Safe and Aesthetic Design of Urban Roadside Treatments

DETAILS

64 pages | | PAPERBACK
ISBN 978-0-309-11753-1 | DOI 10.17226/14171

AUTHORS

Michael P Hunter; Karen K Dixon; Hong Zhu; Michael Liebler; Berry Mattox; Transportation Research Board

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

NCHRP REPORT 612

Safe and Aesthetic Design of Urban Roadside Treatments

Karen K. Dixon
Michael Liebler
Hong Zhu
OREGON STATE UNIVERSITY
Corvallis, OR

Michael P. Hunter
Berry Mattox
GEORGIA INSTITUTE OF TECHNOLOGY
Atlanta, GA

Subject Areas
Safety and Human Performance

Research sponsored by the American Association of State Highway and Transportation Officials
in cooperation with the Federal Highway Administration

TRANSPORTATION RESEARCH BOARD

WASHINGTON, D.C.
2008
www.TRB.org

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 612

Project 16-04
ISSN 0077-5614
ISBN: 978-0-309-11753-1
Library of Congress Control Number 2008909154

NOTICE

The project that is the subject of this report was a part of the National Cooperative Highway Research Program conducted by the Transportation Research Board with the approval of the Governing Board of the National Research Council. Such approval reflects the Governing Board's judgment that the program concerned is of national importance and appropriate with respect to both the purposes and resources of the National Research Council.

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.

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

The Transportation Research Board of the National Academies, the National Research Council, the Federal Highway Administration, the American Association of State Highway and Transportation Officials, and the individual states participating in the National Cooperative Highway Research Program do not endorse products or manufacturers. Trade or manufacturers' names appear herein solely because they are considered essential to the object of this report.

Published reports of the

NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

are available from:

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

and can be ordered through the Internet at:

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

Printed in the United States of America

THE NATIONAL ACADEMIES

Advisers to the Nation on Science, Engineering, and Medicine

The **National Academy of Sciences** is a private, nonprofit, self-perpetuating society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare. On the authority of the charter granted to it by the Congress in 1863, the Academy has a mandate that requires it to advise the federal government on scientific and technical matters. Dr. Ralph J. Cicerone is president of the National Academy of Sciences.

The **National Academy of Engineering** was established in 1964, under the charter of the National Academy of Sciences, as a parallel organization of outstanding engineers. It is autonomous in its administration and in the selection of its members, sharing with the National Academy of Sciences the responsibility for advising the federal government. The National Academy of Engineering also sponsors engineering programs aimed at meeting national needs, encourages education and research, and recognizes the superior achievements of engineers. Dr. Charles M. Vest is president of the National Academy of Engineering.

The **Institute of Medicine** was established in 1970 by the National Academy of Sciences to secure the services of eminent members of appropriate professions in the examination of policy matters pertaining to the health of the public. The Institute acts under the responsibility given to the National Academy of Sciences by its congressional charter to be an adviser to the federal government and, on its own initiative, to identify issues of medical care, research, and education. Dr. Harvey V. Fineberg is president of the Institute of Medicine.

The **National Research Council** was organized by the National Academy of Sciences in 1916 to associate the broad community of science and technology with the Academy's purposes of furthering knowledge and advising the federal government. Functioning in accordance with general policies determined by the Academy, the Council has become the principal operating agency of both the National Academy of Sciences and the National Academy of Engineering in providing services to the government, the public, and the scientific and engineering communities. The Council is administered jointly by both the Academies and the Institute of Medicine. Dr. Ralph J. Cicerone and Dr. Charles M. Vest are chair and vice chair, respectively, of the National Research Council.

The **Transportation Research Board** is one of six major divisions of the National Research Council. The mission of the Transportation Research Board is to provide leadership in transportation innovation and progress through research and information exchange, conducted within a setting that is objective, interdisciplinary, and multimodal. The Board's varied activities annually engage about 7,000 engineers, scientists, and other transportation researchers and practitioners from the public and private sectors and academia, all of whom contribute their expertise in the public interest. The program is supported by state transportation departments, federal agencies including the component administrations of the U.S. Department of Transportation, and other organizations and individuals interested in the development of transportation. **www.TRB.org**

www.national-academies.org

AUTHOR ACKNOWLEDGMENTS

The research reported herein was performed under NCHRP Project 16–04 by the Georgia Research Institute and faculty and staff in the Department of Civil and Environmental Engineering at the Georgia Institute of Technology (Georgia Tech). The School of Civil and Construction Engineering at Oregon State University (OSU) also participated substantially in this research effort. Georgia Tech served as the primary contractor for this study while OSU served as a subcontractor for the project. In addition, Glatting Jackson served as a subconsultant during the early project stages.

Dr. Karen K. Dixon, P.E., Associate Professor at OSU, was the project director and co-principal investigator. Dr. Michael P. Hunter, Assistant Professor at Georgia Tech, served as co-principal investigator. The other authors of this report are Michael Liebler and Hong Zhu, Graduate Research Assistants at OSU, and Berry Mattox, Graduate Research Assistant at Georgia Tech. In addition, Dr. Eric Dumbaugh of Texas A&M contributed to the literature review portion of this report.

The authors would like to acknowledge agencies that provided data and case study material for this research effort. These include the cities of Phoenix, Arizona; Sacramento, California; Eden Prairie, Minnesota; Billings, Montana; Charlotte, North Carolina; Bend, Oregon; Portland, Oregon; and Salt Lake City, Utah. In addition, the Georgia Department of Transportation, the Oregon Department of Transportation, and the Federal Highway Administration also provided data for this project.

