
- limiting the number of driveways (or establishing minimum spacing between driveways),

- providing for right-in, right-out only movements,
- locating signals to favor through movements,
- restricting turns at certain intersections, and
- using non-traversable medians to manage left- and U-turn movements.

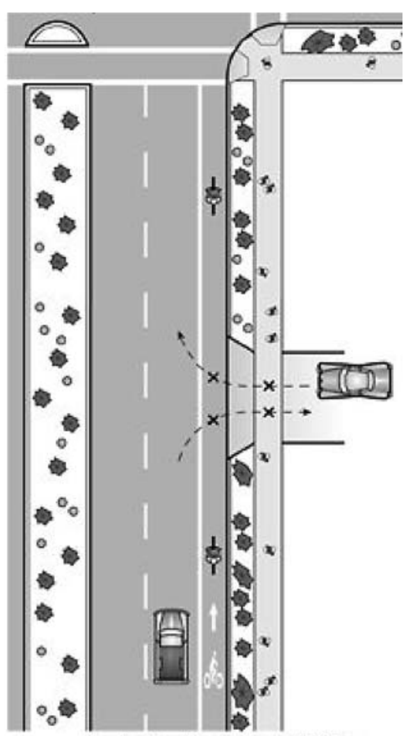
For more information:

- The Transportation Research Board (TRB) Committee on Access Management identifies 10 principles or strategies of access management altogether, along with the rationale and elements of a comprehensive program (see http://www.accessmanagement.gov/).
- TRB also published the *Access Management Manual* in 2003 that provides comprehensive descriptions of access management principles, techniques and effects, and rationale and steps toward developing an access management program and policies.
- Oregon DOT provides extensive guidance to local communities for access management as it relates to bicycle and pedestrian planning and facility development (see http://www.odot.state.or.us/techserv/bikewalk/planimag/backgrnd.htm).

EXHIBIT V-58
Effective Access Management Reduces the Number of Conflict Points
(Oregon DOT, http://www.odot.state.or.us/techserv/bikewalk/planimag/backgrnd.htm)



Uncontrolled accesses create 8 potential conflict points at every driveway.



A raised median and consolidating driveways reduce conflict points.

EXHIBIT V-59
Strategy Attributes for Implementing Access Management (T)

Attribute	Description
Technical Attributes	
Targets	This strategy targets bicyclists who utilize multi-lane arterial or collector roadways and left-turning motorists on those roads.
Expected Effectiveness	By limiting and consolidating driveways, by providing raised or landscaped medians, or by creating frontage roads, bicyclists and pedestrians benefit in several ways: • The number of conflict points is reduced; this is best achieved by replacing a center-turn lane with a raised median (left turns account for a high number of crashes with bicyclists and pedestrians). • Motor vehicles are redirected to intersections with appropriate control devices or appropriate assignment of right-of-way. • Pedestrian crossing opportunities are enhanced with an accessible raised median and fewer conflicts with turning cars. • Accommodating people with disabilities is easier, as the need for special treatments at driveways is reduced. • Improved traffic flow may reduce the need for road-widening, allowing part of the right-of-way to be recaptured for bicyclists, pedestrians, and other users. Benefits of this strategy include smoother vehicle flow, reduced delay, and fewer crashes (Gluck et al., 1999; Demosthenes, 2003). Effective access management planning can also reduce total roadway facility costs by reducing the number of driveways and intersections. Demosthenes (2003) found that access locations (driveways and intersections) account for more than 60 percent of vehicular crashes in urban areas, so incorporating access management strategies can significantly reduce urban crash rates.
Keys to Success	It is difficult to retroactively reduce, consolidate or eliminate existing accesses. Policies that properly control access should be adopted so that agencies can proactively work to improve safety for bicyclists and motorists. A PI&E program should be developed and implemented to educate bicyclists and motorists of the intended purpose of the access management changes, as well as alert them to upcoming changes in traffic patterns. A test period may be helpful to identify and make adjustments to potential problems for affected properties.
Potential Difficulties	Limiting the number of street connections may have a negative impact on non-motorized mobility, especially for pedestrian crossings: • Providing for free-flow of traffic by reducing connections may result in increased travel speeds and volumes. • Eliminating local street crossings eliminates pedestrian crossing opportunities, reduces pedestrian and bicycle travel choices, and may increase out-of-direction travel. • Reduced access to businesses may require out-of-direction travel, discouraging walking and bicycle trips.

EXHIBIT V-59 (Continued)
Strategy Attributes for Implementing Access Management (T)

Attribute	Description
Technical Attributes	
	• Placing concrete barriers down the middle of the road (rather than a raised or landscaped median) effectively prohibits pedestrian crossings. • Improperly designed raised medians act as barriers: pedestrians should be able to see to the other side of the street (vegetation should not decrease visibility) and curbs should be no more than standard height. Access management that reduces traffic conflict and traffic speeds, or reduces total vehicle travel, is expected to result in increased traffic safety. By contrast, access management that simply increases arterial traffic speeds can increase automobile use, and may discourage nonmotorized transportation. Development of an access management program should include awareness of this difference and focus on activities that reduce traffic conflict and speed. There may be costs associated with specific designs and changes to driveway access. It can favor economic development in some locations over others, which imposes costs on some businesses and property owners, and benefits others.
Appropriate Measures and Data	Performance measures include the number of crashes involving bicyclists at mid-block locations, and bicycle and motor vehicle volume data are needed to represent exposure.
Associated Needs	Access management policies need to be coordinated with land use regulations. These policies may easily conflict with each other unless all agency stakeholders are involved. Development of access management requires consistency so that all aspects of motorized transportation, nonmotorized transportation, and land use management/development support the desired outcomes.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Agencies that implement access management changes should involve all potentially affected parties early in the planning process. Agencies may need to develop new or revised policies regarding access management, or support their governing bodies in the development of new or revised policies. Public hearings may be required if driveway access will be restricted or changed.
Issues Affecting Implementation Time	It may take significant time to implement this strategy. Studies should be conducted to determine whether the strategy is appropriate and to identify the most appropriate treatment or countermeasure to address the existing environment.
Costs Involved	If included in initial design and construction, access management measures might raise or decrease costs compared to other designs. Cost of retrofit measures would depend on the type and extent. For example, adding a raised median is estimated to cost \$15,000 to \$30,000 per 30 m (100 ft). Prohibiting left turns with diverters may cost from \$15,000 to \$45,000 each. Access management activities can have a number of equity impacts. Changing vehicle access and development patterns can harm some businesses and property owners, while benefiting others. Property owners sometimes receive compensation for lost access.

EXHIBIT V-59 (Continued)
Strategy Attributes for Implementing Access Management (T)

Attribute	Description
Organizational and Institutional Attributes	
Training and Other Personnel Needs	Training may be needed to improve awareness of access management among transportation professionals. Training will help overcome institutional resistance to new approaches within transportation agencies and will reduce conflicts among stakeholders.
Legislative Needs	Governing bodies may need to adopt policies that require access management.
Other Key Attributes	
	None identified.

Objective E. Improve Safety Awareness and Behavior

Safety behavior and awareness are major factors in many bicycle crashes, and addressing them through improved skill education for bicyclists, better education about and enforcement of bicycle-related traffic laws (which educates both bicyclists and motorists), and increased use of helmets and other safety-related devices is an often-overlooked technique for reducing collisions involving bicyclists and reducing the severity of injuries from such collisions.

Child bicyclists are deemed to be solely at fault 70 to 80 percent of the time in crashes with motor vehicles, while only about 40 percent of adult bicyclists are deemed to be at fault (Hunter et al., 1996). Both bicyclist and motorist are identified as contributing to the crash in 5 to 20 percent of crashes over various bicyclist ages. Motorists were deemed to be solely at fault in from 5 percent of crashes with the youngest aged bicyclists to about 36 percent of crashes involving adults ages 50 to 59. Improving safety awareness and behavior for all roadway users should help reduce these percentages.

Strategy E1: Provide Bicyclist Skill Education (T)

A comprehensive approach to bicyclist safety encompasses education and enforcement as well as changes to the built environment. Bicyclist education can provide bicyclists with the training, knowledge, and practical experience necessary to ride skillfully and interact safely with motorists on the roadway. Bicyclist educational programs can be carried out at many levels from distributing brochures or showing videos, to comprehensive school-based on-bike programs, to community or adult education or recreation facility-based program. Bicyclist educational programs can also target audiences from young preschool-age children to seniors. They may touch on a number of issues, including: safety-related training, bicycle-related laws, helmet information, and nearly any other behavioral aspects of bicycling.

Understanding the different needs for educational audiences and the resources available for each is important when considering educational activities. For example, the educational needs of children are substantially different from those of adult bicyclists. Similarly, language needs should be considered when evaluating educational materials. Resources for bicyclist education are extensive and provide information for many audiences, although as more is learned about the actual effectiveness of different education approaches and methods, additional resources that incorporate better information should be developed. Specifically, with increasing national diversity, materials should be developed for individuals with different ethnic and/or cultural backgrounds.

General Education Resources

The FHWA National Bicycle Safety Education Curriculum identifies and prioritizes the specific topic areas that should be addressed for various target audiences and includes a resource catalog with information on training programs that address each of the various topics. The Resource Catalog is also available as an online searchable database (www.bicyclinginfo.org/ee/fhwa.html). Users can search this database by key word(s), by a specific target audience (e.g., young bicyclists ages 9 through 12; adult bicyclists; motorists); and by selected topic or subtopic areas (e.g., bicycle-riding skills, rules of the road, essential equipment, riding for health and fitness, etc.).

In 2006, NHTSA released the *Bicycle and Pedestrian Safety Resource Guide,* which updates the previous bicycle resource guide and combines the new information with pedestrian resources, as well. The guide provides a compilation of existing and proposed countermeasures that can be used by a variety of implementers to help solve a wide range of bicyclist and pedestrian safety problems. The guide also includes an extensive listing of educational resources (DOT HS 809 977, available on CD-ROM from U.S. DOT).