FOREWORD

By Charles W. Niessner
Staff Officer
Transportation Research Board

This report presents the findings of a research project to develop recommended design guidelines for safe and aesthetic roadside treatments in urban areas and a toolbox of effective roadside treatments that balance pedestrian, bicyclist, and motorist safety and mobility. The report will be of particular interest to designers and safety practitioners responsible for the design of arterial and collector-type facilities in urban areas.

Many challenges are encountered when designing highway projects that pass through urban areas. Arterial and collector highways are typically designed to move vehicles as quickly and efficiently as possible. However, many times these highways are the centers of communities that have developed around them. Increasingly, citizens of these communities have requested that these highways be redesigned using roadside solutions that enhance the appearance and, in many cases, the functional use of the highway.

Many of the solutions involve introducing roadside treatments such as trees, sculptures, and signs. In addition to enhancing the appearance of these highways, these treatments are often also intended to slow or "calm" traffic to enhance safety. However, many of these treatments are considered fixed objects, as defined in the *AASHTO Roadside Design Guide*, and they will often be located within the design clear zone. Recommended clear zone dimensions generally represent minimum lateral offset distances. Thus, reducing existing, wider clear zones by introducing fixed objects, even at these minimum distances, reduces the recovery distance. In addition, slowing traffic may cause changes in traffic operations. Therefore, it is crucial that the impacts of these designs be understood so that decisions can be based on facts. There is also a need to identify designs that have performed acceptably and a need to develop new design guidelines that enhance the roadside environment while being forgiving to errant vehicles.

Under NCHRP Project 16-04, "Design Guidelines for Safe and Aesthetic Roadside Treatments in Urban Areas," researchers at Oregon State University and the Georgia Institute of Technology developed recommended design guidelines for roadside treatments in urban areas and a toolkit that includes strategies for placing roadside objects with respect to driveways, intersections, merge lanes, and so forth. They also developed a draft of Chapter 10 for the *AASHTO Roadside Design Guide*.

Two analysis approaches were used in developing the guidelines. First, a corridor assessment of urban roadside conditions was performed and contrasted with 6 years of historic crash data. The goal was to identify potential configurations that posed a greater risk using cluster crash analysis. By contrast, assessment of locations with similar features but without these crashes provided insight into prospective alternative treatments for roadside safety in urban environments.

In the second analysis approach, the researchers assembled case studies in which jurisdictions had performed roadside enhancement or "beautification" projects without companion major road reconstruction. A simplified before-after crash analysis, crash summaries, and project descriptive information were assembled to help determine the safety influence of the enhancement projects. The results of this case study task varied, but can be used by agencies to estimate the potential safety implications of their future roadside enhancement projects.

CONTENTS

SUMMARY

Safe and Aesthetic Design of Urban Roadside Treatments

Roadside safety in rural environments has been the focus of considerable study, but direct application of this knowledge to the urban environment is challenging because the urban environment is constrained in ways that the rural environment isn't. In urban environments, restricted right-of-way, with a greater demand for functional use of the space adjacent to roads, makes the maintenance of a wide clear zone impractical. This report summarizes work performed under NCHRP Project 16-04 to identify urban roadside safety issues and seek solutions for mitigating hazards where possible.

The objectives of NCHRP Project 16-04 were to develop (1) design guidelines for safe and aesthetic roadside treatments in urban areas and (2) a toolbox of effective roadside treatments that can balance the safety and mobility of pedestrians, bicyclists, and motorists and accommodate community values. The guidelines that were developed are based on an evaluation of the effects of roadside treatments such as trees, landscaping, and other features on vehicle speed and overall safety. The guidelines generally focus on arterial and collector-type facilities in urban areas with speed limits between 40 and 80 km/h (25 and 50 mph).

The research included two analysis approaches. In the first approach, the authors assessed roadside conditions in various urban corridors, performed a cluster crash analysis to identify locations with an overrepresentation of fixed-object crashes during a 6-year period, and identified fixed-object crash features for each location. This analysis enabled the authors to identify the road and roadside configurations that posed the most risk for fixed-object crashes. These higher risk road and roadside configurations were referred to as urban control zones.

The road and roadside configurations most commonly associated with fixed-object crashes included those with the following:

- Obstacles in close lateral proximity to the curb face or lane edge;
- Roadside objects placed near lane merge points;
- Lateral offsets not appropriately adjusted for auxiliary lane treatments;
- Objects placed inappropriately in sidewalk buffer treatments;
- Driveways that interrupt positive guidance and have objects placed near them;
- Three kinds of fixed-object placement at intersections;
- Unique roadside configurations associated with high crash occurrence; and
- Roadside configurations commonly known to be hazardous.

In the second approach, the authors assembled case studies in which jurisdictions had performed roadside enhancement projects (often known as beautification projects) without

companion major road reconstruction. For these case studies, a simplified before-after crash analysis, crash summaries, and project descriptive information were assembled to help determine the safety influence of the enhancement projects. The results of this case study task varied, but can be used by agencies to estimate the potential safety implications of their future roadside enhancement projects.

CHAPTER 1

Background

Problem Statement and Research Objective

Many challenges are encountered when designing highway projects that pass through urban areas. Arterial and collector highways are typically designed for moving vehicles as quickly and efficiently as possible. However, many times these highways are at the center of a community that has developed around them. Increasingly, citizens of these communities have requested that highway corridors be redesigned using roadside solutions that enhance the appearance and, in many cases, the functional use of the highway roadside.