Age-Specific Education Resources

The PBIC website provides an education page (http://www.bicyclinginfo.org/ee/education.htm) that contains links to many bicyclist safety education programs, tools, and resources that can be used by professionals planning a program as well as by individual bicyclists. For example, the section for young bicyclists ages 9 through 12 contains links to sites with information on choosing the right bike and helmet and how to park and secure your bike, among others. The section for adult bicyclists contains links to materials available from the League of American Bicyclists ("League") covering areas ranging from "A Guide to Commuting for the Employee" to "How to Shift and Change Gears" to "Bike Maintenance 101." FHWA developed the "Bicycle Safety Education Resource Center," hosted by PBIC at http://www.bicyclinginfo.org/ee/fhwa.html/, which includes a database with hundreds of case studies, examples, and recommended education messages and practices for all age groups. The database can be searched by word, age range, or main topic areas. With ready access to these resources, program developers do not need to reinvent the wheel to implement a bicycle safety education program, and young and old riders alike can readily find the information they need to be safer riders.

The League operates a "BikeEd" program that provides education for many audiences. The program includes different courses for adults, children (5th to 7th grade), and commuters, as well as motorists. NHTSA's "SRTS for Middle School Youth" is designed to be taught by anyone and provides students with an overview of the safe routes to school initiative and the basic principles of walking and bicycling safely to school. It is hoped that this basic program will inspire schools and youth to initiate and develop a SRTS program in their school. For more information contact NHTSA at: http://www.nhtsa.dot.gov. Schools or groups wishing to advance to more in-depth bicycle training including on-bicycle experience may contact the League for assistance in finding local instructors to provide this series of classes. For more information see http://www.bikeleague.org.

NHTSA has developed three bicycle safety videos, including: "Ride Smart-It's Time to Start" for elementary and middle school-age children. This video discusses why everyone should wear a bicycle helmet and proper helmet fitting. Another video for elementary and middle school-age children is "Bike Safe. Bike Smart." It discusses rules of the road for bicycling and reviews proper helmet fit. A third video, "Bicycle Safety Tips for Adults," discusses basic tips for choosing and fitting a bicycle, proper helmet fit, rules of the road, and responsibility for personal safety while bicycling. The League has also developed a video that further expands on the basic tips presented in the NHTSA video. This video, "Enjoy the Ride: Essential Bicycling Skills," may be purchased through the League.

FHWA has also developed a "Good Practices Guide for Bicycle Safety Education" (http://www.bicyclinginfo.org/ee/bestguide.cfm) that contains case study descriptions of 16 programs spanning riders of all ages, along with helpful information on planning, funding, implementing, and evaluating a program in your own community or state.

Other Useful Resources

A number of Spanish language materials have been developed including a version of "Be Smart. Bike Safe." NHTSA developed the "Bicycle Safety Activity Guide," a collection of educational materials and activities in Spanish and English that teachers, parents, and caregivers can use to teach bicycle safety to children ages 4 to 11.

Using trained, adult crossing guards is another fairly simple but effective method of providing correction and education to bicyclists and pedestrians, particularly children traveling to and from school. Crossing guards can educate children on safe bicycling and walking behaviors, assist them in crossing at certain locations, and may help to encourage use of these modes in traveling to school, since they provide a measure of comfort that engineering treatments alone cannot provide. Additionally, well-trained adult crossing guards may assist in enforcing motorist speed limits, yielding, and other laws (through reporting offending motorists), and in educating motorists. The state of Florida requires that most localities provide minimum training using the Florida School Crossing Guard Training Guidelines, produced by the Florida DOT and administered by the Florida Department of Highway Safety and Motor Vehicles. The guidelines are available at: http://www.dot.state.fl.us/Safety/ped_bike/training/ped_bike_training.htm. A comprehensive guide to crossing guards has also been developed by the National Center for Safe Routes to School, and can be accessed at: http://www.saferoutesinfo.org/guide/crossing_guard/index.cfm.

Other examples of bicycle education programs include:

Chicago, IL—Mayor Daley's Bicycling Ambassadors and Bike Lane Education (http://www.chibikefed.org/ambassador/)

BikeSafe Bicyclist Safety and Countermeasure Selection Guide case studies (available at http://www.bicyclinginfo.org/bikesafe/):

- Duval County, FL—Injury Control for Bicycle-related Injury in Duval County, Florida (McCloskey et al.)
- Victoria, Canada—Share the Road: Motorist/Cyclist Traffic Rule Education and Enforcement Programs (Litman)

EXHIBIT V-60
Strategy Attributes for Providing Bicyclist Education (T)

Attribute	Description
Technical Attributes	
Targets	Bicyclist education programs target the behavior of bicyclists.
Expected Effectiveness	This strategy is intended to teach bicyclists of all ages safe bicycling skills, including how to interact with motorists in traffic. Education programs should teach bicyclists the importance of having a bike that fits, maintaining the bike in good condition, and always wearing a helmet when riding. Bicycle safety training programs are based on the premise that behavior by bicyclists contributes to the risk of crashes and injuries, and that this behavior can be changed through training programs. Several studies have shown that most crashes were primarily due to some form of human error and very few were due to environmental conditions (Clarke and Tracy, 1995). Nationally, bicyclist errors contributed to almost 65 percent of the bicycle/motor vehicle fatalities in 1991. NHTSA's 1993 report indicated that the most common crashes were due to bicyclist's failure to yield (21.8 percent), improper crossing of roadway or intersection (12.6 percent), and failure to obey traffic signs, signals, or a police officer (8.6 percent) (Clarke and Tracy, 1995). Reports on a state level have similar data suggesting that the five leading contributing factors attributed to bicyclists in bicycle/motor-vehicle crashes were: (1) failure to yield right of way, (2) non-motorist error, (3) disregard for traffic control devices, (4) driver inattention/distraction, and (5) improper/unsafe lane use (Minnesota Department of Public Safety, 2005). The monograph *"Training Programs for Bicycle Safety"* (http://depts.washington.edu/hiprc/pdf/report.pdf) includes a review of 27 educational programs for children and adults. The most comprehensive programs have all incorporated helmet education, traffic rules, safety guidelines, and on-bike training into their curricula. Six of these programs have been evaluated and shown to be effective in increasing participant's knowledge and observed riding skills. There has been little evaluation of program effectiveness in reducing injuries, or evaluation of long-term program effects.
Keys to Success	An education strategy should do more than just provide information. The goal is to motivate a change in specific behaviors to reduce the risk of bicyclist injuries. The most successful education programs encourage people to think about their own travel attitudes and behaviors and help them make informed, better choices.

EXHIBIT V-60 (Continued)
Strategy Attributes for Providing Bicyclist Education (T)

Attribute	Description
Technical Attributes	
	Education should target all road users; one very important element of a comprehensive education program is to educate the general public and motorists about current laws relating to bicycles. Many State DOTs include an information page for relevant laws and regulations on their Bicycle and Pedestrian Program websites. A long-term commitment is required, both to reinforce learned behaviors and to accommodate new bicyclists. Long-term programs are also more likely to be effective in achieving results with regards to educating motorists about proper behavior around bicyclists. The most comprehensive programs have incorporated multiple educational elements, particularly those programs aimed at children. The length of these programs is highly variable, ranging from 1 hour to 40 or more hours. Many programs are strictly classroom based, while others utilize extensive riding experiences. Two common themes have emerged from the overview of various bicycle safety education programs. First, it is the opinion of many researchers that bicycle safety education curriculum for youth should be institutionalized in a school environment to reach more children more consistently (Thomas et al., 2005; Stutts and Hunter, 1990). Second, several experts feel that bicycle education curriculum should be presented as part of a continuum of traffic safety education that begins in elementary school and ends in high school, where children previously trained in bicycle safety transfer their knowledge and skills to motor vehicle driving skills and safety (Thomas et al., 2005; Stutts and Hunter, 1990). Another reason for implementing bicycle education in schools is that schools are more likely to administer a bicycle education course for a time period that will be sufficient for children to learn. Illustrating this point, a Canadian study that evaluated a 2-hour bicycle skills training program found that their brief skills training program (*The Kids CAN-BIKE Festival*) was not effective in improving safe bicycling behavior, knowledge, or attitudes among fourth grade children due to its inadequate time frame (Macarthur et al., 1998). However, it is perhaps unrealistic to expect schools to devote a sizable amount of time out of their curriculum for bicycle safety training. For older youths and adults, the optimal length of a training program is unclear. While a longer training program might impart more skills, few except the most dedicated bicycle riders will spend a substantial amount of time (and money) on bicycle training. For children, a comprehensive bicycle safety education program should include an on-bike component. The NHTSA-supported National Bicycle Safety Network (http://www.bicyclinginfo.org/nbsn/) has proposed that the following elements or messages be part of every education curriculum: • Wear a helmet every time you ride. • Ride with, not against, traffic. • Don’t ride on sidewalks—drivers don’t expect it. • Obey traffic laws and signs, and use proper hand signals. • See and be seen—wear brightly colored or reflective clothing; use lights and reflectors. • Stay alert—always look and listen for traffic, pedestrians, and other bicyclists.