Many of these solutions involve introducing roadside treatments such as trees, street furniture, and signs. In addition to enhancing the appearance of these highways, some roadside treatments are intended to slow or "calm" traffic. However, many of these same features are considered fixed objects and will likely be located within the design clear zone. Recommended clear zone dimensions vary based on sideslope, design speed, and traffic volume; however, the generally wider road widths that are needed to include roadside treatments are usually difficult to achieve and impractical in constrained urban settings. As a result, designers often use minimum lateral offset distances that simply enable operational use of the road. Thus, introducing fixed objects—which can result in the reduction of existing wider lateral offsets—can potentially have a direct impact on roadside safety. In addition, slowing traffic may cause changes in traffic operations. Therefore, it is crucial to informed decision making that the impacts of roadside enhancement designs be understood. There is also a need to identify designs that have performed in an acceptable manner and to develop new design guidelines that will lead to enhanced roadside environments and be forgiving to errant vehicles. These guidelines will provide the American Association of State Highway and Transportation Officials (AASHTO) Technical Committee for Roadside Safety with critical information for the update of Chapter 10 of the *Roadside Design Guide* (*1*).

The objectives of NCHRP Project 16-04, therefore, were to develop (1) design guidelines for safe and aesthetically pleasing roadside treatments in urban areas and (2) a toolbox of effective roadside treatments that can balance the safety and mobility needs of pedestrians, bicyclists, and motorists and accommodate community values. The guidelines developed in this project were based on an evaluation of the effects of treatments such as poles, trees, landscaping, and other roadside features on vehicle speed and overall safety. The guidelines generally focus on arterial and collector-type facilities in urban areas with speed limits between 40 and 80 km/h (25 and 50 mph).

Scope of Study

This study includes two approaches for identifying the potential influence of urban roadside features on systemwide safety. The first approach was a corridor analysis of over 241 km/h (150 mi) of urban roadways, in which the research team examined historic crash information to identify common roadside crash conditions. Crashes were displayed on spot maps and also summarized individually for additional analysis. The research team then used video to record the corridors and the placement of roadside features. The result of this corridor analysis is proposed urban control zones where the likelihood of crashes is significantly greater. This information has then been used to develop recommended guidelines for enhancing roadside safety in the urban environment.

The second approach to evaluating the roadside safety problem was the assembly of case studies with crash type, crash severity, and before-after safety assessments. Ideally, a candidate case study would include the change of only one roadside feature so that the direct influence of that change on safety could be evaluated; however, such unique improvement projects are limited, so this case study task included general beautification projects with roadside enhancements and excluded projects with major reconstruction. The results of these case study evaluations were mixed, but an agency seeking to perform a similar project can use the results to help understand the general safety performance that can be expected following the completion of the project.

Chapter 2 of this report summarizes current knowledge from literature on the urban roadside and objects commonly placed in the urban roadside environment. Chapter 3 summarizes the analysis procedures and subsequent findings for each task. Chapter 4 provides general research conclusions as well as future research needs identified during this research effort. In addition, this report includes four appendices. Appendix A provides detailed information about the urban control zone corridor sites. Appendix B includes the summary statistics for the case study sites. Appendix C includes an urban roadside design toolbox, and Appendix D provides draft language for the urban chapter in the AASHTO *Roadside Design Guide* (*1*). Appendixes A, B, and D are available on the TRB website at http://trb.org/news/blurb_detail.asp?id=9456. Appendix C is appended to this report.

CHAPTER 2

State-of-the-Art Summary

Urban areas present unique challenges to the roadway designer. Urban and regional stakeholders need a transportation network that allows them to accomplish their travel objectives with a minimum amount of travel delay and to have these travel demands met on a road network that is both operationally efficient and safe.

While the transportation profession has made dramatic advancements toward meeting safety and mobility mandates, it is critical that the function of the street system complement the adjacent land use and balance the needs of all users while maintaining the safest possible transportation facility. Of particular interest is the design of roadsides—the area between the shoulder (or curb) and the edge of the right-of-way (*1*). The roadside is a common location for pedestrian activity, utility placement, landscaping, transit stops, driveway placement, mailbox placement, and placement of a variety of other roadside features typical of the urban environment. Urban roadside environments can range from dense downtown zones with on-street parking to high-speed zones with motor vehicle operational priorities.

Given the importance of the roadside environment to the quality of urban life, it is unsurprising that urban residents and stakeholders often seek to have the roadside designed in a manner that enhances the quality of the urban environment. Commonly requested functional roadside elements include sidewalks, street trees, and street amenities such as seating. Requested aesthetic elements include public art and special paving materials. Placing these roadside elements in a way that enhances urban roadside safety is the focus of this literature review.

Overview of Roadside Crash Statistics

In 2005, over 6.2 million crashes occurred on U.S. roadways. Almost 1.9 million of these crashes involved an injury, and 39,189 people were fatally injured (*2*). Of particular concern are crashes that involve a vehicle that leaves the roadway. Of the 6.2 million crashes in 2005, run-off-road crashes accounted for 0.95 million, or about 15 percent of the total. While run-off-road crashes happen less frequently than other types of crashes, they are often severe. Although run-off-road crashes accounted for only 15 percent of all crashes in 2005, they accounted for 32.2 percent of the total fatal crashes in that year (see Table 1).

Examining fatal crashes by the first harmful event illustrates the magnitude of specific roadside hazards. Of the fatal crashes occurring in 2005, 39 percent involved collisions between motor vehicles. Rollover crashes and collisions with fixed objects—two kinds of crashes that are associated with the roadside environment—made up 11 percent and 32 percent, respectively, of fatal crashes in 2005. The highest percentage of fixed-object crashes was in the category of tree/shrub, with tree or shrub impacts accounting for slightly more than 3,200 crashes, or roughly 8 percent of all fatal crashes. Poles and posts accounted for a little less than 5 percent of all fatal crashes (see Table 2).

Roadside Safety: Current Practices

The literature on roadside safety establishes three roadside crash strategies that can be considered when seeking to improve run-off-road crash statistics (*1*). First, the ideal scenario is to **prevent vehicles from leaving the travelway,** thereby eliminating the crash entirely. Preventing the conditions that lead to run-off-road crashes (conditions such as driving while impaired or fatigued) and alerting a driver that he or she is leaving the travelway would be potential countermeasures included in this category.

The second strategy, which is based on the idea that run-off-road events are impossible to prevent entirely, is to **design a roadside that is "forgiving."** In other words, a roadside should be designed to minimize the consequences of a run-off-road event. Under current practice, the ideal roadside

Table 1. Crashes by number of vehicles and relation to roadway (2005).

Crash Type	On Roadway	Run-Off-Road	Shoulder	Median	Other/ Unknown	% Run-Off-Road	Total
Fatal Crashes							
Single Vehicle	6,507	12,340	2,431	1,022	353	54.5	22,653
Multiple Vehicle	15,647	297	302	198	92	1.8	16,536
Total	22,154	12,637	2,733	1,220	445	32.2	39,189
Injury Crashes							
Single Vehicle	154,000	320,000	14,000	48,000	28,000	56.7	564,000
Multiple Vehicle	1,235,000	7,000	1,000	7,000	2,000	0.6	1,252,000
Total	1,390,000	327,000	16,000	54,000	30,000	18.0	1,816,000
Property-Damage-Only Crashes							
Single Vehicle	328,000	598,000	31,000	81,000	277,000	45.5	1,314,000
Multiple Vehicle	2,957,000	11,000	3,000	14,000	5,000	0.4	2,990,000
Total	3,284,000	609,000	34,000	94,000	282,000	14.1	4,304,000
All Crashes							
Single Vehicle	488,000	930,000	48,000	129,000	306,000	48.9	1,900,653
Multiple Vehicle	4,208,000	18,000	5,000	21,000	7,000	0.4	4,258,536
Total	4,697,000	948,000	53,000	150,000	313,000	15.4	6,159,189

Source: Adapted from *Traffic Safety Facts 2005* (*2*).

allows errant vehicles to come to a controlled stop before encountering an object located along the roadside by including a clear zone adjacent to the travelway. In many situations, however, such as urban roadways located in narrow rights-of-way, a clear zone may be impractical. Thus, in many cases, in which the provision of a clear zone and/or wider right-of-way may be desirable from a safety perspective, achieving this clear zone may be infeasible. Under these circumstances, design agencies should strive to **minimize the severity of an impact with a fixed object** should such a crash occur.

This literature review summarizes known roadside design safety guidance for roadways in urban areas. There is often little substantive knowledge on the safety impacts of various design treatments, leaving the definition of what constitutes a "safe" facility open to question. The ability to clearly and reasonably evaluate and demonstrate the safety impacts will go a long way toward resolving many of the contentious issues that relate to the design of urban roadways and toward satisfying the needs and interests of project stakeholders. This review, therefore, summarizes focused research on the safety of roadside treatments in urban areas with particular attention to the high-speed (thus more severe) crash locations such as suburban-to-urban arterial transitions where land use is less dense, on-street parking is rarely permitted, and the presence of driveways/intersections is considerably less frequent than it is in more congested urban business corridors.

Table 2. Fatal crashes by most harmful event (2005).

First Harmful Event		Fatal Crashes	% of All Fatalities
Collision with Motor Vehicle in Transport		15,357	39.2
Object Not Fixed	Pedestrian	4,520	11.5
	Bicycle	776	2.0
	Other Object Not Fixed	1,209	3.1
Overturn (Rollover)		4,266	10.9
Fixed Object	Tree/Shrub	3,215	8.2
	Pole or Post	1,852	4.7
	Culvert/Ditch/Curb	2,591	6.6
	Embankment	1,444	3.7
	Guardrail	1,189	3.0
	Bridge	336	0.9
	Other Fixed Object	1,812	4.6
Other Unknown First Harmful Events		622	1.6
Total		**39,189**	**100.0**

Source: Adapted from *Traffic Safety Facts 2005* (*2*).

In the first volume (and subsequent volumes) of *NCHRP Report 500*, prospective engineering countermeasures and their associated effectiveness are classified as "Tried," "Experimental," or "Proven" (*3*, pp. V-2 through V-3). This classification permits readers to understand the level of testing performed on a specific countermeasure perceived to be effective for a safety improvement program. Summarized versions of the definitions given in the first volume of the *NCHRP Report 500* series for "Tried," "Experimental," and "Proven" are given below (*3*, pp. V-2 through V-3):

- **Tried (T)**—Strategies that have been implemented at a number of locations but for which valid safety evaluations have not been identified. As a result, these strategies should be used with caution until information about their effectiveness can be accumulated and they can be reclassified as Proven strategies.
- **Experimental (E)**—Strategies that appear sufficiently promising so that application and testing appear feasible for a small-scale evaluation. These strategies do not have any valid safety evaluations or large-scale applications and warrant pilot studies to help elevate them to the category of Proven strategies.
- **Proven (P)**—Strategies that have been used in more than one location and for which properly designed evaluations were conducted to show their level of effectiveness. A user can apply a proven strategy with some level of confidence, but is also aware of appropriate applications as a result of these previous studies.

The roadside-object literature review included in this report focuses on proven safety strategies for urban roadside safety; however, Tried and Experimental strategies are also included in an effort to provide a comprehensive listing of known or perceived applications. In addition, this chapter reviews the following:

- Roadside crash statistics, in an effort to identify the specific nature of roadside crashes in urban areas;
- The various strategies currently in use in urban environments to keep vehicles from leaving the travelway; and
- General information, safety research, and proposed safety strategies for a variety of potential roadside objects common to the urban environment.

Although this review targets the design of roadsides in *urban* areas, much of the literature on roadside design has been based on studies of rural environments. As a result, the literature on rural roadside safety is included when it is applicable.