EXHIBIT V-60 (Continued)
Strategy Attributes for Providing Bicyclist Education (T)

Attribute	Description
Technical Attributes	
Potential Difficulties	Adequate educational materials are not available for all populations that may need education. For example, no resources for education relating to alcohol-impaired bicyclists could be found. (Note that the primary message should be convincing them not to ride while impaired.) Limited resources are available for many minority populations, particularly Hispanic audiences. Most Spanish language materials are developed locally and are not available nationally. There is no mechanism to identify and track most locally developed materials. The primary challenge of any bicycle safety education program is sustained results. Studies have shown that most one-time education activities have a maximum effect of 6 weeks, and by 6 months have lost most of their effectiveness (Thomas et al., 2005). Repeating education activities may be necessary to achieve a lasting result. Education programs and curriculums are different, with different intended audiences. Although many bicycle safety education materials and programs exist, it is important to choose the right program for your particular needs and situation. Some studies have also raised questions about the value of children's bicycle safety education as an injury prevention intervention, primarily because the links between safety knowledge, safe behavior, and fewer crashes is insufficiently researched (Thomas, et al., 2005). An early evaluation of the "BikeEd" program in Victoria, Australia, showed that it significantly increased children's bicycle knowledge and riding performance, but subsequent research revealed that trained children were no less likely than untrained children to receive emergency room treatment for a bicycle-related injury (Carlin et al., 1998). Another study evaluating the effect of skill training on injuries, a population-based case control study from Melbourne, Australia, further indicated that this type of education did not reduce injuries but appeared to actually increase injuries. This negative effect was stronger among children whose parents did not themselves bicycle, among low socio-economic groups, and younger children. The authors suggest skills training might produce harmful effects in some children, perhaps due to inadvertent encouragement of risk-taking behavior or of bicycling without proper supervision. Adult education can be particularly challenging. Anecdotal reports from adult bicyclist educators indicate that many adults are not receptive to education because the value of the education is not clear. Most adults feel that they already know how to ride a bicycle and are not aware of the safer behaviors they might learn through an education program. Liability is an unresolved potential difficulty. In some jurisdictions, educators may be liable during safety education or for the post-education activities of participants. In general, reasonable attention to the quality of the education program should avert liability concerns, although agencies should consult their legal advisors if this concern is raised. Clarification should also be sought to establish whether the liability concern is related to concerns about the actual safety training activities (i.e., conducting on-bicycle education or on-street practice), or is more general about the overall institutional fear of liability that might arise from encouraging (or even allowing) children to bicycle or walk to school. Each of these liability concerns might be addressable, but likely require different strategies.

EXHIBIT V-60 (Continued)
Strategy Attributes for Providing Bicyclist Education (T)

Attribute	Description
Technical Attributes	
Appropriate Measures and Data	The overall effectiveness of different and age-appropriate bicycle safety education programs should be better evaluated, both to verify the usefulness of these programs and to improve the selection of most appropriate curricula and programs. In general, the appropriate measures for evaluating bicycle safety education programs should include the following: • Changes in behavior • Changes in knowledge • Changes in crashes or injuries Program effectiveness evaluations should compare program participants to a comparable group that did not receive training. Outcomes assessed should include number and types of crashes, the number and/or severity of injuries, the level of helmet use, and the number of bicyclists in the area. An ideal assessment should also measure the extent to which the learned program skills are retained correctly and for the long term. As with most bicycle-related evaluations, better data regarding exposure would improve analysis and understanding of the effectiveness of bicycle safety education.
Associated Needs	Motorist education programs should also be addressed to improve bicyclist safety. Motorists are often also bicyclists, so this approach will increase the reach of safe bicycling information. Motorist education can also help improve motorist awareness and safe driving around bicyclists. Bicycle education programs should be thoroughly evaluated before their implementation. Plans and funding for proper evaluation should be set forth at the beginning of the program.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Coordination between interested agencies can provide a balanced approach to bicycle safety training, so that students receive information from more than one discipline (i.e., law enforcement and safety education) during the training.
Issues Affecting Implementation Time	Bicycle education programs can be implemented in less than 3 months.
Costs Involved	Costs for bicycle education programs vary widely depending on the nature of the program. Costs might range from no direct costs, with activities provided by volunteers, to extensive safety training sessions that might involve national experts and cost thousands of dollars.
Training and Other Personnel Needs	Implementation of bicycle-related training requires expertise in safe bicycle riding techniques. Qualified instructors should be used for bicycle education programs. Basic safety principles that don’t include on-bicycle training can be taught by other qualified trainers.
Legislative Needs	No necessary legislative needs are identified, although legislative bodies may be able to influence any liability concerns by taking action to indemnify agency-sponsored programs.

EXHIBIT V-60 (Continued)
Strategy Attributes for Providing Bicyclist Education (T)

Attribute	Description
Other Key Attributes	
National Strategies	The *National Strategies for Advancing Bicycle Safety* includes goals, strategies, and short- and long-term actions that can be taken to reduce injury and mortality associated with bicycle-related incidents. Efforts to change the bicycling environment have five key goals (http://www.nhtsa.dot.gov/people/injury/pedbimot/bike/bicycle_safety/): • Motorists will share the road • Bicyclists will ride safely • Bicyclists will wear helmets • The legal system will support safe bicycling • Roads and paths will safely accommodate bicyclists

Strategy E2. Improve Enforcement of Bicycle-related Laws (T)

Along with engineering and education approaches to improving bicyclist safety, enforcement of traffic laws can help to create a safer riding environment, whether this enforcement is directed at the motorist or the bicyclist. With respect to motorists, efforts to reduce speeding in residential areas and along roadways frequented by bicyclists can make them safer places for bicyclists and also safer for other motorists and pedestrians sharing the roadway. Similarly, efforts to curb running of red lights and/or stop signs at intersections will benefit all road users. In most instances, enforcement programs should focus on simultaneous enforcement activities for both bicyclists and motorists, rather than just enforcement against one population. Dangerous behavior by motorists, including driving or passing too close to bicyclists, throwing objects at bicyclists, or yelling at bicyclists, can distract or frighten bicyclists and may cause them to crash.

Law enforcement officers sometimes find it difficult to "ticket" bicyclists or even to stop a young child; however, actions such as wrong-way riding (riding facing traffic), weaving in and out of traffic, ignoring "Stop" signs, and riding without proper lights at night are dangerous, and these behaviors can create ill will with motorists. Law enforcement officers can take advantage of the opportunity to stop and educate the offending bicyclist about the importance of obeying traffic laws.

Because helmet laws have been proven to reduce fatalities and serious head injuries, it is especially critical that officers enforce any helmet wearing law in effect, to increase the effectiveness of the law.

Although law enforcement officers are trained to make motor vehicle traffic stops for speeding, red-light running, and other dangerous behaviors by motorists, they typically do not receive any special training with respect to bicycle law enforcement. It is not surprising, then, that there is very little active enforcement of traffic laws affecting bicyclists in U.S. communities. In the state of Wisconsin, however, the situation is improving because of an innovative training program that is offered upon request to individual police departments. Officers who participate in the 2-day "Enforcement for Bicycle Safety Course" are taught which laws to enforce and how to enforce them to improve safety. Participants significantly improve both their knowledge and attitudes about enforcement for bicycle safety and are more likely to make enforcement contacts in their communities.

NHTSA offers a 2-day course to train law enforcement officers on steps that they can take to improve bicycling safety in their communities. The "Community Bicycle Safety for Law Enforcement" course provides guidance to officers interested in working with their communities to encourage bicycling and improve bicycle safety, with a focus on assessing safety needs and promoting bicycle safety programming (see http://www.bicyclinginfo.org/ee/enforce_officer03.htm for more information).

Another source of support for law enforcement officers is the Law Enforcement Bicycle Association (LEBA), an organization "run by cops for cops" (http://www.leba.org). LEBA's courses focus on bicycling techniques and issues for bicycle-mounted police. For communities considering a more aggressive approach to enforcing bicycle traffic laws, the International Police Mountain Bike Association (http://www.ipmba.org) and a growing number of consultants offer training to help police departments understand bicycle law enforcement issues (http://www.witc.tec.wi.us/pgmpages/lawenf/rlake/bicycle.htm).

With sponsorship from NHTSA, the Massachusetts Bicycle Coalition developed a training program for law enforcement officers that covers most bicycle-related aspects of law enforcement. The program is intended to be taught by law enforcement officers to law enforcement officers as a stand-alone resource. The major objective of the program is to give law enforcement officers of all backgrounds the tools they need to properly enforce the laws that affect bicyclists. The program focuses on all police officers, including those who may not be interested in bicycling or who are not able to attend in-depth trainings. The guide, including video examples, can be downloaded at http://massbike.org/police/.

The Florida Bicycle Association has been very active in developing multimedia materials for law enforcement education. These resources, available at http://www.floridabicycle.org, include "Ride on By," "Ride on By II," and "Understanding Bicycle Law Enforcement." A "Florida Bicycle Law Enforcement Guide" is also available.

Finally, there are two recommended sources for information about bicycle-related laws:

- NHTSA has compiled a resource guide on laws related to pedestrian and bicycle safety. The guide is available for downloading at http://www.nhtsa.gov/people/injury/pedbimot/bike/resourceguide/index.html.
- The Massachusetts Bicycle Coalition also maintains a list of bicycle-related law resources at http://www.massbike.org/bikelaw/law_resources.htm and a page with links to state bicycle laws at http://www.massbike.org/bikelaw/statelaws.htm.

Additional Resources:

The PBIC maintains a resource listing of law enforcement-related materials: http://www.bicyclinginfo.org/ee/enforcement.htm.