Finally, this review focuses specifically on those roadways classified as urban arterials, collectors, and local streets because urban stakeholders are most vocal about wanting roadside treatments that balance the demands of agencies, stakeholders, and users on these roadways. While highways, freeways, and other high-speed, limited-access roadways may have important roadside safety issues, the design of such roadways is outside the scope of this study.

Examining Roadside Safety in Urban Environments

The majority of travel undertaken in the United States occurs on urban roadways. Of the 2.9 trillion miles of travel in 2003, roughly 1.8 trillion—62 percent—occurred in urban areas (*4*). Urban roadways experience higher levels of traffic congestion, particularly during morning and evening peak periods, and are much more likely to incorporate multimodal travel, including transit, bicycling, and walking. Trip characteristics differ as well. While rural roadways experience more freight and long-distance, inter-regional trips, most urban travel is characterized by intra-regional travel, particularly household-related travel, such as work or shopping trips. Thus, it is not surprising that the nature of urban roadside crashes may also differ from the nature of rural roadside crashes.

When one compares fatal crash frequency in rural areas with crashes in urban areas, it is clear that fatal rural roadway crashes occur more often than fatal urban roadway crashes. While on-roadway crashes are slightly more frequent in rural areas, off-roadway crashes, which include rollover as well as fixed-object crashes, are considerably more frequent in rural areas. In the categories of fixed-object and rollover crashes only, fatal crashes are still more frequent in rural environments. Approximately 60 percent of fatal fixed-object crashes and 77 percent of fatal rollover crashes occurred in rural environments.

Although focusing solely on fatal crashes risks underestimating the likelihood of a roadside crash for urban areas, fatality crash information is dependably reported and does provide some indication regarding crash trends. Table 3 shows fatal crash conditions for common roadway classes for urban and rural environments. Fatal fixed-object crashes for the roadway classes shown are more pronounced in rural areas.

Pedestrian and bicycle fatalities, on the other hand, are much more of an urban problem. For the road classes under consideration, fatal pedestrian crashes are almost twice as likely to occur in urban environments as in rural ones. Pedestrian and bicycle activity is more common in urban environments, and the increased presence of pedestrians and bicyclists increases the possibility that such a crash will occur.

In general, fatal crashes with most types of fixed objects occur more often in rural environments than in urban ones (see Table 4). When one considers specific roadway classes, however, several exceptions emerge, particularly on roadways

Table 3. Fatal crash conditions on arterial, collector, and local roads (2005).

Crash Condition	Rural					Urban				
	Principal Arterial	Minor Arterial	Collector	Local	Total Rural	Principal Arterial	Minor Arterial	Collector	Local	Total Urban
Motor Vehicle Collision	2,256	1,912	2,211	891	7,270	2,262	1,442	447	877	5,028
Ped/Bike	269	221	377	322	1,189	1,353	865	257	748	3,223
Overturn (Rollover)	472	420	905	560	2,357	153	116	57	184	510
Fixed Object	821	1,088	2,740	1,811	6,460	805	851	442	1,058	3,156
Other Causes	119	154	271	270	814	145	148	66	266	625
Total	**3,937**	**3,795**	**6,504**	**3,854**	**18,090**	**4,718**	**3,422**	**1,269**	**3,133**	**12,542**

Source: Fatality Analysis Reporting System (*118*).

classified as minor arterials. As depicted in Table 4, principal arterials in urban areas have fatal crashes involving utility poles, light poles, and sign poles more often than their rural counterparts.

Preventing Vehicles from Leaving the Travelway

The logic behind keeping vehicles on the travelway is simple: if a vehicle does not leave the travelway, it cannot be involved in a roadside crash. The difficulty posed by strategies aimed at keeping vehicles on the roadway is that, unlike providing appropriate clear zones or effective impact attenuators, these strategies are oriented toward the driver rather than the vehicle.

The literature on roadside safety shows that, of the strategies identified in this report, knowledge on the design factors that may help prevent vehicles from leaving the roadway is the least developed. Typically, research has focused on the geometric characteristics of locations where vehicles leave the travelway and has found that a disproportionate share of these crashes is associated with shifts in the horizontal curvature of the roadway, particularly an isolated, sharp, horizontal curve. Approximately 45 percent of all fixed-object crashes (*5*) and up to 77 percent of tree-related crashes (*6, 7*) are due to vehicles traveling off the roadway on the outside of a horizontal curve.

Because of such findings, the principal design strategy for keeping vehicles on the roadway is to address horizontal shifts in the roadway. While eliminating the isolated sharp curve is perhaps the most effective treatment, such applications are often prohibitively costly for mitigating safety problems on existing roads. As an alternative, designers have adopted a secondary strategy, which is to delineate potentially hazardous environments, such as curves, using traffic control devices such as posted advisory speeds, chevrons, and other markings or strategies to more clearly indicate the edge of the travelway. Another secondary strategy that is commonly employed to alert drivers before their vehicle leaves the travelway is to place rumble strips on the shoulder of the roadway.

Delineate Potentially Hazardous Roadside Environments

A common practice in minimizing run-off-road crashes is to use signs to delineate potentially hazardous roadside conditions. Signs and other indicators are used to increase the driver's awareness of changes to the operating characteristics of the roadway. Under conventional practice, the delineation of hazardous roadside conditions is limited almost exclusively to the use of signs to denote shifts in the horizontal curvature of the roadway or other oncoming hazards. Other features, such as the physical characteristics of the surrounding roadway,

Table 4. Fatal fixed-object crashes on arterial, collector, and local roads (2005).

Fixed Object	Rural					Urban				
	Principal Arterial	Minor Arterial	Collector	Local	Total Rural	Principal Arterial	Minor Arterial	Collector	Local	Total Urban
Tree/Shrub	184	247	835	650	1,916	121	185	113	334	753
Utility Pole	39	73	181	138	431	103	116	59	119	397
Culvert/Ditch/Curb	143	237	583	401	1,364	240	239	111	242	832
Embankment	151	182	491	191	1,015	30	45	27	54	156
Guardrail	123	116	147	56	442	53	54	26	28	161
Building/Fence/Wall	30	50	160	110	350	40	46	26	82	194
Light/Sign Poles	86	84	139	95	404	108	81	36	72	297
Bridge	13	23	65	39	140	21	28	6	15	70
Other Fixed Object	52	76	139	131	398	89	57	38	112	296
Total	**821**	**1,088**	**2,740**	**1,811**	**6,460**	**805**	**851**	**442**	**1,058**	**3,156**

Source: Fatality Analysis Reporting System (*118*).

also may give drivers cues as to safe operating behavior. Many governing jurisdictions consider the design of the street and the surrounding environment collectively, thus taking advantage of environmental characteristics to alert the driver of safe operating behavior.

Identifying Hazardous Conditions Using Signage

A common practice aimed at keeping vehicles on the roadway is to post advisory speeds or other signage applications to denote potentially hazardous conditions. While such a practice makes sense, the inconsistency of the practice of posting advisory speeds (*8*) and the variability of posted speed limit practices (*9, 10, 11, 12*) have led drivers to regularly disregard speed signs.

Further limiting the effectiveness of the signage practice is the fact that drivers are not merely disregarding signs; they are failing to notice them. Studies have found that drivers typically comprehend only 56 percent of the signs posted along the roadway (*13*). Further, even when drivers are conscientious in their attempts to adhere to factors such as posted speeds, they naturally increase speeds toward the roadway's design speed when they begin to shift their concentration away from monitoring the speedometer (*14*). This has implications for both geometric design and broader design practice, as it indicates that violations of driver expectations may, to some extent, be directly associated with the design speed of the specific road. Overall, these findings suggest that signage and other similar applications may have only a moderate effect on preventing run-off-road events.

Enhancing Lane Delineation

Run-off-road crashes often occur during reduced visibility conditions (e.g., at dusk, dawn, and night, and during rain). Thus, enhanced lane delineation may help keep an alert driver from departing the road unexpectedly. There are several methods for improving lane delineation in urban areas. These may include curb lines, edge striping, street lighting, reflective pavement markers, and pavement texture and/or color treatments.

The location of a concrete curb adjacent to an asphalt road is common for many urban regions. The contrasting light color of the curb helps define the edge of the travelway. In regions where both roads and curbs are made of concrete, the face of the curb may sometimes be painted to create a contrast. One disadvantage to using the curb line as the sole method for lane edge delineation is that frequent curb cuts or disruptions (at driveways or pedestrian crossing locations) may misdirect drivers who are fatigued or impaired. Information about the curb condition as a common urban roadside feature is included later in this chapter.

In rural and select urban environments where roadways do not have curb lines, a common method for lane edge delineation is edge striping (using reflective paint for low-volume roads and thermoplastic stripes for more densely traveled facilities). The use of edge striping in the urban environment varies. Many jurisdictions elect to use edge striping for major facilities only and allow the standard center striping combined with the curb line to delineate lane edges for lower speed local roads.

A common strategy for enhancing roadway visibility on urban streets is the use of street lighting. This not only illuminates the travelway, but also provides safety and security for adjacent pedestrian facilities. Lighting is further discussed later in this chapter.

The use of reflective pavement markers (raised or snowplowable) can also help delineate the vehicle travelway. These pavement markers often require regular maintenance (for lens replacement or replacement of missing markers), so extensive use of reflective pavement markers is generally reserved for high-volume locations or for locations that are perceived to be high risk.

Finally, many jurisdictions are experimenting with alternative pavement treatments. The use of skid-resistant pavement surfaces has been a common recommendation for minimizing run-off-road crashes during inclement weather (*1*); however, an additional strategy is to change actual pavement color or pavement type at critical locations such as pedestrian crosswalks (for transverse delineation) and pavement edge (for longitudinal delineation). The City of Charleston, South Carolina, has maintained several cobblestone roads in their historic peninsula district. These roads serve to clearly identify the motor vehicle space from the adjacent pedestrian space and also provide the added benefit of dramatically slowing motor vehicle operating speeds on these roads. The rough cobblestone pavement treatment is not conducive, however, to safe bicycle activity. In Denmark, the road surface treatments help road users to clearly define who is to use a specific area of the road system. These road surface treatments also help to define transitions from public to private space (*15*). Variations in road surface can be achieved by using patterns, textures, and similar treatments.

Taking Advantage of Characteristics of the Surrounding Environment

While signage is most typically used to delineate hazardous conditions, the FHWA scan of European practice suggests that signage is only one means of informing the driver of changes in appropriate driving behavior (*16*). Drivers are monitoring both traffic signs and the physical environment as part of the driving task. While adequate signage is important for encouraging safe driver behavior under changing environmental conditions, environmental hazards are signaled by more than just the signs posted adjacent to the travelway. The geometric design of the roadway and the characteristics of the surrounding environment provide the driver with cues regarding safe operating behavior.

One observation from the previously mentioned scanning tour was that Europeans try to make the entire roadway send a clear and consistent message regarding safe operating behavior. Thus, design speeds are related to the physical environments in which the roadways are located, and the posted speed is meaningfully related to both. Typically, European design guidance specifies tight design ranges for each roadway class, with a range of typically not more than 20 km/h (approximately 12 mph) for any single road type in the urban environment. By narrowly specifying an appropriate design speed range, designers are able to minimize the instances—such as an isolated sharp curve—that may be a potential hazard.