EXHIBIT V-61
Strategy Attributes for Improving Enforcement of Bicycle-related Laws (T)

Attribute	Description
Technical Attributes	
Targets	This strategy directly targets activities of law enforcement officers as they relate to bicycling and indirectly targets behavior of bicyclists and motorists.
Expected Effectiveness	The ultimate goal of this strategy is to prevent crashes and enhance traffic safety. Many crashes can be avoided if both bicyclists and motorists follow the rules of the road. Heightened awareness among law officers of these rules can lead to: enforcing of laws, modeling of good behaviors, and recognizing and taking advantage of opportunities to educate both bicycles and motorists.
Keys to Success	Some communities have periodic enforcement blitzes, and others may concentrate enforcement efforts on particular intersections and behaviors in order to have the maximum impact. Enforcing bicycle laws has the same effect as enforcing other traffic laws: it curtails behavior that may result in injuries and fatalities. This point should be reinforced for law enforcement officers who do not feel that enforcing bicycle laws is worth the effort. Officers could probably make up to 100 ten-minute traffic stops for the same amount of effort as one fatal crash investigation, and they will have 100 individuals who are less likely to be involved in a crash because of their efforts. A successful law enforcement strategy must effectively communicate the message that “Crash prevention pays off.” Bicycle law enforcement programs are most needed in communities and areas with high levels of bicycling, such as on and around college campuses. Enforcement campaigns should be preceded by PI&E programs that communicate to bicyclists and motorists the proper behaviors that will avoid enforcement action.
Potential Difficulties	Law enforcement officers are the only ones who can enforce laws, both for bicyclists and motorists, to improve bicycle safety. They must, therefore, be supportive of the enforcement effort. Because of the many demands placed on law enforcement officials’ time, it may be difficult to convince police departments of the importance of officers’ receiving training in bicycle law enforcement. Although “education” (i.e. traffic warnings from law enforcement officers) is emphasized over “ticketing,” the problem of how to handle young offenders especially can be a roadblock to effective bicycle law enforcement. Most training programs address this issue. Law enforcement also involves enforcing motor vehicle operating laws as they relate to bicycling. Bicyclists often report law enforcement resistance to citing motorists for unsafe behavior around bicyclists. Specific common examples include non-enforcement (or incorrect enforcement against the bicyclist) of roadway positioning laws and refusal to investigate complaints about motorists. Effective training programs should also include information and training to provide law enforcement officers with the necessary skills to enforce laws pertaining to motorists, as well as bicyclists. Information on how law enforcement officers may enforce laws with motorists can be found at http://www.bicyclinginfo.org/ee/enforce_motorist.htm. Similarly, special skills may be needed to enforce laws with bicyclists, as well. Bicyclists may be difficult to stop for enforcement, may not have proper identification, or may be more resistant to authority than most motorists. Information on how law enforcement officers may enforce laws with bicyclists can be found at http://www.bicyclinginfo.org/ee/enforce_bicyclist.htm.

EXHIBIT V-61 (Continued)
Strategy Attributes for Improving Enforcement of Bicycle-related Laws (T)

Attribute	Description
Technical Attributes	
Appropriate Measures and Data	Process measures for bicycle-related law enforcement might include the number of warnings and/or citations issued. Performance measures include the number of crashes involving bicyclists at driveways, and bicycle and motor vehicle volume data are needed to represent exposure. In addition, directly linking law enforcement activities with safety outcomes may be difficult, although they are generally thought to have an effect.
Associated Needs	None identified.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Law enforcement agencies should adopt policies to enforce traffic laws; without a policy to enforce traffic laws for roadway users—including bicyclists—changes in attitudes and behaviors of officers may be difficult to achieve.
Issues Affecting Implementation Time	Law enforcement training can be prepared and implemented in less than 3 months.
Costs Involved	The Massachusetts Bicycle Coalition law enforcement training program is available as a freely downloadable course, although the course should be taught by an experienced instructor. The estimated cost for an officer to participate in a 2-day Wisconsin course is $90 to $100, with discounts available to sponsoring departments and some training costs covered by the state. Other training programs would have similar costs.
Training and Other Personnel Needs	Law enforcement officers should be properly trained.
Legislative Needs	None identified.
Other Key Attributes	
National Strategies	The *National Strategies for Advancing Bicycle Safety* includes goals, strategies, and short- and long-term actions that can be taken to reduce injury and mortality associated with bicycle-related incidents. Efforts to change the cycling environment have five key goals (http://www.nhtsa.dot.gov/people/injury/pedbimot/bike/bicycle_safety/): • Motorists will share the road • Bicyclists will ride safely • Bicyclists will wear helmets • The legal system will support safe bicycling • Roads and paths will safely accommodate bicyclists

Objective F—Increase Use of Bicycle Safety Equipment

Strategy F1: Increase Use of Bicycle Helmets (P)

The use of bicycle helmets has been proven to reduce fatalities and serious head injuries that result from bicycle crashes. Studies have shown that riders wearing helmets are 70 to 88 percent less likely to suffer serious head injuries or fatalities in a bicycle crash than unhelmeted riders. There is, however, no evidence that use of helmets reduces collisions and crashes. This strategy of encouraging increased helmet use is recommended as an approach for improving bicyclists' behavior (i.e., the decision to wear a helmet) that will result in fewer fatalities. The option of mandatory helmet use laws should be seriously considered. Helmet laws, along with enforcement of those laws, are effective in increasing helmet use, and helmet use decreases fatalities. This is the only proven strategy for reducing bicyclist fatalities when crashes do occur.

Education

Despite clear and convincing data regarding the effectiveness of bicycle helmets, few people across the United States are usually observed wearing bicycle helmets. The latest estimates from 1994 of helmet ownership and helmet use among children in the United States are 50.2 percent and 25.0 percent, respectively. Helmet use varies widely across the country, due to the local variation in educational campaigns and the presence of helmet laws.

Education of bicycle helmet effectiveness in preventing head injury is one popular method used in the attempt to increase and sustain bicycle helmet use. Education interventions can be community-based, school-based, physician-based, or some combination of these settings. They can be multifaceted in their means of increasing helmet use or may just have one method of employing the strategy. Also, they should combine education about proper use and fitting with helmet discount programs that offer helmets for free or at reduced prices. Information about discount programs can be found at http://www.helmets.org/toolkit.htm. Helmet interventions are likely most effective when combined with related activities, such as bike rodeos and media announcements.

Legislation

Mandatory helmet use laws are an effective means of increasing helmet use. Legislation is quite effective in increasing helmet use, and the effect is not heavily dependent on enforcement. Legislation can be at the level of a municipality, county, or entire state and can affect just children, adolescents, or the entire age spectrum. The effectiveness of legislation in augmenting helmet use can be evaluated by direct observation of helmet use, sales of helmets, injuries reported, citations written, or some combination of these data.

As of February 2007 there were 21 state laws (including the District of Columbia) requiring minors to wear helmets while bicycling, and at least another 149 local ordinances, some of which cover bicyclists of all ages. For a comprehensive, state-by-state review on bicycle laws in the United States, visit http://www.helmets.org/mandator.htm.

The Centers for Disease Control and Prevention (CDC) included a compendium of bicycle helmet safety program evaluations in the Morbidity and Mortality Weekly Report (MMWR) issue titled, "Injury Control Recommendations: Bicycle Helmets" (see http://www.helmets.org/evaluate.htm).

The Bicycle Helmet Safety Institute conducted a formal study on the effect of bicycle helmet legislation on bicycling fatalities that can be found at http://www.helmets.org/leggrant.htm.

EXHIBIT V-62
Strategy Attributes for Increasing Use of Bicycle Helmets (P)

Attribute	Description
Technical Attributes	
Targets	This strategy targets the behavior of bicyclists.
Expected Effectiveness	Wearing an approved helmet in the proper manner (i.e., taut chin strap, helmet shifted forward on the head, and proper-fitting helmet) is the most effective way one can prevent serious head injury or death from a bicycle crash or collision. Even a modest increase in helmet use rates can prove beneficial in reducing these rates. Overall, helmets decrease the risk of serious head injury by as much as 85 percent and the risk of brain injury by up to 88 percent. Helmets have also been shown to reduce the risk of injury to the upper and mid face by 65 percent. A Consumer Product Safety Commission study concluded that the presence of a State law increases helmet use by 18.4 percent (http://www.helmets.org/briefs.htm#rodgers_state_laws).
Keys to Success	Passage of mandatory helmet use laws are the most important key to success. Education programs to increase helmet use should be closely coordinated with other bicycle-related education programs, and they should draw from the techniques and programs that are discussed in *Strategy E1—Provide Bicyclist Skill Education.* An important element in intervention programs is the participation of parents. Studies have provided further evidence that children are more likely to wear helmets if their riding partners, whether adults or children, are also wearing helmets. Helmet education programs should be based on research data, focus on a carefully selected target age group, include the use of a bicycle helmet (through discounts or donation) in addition to other tactics, and have a built-in evaluation component. A community-wide program that has these four factors can give an intervention the best chance for success and possibly provide the basis for local, state, and nationwide campaigns.
Potential Difficulties	Developing a comprehensive program to increase helmet use will involve an ongoing dedication of effort and resources. Not all bicyclists can afford a helmet, and this issue should be addressed as part of passing a mandatory helmet law. There are multiple organizations that have established criteria for helmets, which may confuse helmet users. Although many helmets meet all standards, some less expensive ones are only tested by one, rather than multiple, agencies. Mandatory helmet laws that refer to "established and generally accepted standards" are less likely to cause confusion or resistance about this issue.

EXHIBIT V-62 (Continued)
Strategy Attributes for Increasing Use of Bicycle Helmets (P)

Attribute	Description
Technical Attributes	
	Helmets are often thought by inexperienced users to be uncomfortable, to mess up rider's hair, or to be too hot. Ongoing advances in bicycle helmet design may enable manufacturers and promoters of helmet use to circumvent obstacles against helmet use such as poor fit and poor air circulation, high cost, and the "uncoolness" of wearing a helmet. These obstacles, especially peer pressure, are particularly difficult to overcome among children. Legislation mandating bicycle helmets is not universally accepted. The opponents view such legislation as an infringement on personal freedom that will cause some bicyclists to give up a healthy form of exercise. There is evidence that mandatory helmet laws result in less people riding (Robinson, 2006). Opponents of legislation may also claim that bicyclists wearing helmets might engage in risky behavior, which brings their risk of serious injury back up to the same level it would be if they were not required to wear helmets.
Appropriate Measures and Data	This strategy can be evaluated by direct observation of helmet use, sales of helmets, injuries reported, or some combination of these data. To avoid excessive costs, direct observation of helmet use could be conducted through sample observations at a limited number of locations, rather than trying to observe all use.
Associated Needs	Although it makes inherent sense that helmets would protect against head injury, establishing the real-world effectiveness of helmets is important. Numerous studies have established the effectiveness of bicycle helmets. A listing of many of these studies can be found at http://depts.washington.edu/hiprc/practices/topic/bicycles/helmeteffect.html. In all studies reviewed, there are consistent data indicating that wearing an industry-approved bicycle helmet significantly reduces the risk of head injury during a crash or collision.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	A common evaluation barrier for programs that target youth is gaining permission to collect data in a school environment. Arranging this permission through the involvement of the school (district-level or individual school) is a key step for being able to evaluate programs targeted towards children.
Issues Affecting Implementation Time	A helmet education and promotion program can be implemented in less than 3 months. Developing legislation relating to helmet use may require significant time, as public involvement is a necessary component for new rules and regulations.
Costs Involved	Costs for enacting legislation are low, although if enforcement activities are part of the legislative strategy, they will require law enforcement resources. Costs for helmet promotion programs may include acquiring helmets (sometimes available for low cost through local bicycle stores or directly from suppliers) as well as regular costs associated with developing and implementing any education program.
Training and Other Personnel Needs	Any individuals involved in actually fitting helmets should be qualified to provide sound advice and guidance to people unfamiliar with helmet use.