An important aspect of this European practice is that it is adopted for the purposes of enhancing the safety of the roadway. Agencies adopting such practices typically aim to achieve, at a minimum, a 40-percent reduction in crashes over a 5-year period, and, in many cases, agencies aim to have zero fatalities over a 10-year period (*16*).

In a study of how people conceptualize urban environments, Kevin Lynch found that features such as architecturally unique buildings, key viewsheds, and other environmental stimuli serve as central reference points by which individuals orient themselves and cognitively map their travel progress (*17*). The observation that such features figure prominently in the way individuals visualize their travel activity suggests that environmental features provide drivers with important cues regarding appropriate driving behavior. The use of environmental factors to help inform drivers of safe operating conditions has received little attention in the literature (*18*), although the field of traffic psychology has begun to strongly encourage the use of environmental features as a key strategy for enhancing transportation system safety (*19*). Transit New Zealand's *Guidelines for Highway Landscaping* encourages agencies to use highway planting to help drivers understand the road ahead (*20*). Plantings are recommended to help with curve delineation, headlight glare reduction, visual containment, and speed awareness and stimulation.

In 2001, the City of Las Vegas, Nevada, developed a guide for neighborhood traffic management. For this effort, they performed a community survey in which respondents rated pictures of various street cross sections (*21*). The most popular images were tree-lined streets in residential areas and commercial buildings placed close to the road in business districts. Both the trees and buildings provide a sense of enclosure that frames the street and narrows the driver's field of vision. The Las Vegas guide further suggests that when the buildings are set farther back from the street, the roadway appears to be wide and conducive to excessive speeds. The enclosed environment helps to mitigate speeding. In New Zealand, this enclosed environment is captured using a vertical elements technique in which the heights of vertical features are designed to be greater than the width of the street to provide the optical appearance of a narrow street (*22*). These vertical elements can include trees, light poles, and other elements as long as the human-made objects are frangible, and trees or shrubs have narrower trunks and do not interfere with sight lines.

Rumble Strips

Physical rumble strips are grooves placed into the roadway or paved shoulder and are aimed at alerting the driver of potentially hazardous conditions (see Figure 1). A similar alert can also be achieved using thermoplastic rumble strips which are generally placed on the surface of the road in conjunction with lane edge delineation. While transverse rumble strips are often used for purposes such as alerting the driver of a downstream stop condition such as a toll booth or a stop-controlled intersection, longitudinal rumble strips are also effective for alerting the driver that he or she is leaving the travelway. Although rumble strips do not have speed-reducing capabilities (*23*), they cause a vehicle to vibrate and make noise when it crosses over them, thereby signaling to the driver that greater attention to the traveling environment is warranted. The sound made by a vehicle crossing rumble strips typically does not exceed that of the ambient sound experienced by the driver (*24*); thus, the ability of rumble strips to alert drivers

Photo reprinted from "New Focus for Highway Safety." (*119*)

Figure 1. Rumble strips.

to hazardous conditions is largely restricted to the vibration the rumble strips produce. This vibration is nevertheless a substantial cue for increasing the driver's awareness of the roadway environment. Several studies of the effectiveness of rumble strips have determined that placement of rumble strips can decrease the number of run-off-road crashes between 30 and 85 percent (*25, 26*).

Applicability of Shoulder Rumble Strips to Low-Speed Urban Roadways

While shoulder-based rumble strips have proven effective in reducing run-off-road crashes on interstates and freeways (particularly in rural environments), their applicability to lower-speed roadways may be limited. The use of physical (grooved) shoulder rumble strips assumes the existence of a level, paved shoulder. In many urban environments, raised curb is used in lieu of shoulders. This prevents the possibility of introducing physical rumble strips as a potential treatment for eliminating run-off-road urban crashes; however, thermoplastic rumble strips may be used in the urban setting to achieve a similar result.

Another issue affecting use of shoulder rumble strips in urban areas is that when a shoulder is available in urban areas, in many cases it serves as a travelway for bicyclists (*27*). Beyond the physical unpleasantness that rumble strips may pose for the bicyclist, the application of rumble strips can potentially result in the loss of control of the bicycle (*28*). Given the potentially negative influence on bicycle use in urban areas, as well as the frequent use of raised curb, the use of shoulder rumble strips is typically not appropriate on low-speed urban roadways.

Finally, a common complaint about rumble strips in urban environments is that the noise they generate disrupts the peaceful environment of the adjacent land and the residents of the area (particularly during the quieter night hours). This perceived adverse affect on adjacent property owners resulting from the use of rumble strips also limits their use in urban areas.

Mid-Lane Rumble Strips

A potential rumble strip treatment that may be more applicable to urban roadways—particularly urban arterials—is the use of mid-lane rumble strips. In this treatment, rather than applying rumble strips to the shoulder of the road, rumble strips are placed in the center of the vehicle travel lane. In this application, as vehicles leave their travel lane, their tires cross over the rumble strips, thereby producing the sound and vibration associated with shoulder rumble strips, without requiring a shoulder-based treatment (*25*). While mid-lane rumble strips are largely untested, they nevertheless present possibilities for improving roadside safety in urban areas. Placing a mid-lane rumble strip in the outside travel lane can be used to produce the same effect on the vehicle as a shoulder-based treatment (i.e., sound and vibration) without necessitating a roadside treatment.

The use of a mid-lane treatment raises two potentially important questions. First, what is the appropriate location of such a treatment for a curbed urban roadway? Second, what are the impacts of such a treatment on motorcyclists? In the case of roadways where the shoulders are curbed, or where there is a limited operational offset, the mid-lane rumble strip can be oriented to correspond to the expected location of the left tire of the roadway's design vehicle. In these cases, the narrowest vehicle—a passenger vehicle—is the appropriate design vehicle for the treatment. Thus, the left tire of passenger vehicles will be used to delineate the appropriate position of mid-lane rumble strip treatments (or the right tire, assuming a treatment oriented toward preventing a crash into the median). While such an application will do little to address the safety needs of larger design vehicles, it should, nevertheless, have an effect on decreasing the rates of passenger-vehicle run-off-road crashes.