EXHIBIT V-62 (Continued)
Strategy Attributes for Increasing Use of Bicycle Helmets (P)

Attribute	Description
Organizational and Institutional Attributes	
Legislative Needs	Developing new helmet-related legislation is a legislative process that requires evaluation of alternatives (i.e., which ages, implementation timeline, enforcement policies, etc.) and consensus-building before new policies can be adopted.
Other Key Attributes	
National Strategies	The *National Strategies for Advancing Bicycle Safety* includes goals, strategies, and short-and long-term actions that can be taken to reduce injury and mortality associated with bicycle-related incidents. Efforts to change the cycling environment have five key goals (http://www.nhtsa.dot.gov/people/injury/pedbimot/bike/bicycle_safety/): • Motorists will share the road • Bicyclists will ride safely • Bicyclists will wear helmets • The legal system will support safe bicycling • Roads and paths will safely accommodate bicyclists

Strategy F2: Increase Rider and Bicycle Conspicuity (T)

It is illegal in most states to ride in low light conditions without a front white light and a rear red reflector. These laws, however, are rarely followed and even more rarely enforced. Yet studies show that dark, unlighted conditions increase the severity of injuries to bicyclists and pedestrians relative to daylight conditions (Klop and Khattak, 1999). Darkness decreases bicyclist visibility, and therefore the reaction time of motorists near bicyclists. Logically, dark conditions increase the potential that a bicyclist will not be seen, and subsequently struck, by a motorist. Also, the *Toronto Bicycle/Motor-Vehicle Collision Study* (City of Toronto, 2003) concluded that when bicyclists mix with motor vehicle traffic in dark conditions, they become even more difficult to spot.

There are four stages in the detection and recognition of bicyclists:

1. A motorist's expectation of encountering other vehicles—specifically bicycles,
2. The effort taken to look for the other vehicles or roadway users (including bicyclists),
3. The actual detection of a moving object, and
4. The recognition of the detected moving object as a bicyclist traveling along a potentially conflicting path.

Darkness, poor visibility, and lack of conspicuity can hinder the last two stages of the detection and recognition process (City of Toronto, 2003).

Increasing bicyclists' conspicuity can be achieved in several ways. Bicycle lanes, discussed in Strategy B1, provide a consistent and predictable space for bicyclists, making them easier to detect (City of Toronto, 2003). Some bicyclist education programs teach bicyclists that they can improve their detection and recognition by riding in a prominent position on the road. But the most effective way for bicyclists to make themselves more conspicuous, and hence more detectable and recognizable, is to use headlights and rear lights and to wear retroreflective clothing.

Reflective and Retroreflective Clothing

Studies have found that reflectorization can increase the visibility of bicyclists and pedestrians by a factor of five (Blomberg et al., 1984). Retroreflective materials reflect light using specially designed glass or synthetic beads. These materials are required for most roadway markings such as stop lines and lane markings, so their ability to increase conspicuity is established. Vests and other clothing for bicyclists have been made with retroreflective material. The standard specification for Nighttime Photometric Performance on Retroreflective Markings for Visibility Enhancement is set by the American Society for Testing and Materials (ASTM) International (ASTM, 2003). For access to ASTM standards, visit the ASTM web site, http://www.astm.org.

Lights on Bicycle

Exclusive use of reflectors on bicycles (as required by the Consumer Product Safety Commission) is not effective at increasing the conspicuity of bicyclists, except for when headlights shine directly on the reflector. For example, a car approaching an intersection will not see a reflector on a bicycle approaching on the intersecting street. A headlight, however, is more likely to be visible to the motorist. For this reason, headlights are recommended, if not required, for all riding in low light or dark conditions. Although many states require a headlight and a rear reflector, few have programs in place to help bicyclists acquire the headlight. Just as helmet discount programs are thought to help increase helmet use, headlight discount programs would likely increase headlight use. States that do not require headlights and rear reflectors should consider implementing such a requirement.

EXHIBIT V-63
Strategy Attributes for Increasing Rider and Bicycle Conspicuity (T)

Attribute	Description
Technical Attributes	
Targets	This strategy targets the behavior of bicyclists who are riding at night near motor vehicle traffic, but also affects motorists by making bicyclists more conspicuous.
Expected Effectiveness	Bicyclists that are more visible are expected to be involved in fewer crashes during low light conditions. Although no studies have been identified that indicate this outcome, bicyclists that are more easily seen are likely to be more easily avoidable, as well. In addition, the use of headlights may provide bicyclists with better visibility of roadway conditions.

EXHIBIT V-63 (Continued)
Strategy Attributes for Increasing Rider and Bicycle Conspicuity (T)

Attribute	Description
Technical Attributes	
	A study by Blomberg et al. (1984) investigated the effectiveness of countermeasures to improve conspicuity of bicyclists and pedestrians. Measures such as reflective vests increased detection of users by more than 300 to 400 percent and recognition as a bicyclist or pedestrian by approximately 300 percent over someone not using a reflective vest. Use of lights increased detection by more than 600 percent and recognition by 300 percent.
Keys to Success	Efforts to increase use of lights on bicycles should be combined with activities to increase enforcement of laws that require their use. Also, studies of bicycle/motor vehicle nighttime collisions have concluded that bicyclists do not understand the potential benefits of adequate conspicuity. Therefore, education about the benefits of bicycle lights, as well as retroreflective materials, should be conducted in tandem with efforts to encourage use of these items. Correct information should be communicated. For example, Blomberg et al. (1984) showed that wearing white or light-colored clothing does not effectively increase conspicuity, yet this remains a commonly recommended practice. Similarly, the use of reflective materials that highlight the movement of the bicyclist are more likely to increase recognition or shorten the time it takes a motorist to recognize a bicyclists, but the potential benefits of these types of products are rarely explained to bicyclists. Riding at night should not be discouraged. When properly using lights, bicycle-mounted reflectors, and retroreflective clothing, bicyclists can be sufficiently visible and recognizable at night. Combined with proper riding techniques, riding at night should be as safe as riding during daylight. Many bicyclists rely on their bicycle as primary or important modes of transportation. Promulgating the message that bicyclists should not ride at night may stigmatize those who do, and reduce the belief among drivers that they should expect bicycles at night. Effective recommendations should be that “If you ride at night...” followed by the recommended practice. The message to increase use of lights and retroreflective clothing should be part of any bicycle-related education. There are no established light- or reflector-only promotions, but this message is part of most bicycle rodeo and similar curriculums. The League of American Bicyclists offers advice to bicyclists about the use of lights. Their recommendations could be incorporated into a PI&E campaign (http://www.bikeleague.org/resources/better/advancedcycling.php).
Potential Difficulties	It has proven difficult to overcome numerous barriers to using conspicuity-increasing materials and lights. These include: 1. Lack of understanding by bicyclists of the benefits of lights and reflective materials. 2. Poor (or nonexistent) enforcement of existing laws requiring lights and reflectors on bicycles. 3. Resistance to use of lights and reflective materials based on associated costs, added weight, and inconvenience for bicyclists. 4. A sense that the current Consumer Product Safety Commission (CPSC) requirement of reflectors on new bicycles will make the bicycle adequately conspicuous.

EXHIBIT V-63 (Continued)
Strategy Attributes for Increasing Rider and Bicycle Conspicuity (T)

Attribute	Description
Technical Attributes	
	Over the years, numerous bicycle manufacturers have offered bicycles that included lighting systems. These bicycles have not enjoyed commercial success, so manufacturers only rarely offer products with pre-installed lights. No standards have been developed for evaluating retroreflective materials for bicyclists' conspicuity. It is not known whether commercially available materials are retroreflective enough. Also, the minimum distances at night for detection and recognition have not been determined. Comparisons have been drawn between early automobiles and bicycles; when automobiles were first sold, they did not include headlights. It was only over time, as evidence of their increasing nighttime use and the role of inadequate lighting became established, that governments (federal and state) began requiring lighting systems on all new cars. Further research is needed to understand both conspicuity of bicyclists and the lighting levels needed to effectively see the roadway. This research could lead to conspicuity and lighting standards that ensure visibility and recognizability to motorists, as well as ensure that bicyclists can properly see the roadway.
Appropriate Measures and Data	A reduction in the frequency of low-light (dusk, nighttime, and early morning) bicycle crashes is a prime measure of effectiveness. A surrogate measure might be the percentage of bicyclists using headlights or wearing more retroreflective clothing at night.
Associated Needs	There is need for education/awareness activities to convey the importance of being visible at night while bicycling. In states that do not have mandatory requirements for front headlights and rear reflectors, such laws should be put into place.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Current CPSC regulations that require reflectors are insufficient yet may be referenced to support resistance to mandatory headlight requirements. Alternative national standards for lights, although considered by the CPSC, have not been adopted.
Issues Affecting Implementation Time	None identified.
Costs Involved	Costs for retroreflective materials are minimal, with adhesive materials costing between $5 and $15 and more extensive uses, such as reflective vests, costing up to $40. In addition, retroflective materials are increasingly included in non-bicycling specific outerwear, as well as bicycling-specific commuting clothing. Lighting systems vary widely in cost. Less expensive lights cost between $12 and $25, while the top-of-the line lighting systems can cost over $350. In general, more expensive lights are brighter, have better battery systems, and are easier to install and remove. One relatively recent development that has reduced the cost of bright, low cost lights with long battery lives is the increasing use of light emitting diodes (LEDs) as headlights.

EXHIBIT V-63 (Continued)
Strategy Attributes for Increasing Rider and Bicycle Conspicuity (T)

Attribute	Description
Organizational and Institutional Attributes	
Training and Other Personnel Needs	None identified.
Legislative Needs	None identified.
Other Key Attributes	
National Strategies	The *National Strategies for Advancing Bicycle Safety* includes goals, strategies, and short- and long-term actions that can be taken to reduce injury and mortality associated with bicycle-related incidents. Efforts to change the cycling environment have five key goals (http://www.nhtsa.dot.gov/people/injury/pedbimot/bike/bicycle_safety/): • Motorists will share the road • Bicyclists will ride safely • Bicyclists will wear helmets • The legal system will support safe bicycling • Roads and paths will safely accommodate bicyclists

Objective G—Reduce Effects of Hazards

Strategy G1: Fix or Remove Surface Irregularities (T)

General Description

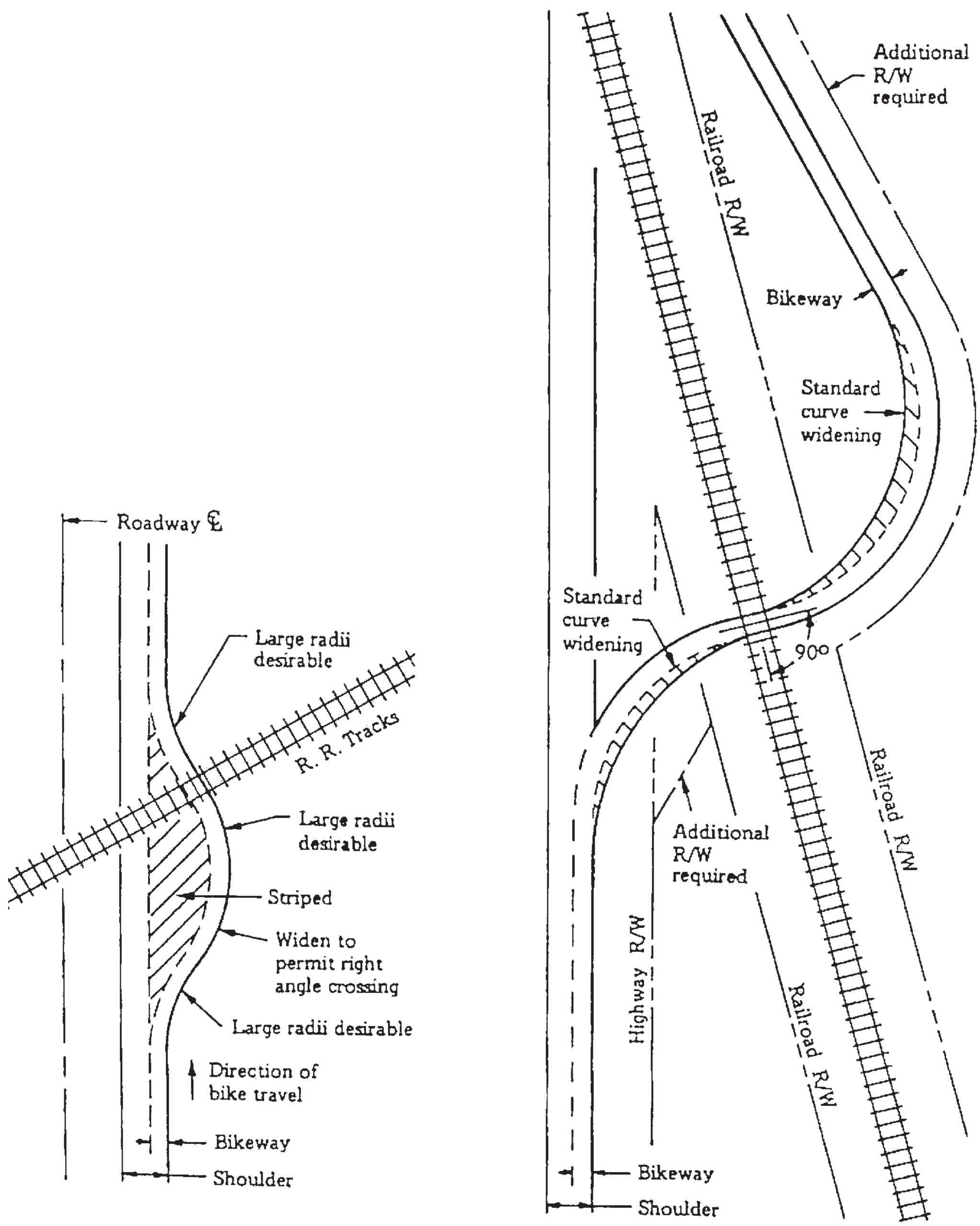
Surface quality directly impacts the safety of bicyclists. Two surface conditions that are singled out for attention are (a) railroad crossings and (b) drainage grates and utility covers.

At-grade railroad crossings can cause serious problems for bicyclists. On diagonal railroad crossings, the gap next to and on the inside of the rail (called the flangeway) can catch the front wheel of a bicycle resulting in a sudden fall for the bicyclist. This problem is most serious when the track crosses at an angle less than 45 degrees to the direction of travel. The more shallow the angle, the greater likelihood of a problem for the bicyclist. Wet weather makes the situation worse, making the tracks even more slippery than normal (Williams et al., 1998). The vertical offset between the rail and the pavement surface can also jar bicyclists, causing control problems.

Drainage grates and utility covers can also cause serious problems for bicyclists in several ways. Raised or sunken grates and covers can stop or divert the front wheel of a bicycle, potentially causing a crash. Similarly, old-style drainage grates with parallel bars can trap the front wheel of a bicycle, potentially causing a crash (Williams et al., 1998).

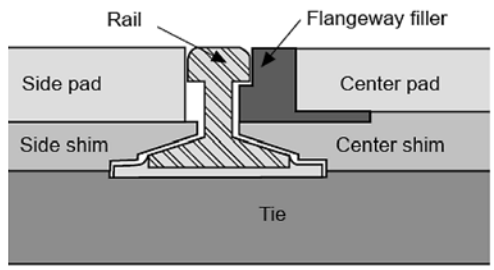
The goal of this strategy is to fix or remove particular surface conditions that may be hazardous for bicyclists. There are two primary solutions for addressing problems associated with diagonal railroad crossings: (1) provide a way for bicyclists to approach the crossing at a wider angle, and (2) fill the flangeway with rubberized material. The first approach can be best accomplished by flaring out the bicycle facility. Exhibit V-64 illustrates two ways that bicyclists can cross railroad tracks at a better angle without swerving into the motor vehicle travel lanes. One solution is to provide a flare near the crossing, and the other solution requires providing a short separated path near the crossing. Alternatively, rather than changing the approach angle to the crossing, installing a flangeway fill works only on

EXHIBIT V-64
Bicycle Crossing at Right Angle (Clarke and Tracy, 1995)



very slow speed rail lines (Exhibit V-65). Since a train's wheels must compress the material, the train must be moving slowly, if not, the fill will cause a train to derail. All surface gaps at railroad crossings should meet the most current requirements of the U.S. Access Board.

EXHIBIT V-65
Flangeway Filler Strip Applied to the Inside Flangeway (Williams et al., 1998)



There are several solutions for problems associated with drainage grates and utility covers. For grates and utility covers that are sunken below the roadway surface, these should be brought to the proper grade. Ideally, during reconstruction of a facility, grates and utility covers can be relocated to positions outside of the common paths of bicyclists. Finally, old-style drainage grates (i.e., with parallel bars) can be replaced with bicycle safe grates that are hydraulically efficient. Consideration should also be given to installing curb face inlets which could move the inlet out of the roadway entirely.

Other surface irregularities, in addition to those addressed above, that may cause problems for bicyclists should also be remedied.

EXHIBIT V-66
Strategy Attributes for Fixing or Removing Surface Irregularities (T)

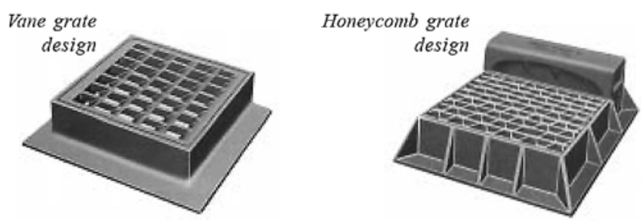
Attribute	Description
Technical Attributes	
Targets	Surface defects that may cause bicyclists to crash. In most cases, this strategy focuses on bicycle-only crashes, or bicycle/motor vehicle crashes where the most harmful event is the result of a surface defect rather than a movement/maneuver made by a motorist.
Expected Effectiveness	The expected safety effectiveness of this strategy is difficult to assess. No studies have been conducted to evaluate its impact on the frequency and/or severity of bicycle crashes. This may be in part because bicycle crashes caused by surface defects rarely involve a motor vehicle, and thus they often do not get reported to the police. Consequently, accident databases may not include these bicycle-only crashes, or if they do, it is likely only a small percentage of the crashes. However, this strategy is expected to reduce the frequency of bicycle crashes because it reduces the likelihood of the front wheel being suddenly trapped or diverted, which may result in a sudden fall by the bicyclist.
Keys to Success	Keys to successfully treating irregular surface conditions at railroad crossings are to identify all diagonal crossings of bicycle facilities and prioritize the degree of the hazard. The need for a treatment is based upon the angle of the crossing, the width of the flangeway opening, and the amount of bicycle traffic that uses (or potentially uses) the crossing. The second type of treatment (i.e., installing a flangeway filler material) can only be used on low speed rail lines. The key to successfully treating irregular surface conditions caused by drainage grates and/or utility coverings is to identify the hazards and develop a program to replace/address the problem locations. If all of the problem locations cannot be

EXHIBIT V-66 (Continued)
Strategy Attributes for Fixing or Removing Surface Irregularities (T)

Attribute	Description
Technical Attributes	

addressed at one time, then a schedule should be developed to fix or remove the problem locations over a period of several years. Bicyclists can be utilized to identify surface irregularities by developing a postcard program (or similar programs) where bicyclists can mail in postcards to the highway agency to report problem locations. These types of programs can be established through communications between the highway agency and local bicycle clubs or bicycle shops. Old-style drainage grates should be replaced with bicycle-safe, hydraulically efficient models. Exhibit V-67 illustrates vane and honeycomb grate designs. FHWA has conducted extensive research to develop bicycle safe, hydraulically efficient drainage grates (Chang, 1980; Burgi, 1978a; Burgi, 1978b; Burgi and Gober, 1977; Pugh, 1980a; Pugh, 1980b; and Woo and Jones, 1974).

EXHIBIT V-67
Bicycle Safe Grate Designs (Williams et al., 1998)



Finally, drainage grates and covers can be relocated out of common bicycle paths whenever routine field work is scheduled for the facility.

Potential Difficulties: Train derailment if filler material is installed within the flangeway of high speed rail lines.

Appropriate Measures and Data: A key process measure is the number of locations that were addressed where known surface defects existed (i.e., were reported). This number can be compared to the number of locations with reported surface defects that were not addressed.

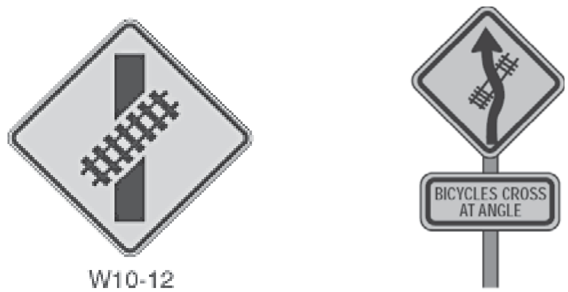
Frequency and severity data are key for determining safety effectiveness. This data may be difficult to obtain because bicycle crashes caused by surface irregularities and defects are often not reported to the police. It may be necessary to collect frequency and severity data from hospital (i.e., emergency department) records.

Associated Needs: If a railroad crossing is particularly hazardous but no treatment is possible in the near term, installation of warning signs may be necessary. Exhibit V-68 illustrates a typical skewed highway-rail grade crossing sign which could be used to warn both bicyclists and motorists. Exhibit V-68 also shows a sign with which several communities have experimented, illustrating a flared approach for bicyclists (Williams et al., 1998). Once again, if an agency plans to install a sign that is not an accepted traffic control device in the MUTCD, the agency should follow the provisions outlined in Section 1A.10 of the MUTCD for design, application, and placement of traffic control devices that are not adopted in the most recent edition of the MUTCD.

EXHIBIT V-66 (Continued)
Strategy Attributes for Fixing or Removing Surface Irregularities (T)

Attribute	Description
Technical Attributes	

EXHIBIT V-68
Examples of Warning Signs for Use at Diagonal Railroad Crossings (Williams et al., 1998)



FROM MUTCD — EXPERIMENTAL

Many railroad crossings take a continual beating from both motor vehicle traffic and train traffic. As a result, these crossings become rough and uneven. Frequent maintenance is essential to minimize problems for bicyclists. However, the best solution is to replace a defective crossing with either a non-slippery concrete crossing or one of the rubberized installations. Exhibit V-69 shows a railroad crossing treated with rubberized material to improve bicycle safety (Clarke and Tracy, 1995).

EXHIBIT V-69
Rubberized Railroad Crossing to Improve Bicycle Safety(Clarke and Tracy, 1995)

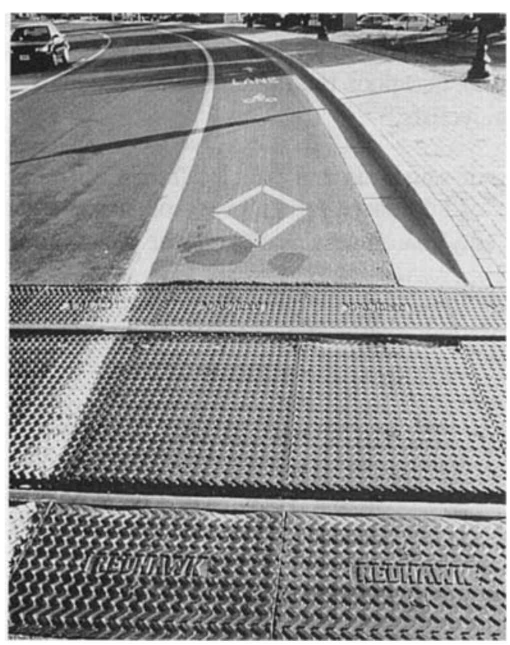
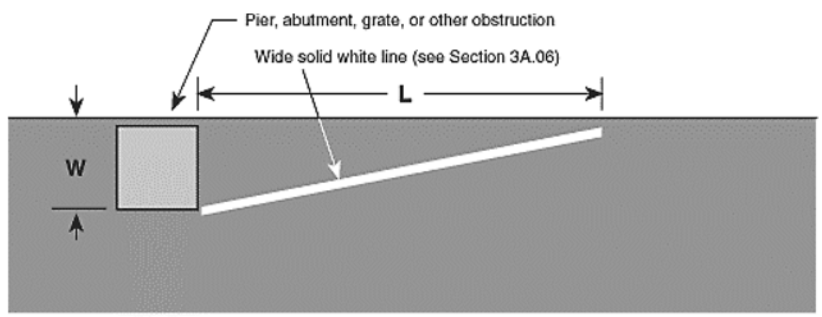


EXHIBIT V-66 (Continued)
Strategy Attributes for Fixing or Removing Surface Irregularities (T)

Attribute	Description
Technical Attributes	
	Where it is not practical to eliminate a drainage grate or other surface defect that may cause problems for bicyclists, pavement markings may be used to delineate the area (Exhibit V-70). To the extent possible, utilities should not be located in common or desired bicycle paths. Although not a long term solution, steel bars may be welded perpendicular to old-style parallel bars so bicycle wheels do not become trapped (AASHTO, 1999).

EXHIBIT V-70
Pavement Marking for Obstructions (USDOT, 2003)



Attribute	Description
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Agencies may need to go through procedures to adopt standard warning signs for hazardous bicycle/railroad crossings that cannot be immediately treated.
Issues Affecting Implementation Time	In most cases, this strategy can be implemented in a short timeframe (i.e., 3 to 6 months). A separated bicycle path designed and constructed to cross a railroad track at close to a 90 degree angle will take longer to implement. If acquisition of right of way is required, this treatment could take even longer. Many of these problem locations can be prioritized and scheduled for treatment over a period of years during routine maintenance of a facility.
Costs Involved	Depending upon the problem identified and the type of treatment, the resources necessary for particular railroad crossings may vary from a few warning signs to full concrete or rubberized crossings. A few warning signs can be installed for approximately $200. The latter treatment (i.e., full concrete crossing) could easily cost $100,000, depending upon the roadway width and other geometric and traffic considerations (Williams et al., 1998). Costs are minimal for replacing old-style drainage grates with bicycle safe grates. Costs include the grate itself and installation costs. If grates and covers are moved, it is desirable to relocate them during regularly scheduled maintenance to minimize costs.

EXHIBIT V-66 (Continued)
Strategy Attributes for Fixing or Removing Surface Irregularities (T)

Attribute	Description
Organizational and Institutional Attributes	
Training and Other Personnel Needs	None identified.
Legislative Needs	None identified.
Other Key Attributes	
	None identified.

Strategy G2: Provide Routine Maintenance of Bicycle Facilities (T)

General Description

Maintenance programs and activities are critical for successful bicycle facilities (Williams et al., 1998). Bicycles and bicyclists tend to be particularly sensitive to maintenance problems (i.e., loss of control type crashes). Most bicycles lack suspension systems and so potholes that motorists would hardly notice can cause serious problems for bicyclists. In addition, since bicyclists often ride near the right edge of the road, they use areas that are generally less well maintained than the main travel lanes. On higher speed facilities, motor vehicle traffic tends to sweep debris to the right, where most bicyclists travel. In addition, ridges such as those found where a new asphalt overlay does not quite cover the older roadway surface can catch a wheel and cause a bicyclist to fall. Not everyone recognizes shoulders as bicycle facilities, but shoulders should be maintained on a regular basis to allow extra room for bicyclists to ride along the side of the traveled way or to maneuver outside of the traveled way when necessary.

The overall goal of this strategy is to modify the current maintenance program and procedures of highway agencies to satisfy maintenance requirements of bicycle facilities. The following are some of bicyclists' most common maintenance concerns and some common solutions:

- **Surface problems:** For potholes and other surface irregularities, patch to a high standard, paying particular attention to problems near common bicycle travel paths.
- **Debris (sand, gravel, glass, auto parts, etc.**): Sweep close to the right edge. If necessary, use vacuum trucks to remove material, particularly if the debris accumulates adjacent to curbs. Special attention should be paid to locations such as underpasses where changes in lighting conditions can make it difficult for bicyclists to see surface hazards.

  For debris or surface irregularities on curves or at intersections, special attention should be paid to areas between typical turning paths and through motor vehicle traffic. These areas often fill with debris and are in typical bicyclist trajectories. Areas where debris wash across paved surfaces should receive special attention. For example, eliminating the source of the problem by providing better drainage may ultimately be a more cost effective treatment than increased sweeping.

- **Chip seal gravel:** Chip sealing of roadways often leaves deep piles of gravel just to the right of the typical paths of motor vehicles. To reduce the impact on bicyclists, remove excess gravel as soon as possible and suggest alternative routes as detours.
- **Ridges and cracks:** These should be filled or ground down as needed to reduce the chance of a bicyclist catching a front tire. Particular attention should be paid to ridges/cracks that run parallel to the direction of travel (e.g., edgedrops and driveway lips). During overlay projects, care should be taken to minimize the edgedrops that could occur at the edge of the pavement. Ruts in the pavement, particularly on intersection approaches, should be ground down to provide a smoother surface through the intersection.
- **Roadway bicycle signs:** Bicycle signs should be maintained in the same fashion as other roadway signs, paying particular attention to bike route signs at decision points, warning signs at special hazard locations, and regulatory signs on popular bike-lane streets.
- **Pavement markings for bicycles:** Bicycle lane striping should be renewed at the same time that other stripes are painted. The same goes for bicycle lane pavement markings. Some markings may experience more wear and tear than others and deserve special attention.
- **Snow removal:** Bicycle facilities should be cleared of snow and ice during the maintenance of the roadway facilities. Care should be taken not to clear snow and ice from roadway facilities and deposit them onto bicycle facilities.

EXHIBIT V-71
Strategy Attributes for Providing Routine Maintenance of Bicycle Facilities (T)

Attribute	Description
Technical Attributes	
Targets	Problem locations where surface conditions, pavement markings, and signs can be remedied through maintenance programs or activities.
Expected Effectiveness	The expected safety effectiveness of this strategy is difficult to assess. No studies have been conducted to evaluate the impact of maintenance programs and activities on the frequency and/or severity of bicycle crashes. This may be in part because bicycle crashes that may be remedied by maintenance programs and activities rarely involve a motor vehicle, and thus they often do not get reported to the police. Consequently, accident databases may not include these bicycle-only crashes, or if they do, it is likely only a small percentage of the crashes. However, this strategy is expected to reduce the frequency of bicycle crashes because maintenance program and activities can address concerns that are often reported to highway agencies by bicyclists.
Keys to Success	One key to success is encouraging bicyclists to report maintenance problems and other hazards. This can be accomplished by developing a “bicycle spot improvement form” and distributing copies throughout the bicycling community. It is critical that reported problems are addressed in a timely manner (Williams et al., 1998). Another key is to design and build new roadways and bicycle facilities in such a way as to reduce the potential for accumulation of debris. This can be accomplished by using edge treatments, shoulder surfaces, and access controls that reduce the potential for accumulation of debris, and by using materials and construction techniques that increase the longevity of pavement surfaces. In general, engineers should consult bicycle experts and groups during the design process.

EXHIBIT V-71 (Continued)
Strategy Attributes for Providing Routine Maintenance of Bicycle Facilities (T)

Attribute	Description
Technical Attributes	
	It is also key to include maintenance costs and clearly define maintenance procedures in all bicycle facility projects. It is critical to include reasonable maintenance costs in project budgets, and it is important to establish clear maintenance responsibilities in advance of construction.
	Finally, riding the bicycle network from the saddle of a bicycle can help uncover previously unknown problems.
Potential Difficulties	If a spot improvement program is developed, but the reported concerns are not acted upon in a timely manner, the bicycle community will become frustrated with the program and eventually no longer report concerns.
Appropriate Measures and Data	It will be important to review maintenance logs to assess how often maintenance activities are performed on bicycle facilities. It will also be important to keep track of the numbers and kinds of problems reported by bicyclists and how the concerns were addressed.
	Frequency and severity data are key for determining safety effectiveness. These data may be difficult to obtain because bicycle crashes remedied by maintenance programs and activities are often not reported to the police. It may be necessary to collect frequency and severity data from hospital (i.e., emergency department) records.
Associated Needs	For the most part, bicycle-related maintenance activities involve the work an agency already performs. In some instances, though, additional equipment may be necessary.
Organizational and Institutional Attributes	
Organizational, Institutional, and Policy Issues	Agencies should develop modified versions of maintenance policies and practices where warranted. In some cases, it may be necessary to develop new maintenance policies.
Issues Affecting Implementation Time	This strategy can be implemented with regular maintenance programs scheduled throughout the year. If the maintenance programs and activities are implemented as intended, the total mileage of bicycle facilities that need to be maintained will impact the implementation time.
Costs Involved	In most cases, the costs involved are related to work that the agency already performs, so additional costs should be minimal. A percentage of the maintenance budget should be allocated for user-requested spot improvements.
Training and Other Personnel Needs	Bicycle-related maintenance activities should be taught in highway agency courses covering highway maintenance. Similarly, bicycle-related maintenance issues should also be taught in highway design courses so as to minimize future maintenance needs (e.g., utility coverings).
Legislative Needs	Tort liability concerns may arise if bicyclists report maintenance-related problems, but a highway agency neglects to address the problem in a timely manner.
Other Key Attributes	
	None identified.

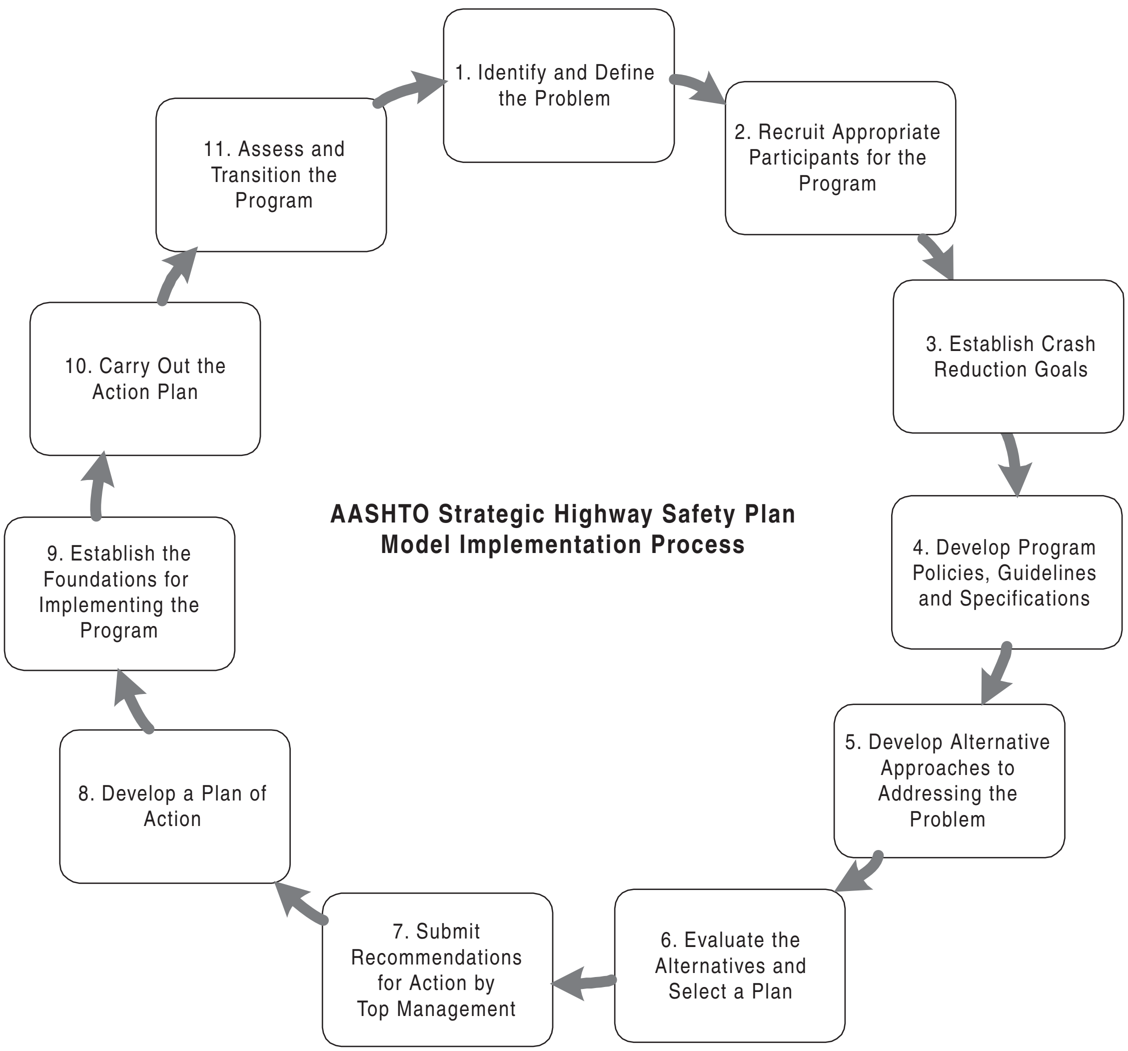
SECTION VI

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/reports/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 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/chhs/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://www.tc.gc.ca/finance/bca/en/Printable_e.htm.

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 are 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

Key References

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Appendixes

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

1 Trail/Roadway Intersection Design in Maryland
2 Bicycle Signal Standards
3 Cost estimates of ITS Technologies for Bicycle Detection
4 Agency Experiences with Improving Signal Timing and Detection
5 Cost estimates of Colored Bicycle Lanes
6 Contact Information for Innovative Pavement Marking Treatments
7 Bicycle-Tolerable Shoulder Rumble Strips

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
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Abbreviations and acronyms used without definitions in TRB publications:

AAAE	American Association of Airport Executives
AASHO	American Association of State Highway Officials
AASHTO	American Association of State Highway and Transportation Officials
ACI–NA	Airports Council International–North America
ACRP	Airport Cooperative Research Program
ADA	Americans with Disabilities Act
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	Air Transport Association
ATA	American Trucking Associations
CTAA	Community Transportation Association of America
CTBSSP	Commercial Truck and Bus Safety Synthesis Program
DHS	Department of Homeland Security
DOE	Department of Energy
EPA	Environmental Protection Agency
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
ISTEA	Intermodal Surface Transportation Efficiency Act of 1991
ITE	Institute of Transportation Engineers
NASA	National Aeronautics and Space Administration
NASAO	National Association of State Aviation Officials
NCFRP	National Cooperative Freight Research Program
NCHRP	National Cooperative Highway Research Program
NHTSA	National Highway Traffic Safety Administration
NTSB	National Transportation Safety Board
SAE	Society of Automotive Engineers
SAFETEA-LU	Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users (2005)
TCRP	Transit Cooperative Research Program
TEA-21	Transportation Equity Act for the 21st Century (1998)
TRB	Transportation Research Board
TSA	Transportation Security Administration
U.S.DOT	United States Department of Transportation