Addressing the needs of motorcyclists is more difficult. While it has been demonstrated that motorcyclists can safely navigate rumble strips (*24*), the vibration associated with rumble strips can create discomfort when the rider is forced to travel over them for prolonged periods. An assumed minimum motorcycle tire width of approximately 13 cm (5 in.) can reasonably be accommodated with a left- or right-tire offset on a 3-m (10-ft) travel lane. Nevertheless, such an application should be further researched before being employed in practice.

While the use of mid-lane rumble strips seems promising, it is important to consider the longer-term behavioral impacts that may result from a widespread use of mid-lane rumble strips. In urban areas, travel is often characterized by frequent lane changing. Where mid-lane rumble strips are common, drivers may become acclimated to the sound and vibration they produce and cease to treat them as special events that require increased attention to the driving task. In addition, the placement of mid-lane rumble strips should not occur at locations of heavy pedestrian activity, such as mid-block pedestrian crossings. Both the raised and grooved rumble strips create a potential tripping hazard for pedestrians by introducing an uneven walking surface.

Safety of Urban Roadside Elements

An urban environment is characterized by many potential roadside hazards. To improve roadside safety, many of these objects can be removed or relocated; however, it is probable that numerous prospective roadside hazards must be retained to facilitate the needs of the community or the road users. As a result, this chapter reviews known roadside objects and strategies that may help improve the safety of their placement. Table 5 provides an overview of common urban roadside features and features often sought by local stakeholders to increase the aesthetic quality of urban roadsides. Each of these items is reviewed in greater detail in this chapter.

Removal/Relocation/Placement of Roadside Objects

Engineers are encouraged to identify potentially dangerous objects adjacent to the travelway and remove them, ideally through the use of a clear zone. The recommended standard practice for higher-speed roadways is the provision of a lateral clear zone that will enable at least 80 percent of errant vehicles to stop or return to their travel lane safely. The appropriate width of clear zones is ultimately based on the slope of the roadside, daily traffic volumes, and speed (*1*).

The opportunities for providing a clear zone in urban areas are often limited due to the restricted width of the existing right-of-way and the density of adjacent roadside development. Use of the available right-of-way includes many competing demands. Further, many communities seek to provide a physical buffer zone adjacent to the travelway to encourage pedestrian activity or to enhance the aesthetic quality of the roadway. Often, this involves the planting of trees or inclusion of landscaping in a buffer area between the sidewalk and the vehicle travelway. Placement of mature street trees in close proximity to the road can present a hazard to the motorist. Minor departures from the travelway under these conditions can result in a potentially serious fixed-object crash, particularly at high speeds. Often, a configuration with rigid objects located immediately adjacent to the travelway is a result of a road-widening project where the only way to accommodate increasing vehicle capacity demands within the constraints of the current transportation infrastructure was by further encroaching on the existing roadside (*29*).

Under current urban roadside design guidelines, engineers are provided with a special designation, the *operational offset*, which effectively permits the location of fixed objects 0.5-m (1.5-ft) from the curb face (*1, 30*). This offset value is a minimum suggested distance associated with avoiding such operational issues as car-door and vehicle mirror conflicts with roadside objects and minimizing the impact to traffic operations; it is not provided for safety purposes (*31*). The operational offset should not be considered as an acceptable clear zone, but simply as a minimum value to ensure elimination of traffic operational conflicts. Where a clear zone cannot be achieved, the individual road should be tailored for the conditions at a specific site. The influence of supplemental factors such as crash history, future traffic, and heavy vehicle presence should be included in the decision process.

For evaluation of changes to the roadside such as removal of potential hazards, an engineer must determine whether the benefits associated with relocating a hazardous object outweigh the cost of doing so. The “cost” may take many forms, such as societal impacts or actual removal dollars, so elaborate cost-benefit methodologies have been developed to estimate the relative benefits of removing these objects (*29, 32, 33, 34, 35*).

If a potentially hazardous object must be located adjacent to the travelway, the principal means of addressing run-off-road crashes where adequate clear zones cannot be provided is to ensure that any object placed in the clear zone is “crashworthy,” that is, any object located in the clear zone is designed to minimize the severity of a potential crash. *NCHRP Report 350* (*36*) provides specific standards and test conditions, such as soil and vehicle specifications, that are used for evaluating the crashworthiness of roadside fixtures such as guardrails, utility poles, and light supports. The reader is referred to *NCHRP Report 350* for a full consideration of the test specifications used in the evaluation of crashworthiness.

Two strategies exist, both of which are subject to the test conditions contained in *NCHRP Report 350*. The first is to incorporate *frangible* roadside objects and hardware into the

Table 5. Common urban roadside features.

Features Immediately Adjacent to the Travelway	*Safety Barriers*
Curbs	Barriers and Guardrails
Shoulders	Bridge Railings
Channelization	Crash Cushions and End Terminals
Medians	
Roadside Grading	
Static Roadside Objects	*Dynamic Roadside Features*
Mailboxes	Bicycle Facilities
Landscaping, Trees, and Shrubs	Parking
Street Furniture	Sidewalks and Pedestrian Facilities
Utility Poles, Luminaires, and Sign Posts/Hardware	

design of the roadside environment, and the second is to *shield* or cushion potentially hazardous objects and environments.

A more detailed description of known safety strategies for the various urban roadside elements previously identified in Table 5 is presented in the following sections.

Features Immediately Adjacent to the Travelway

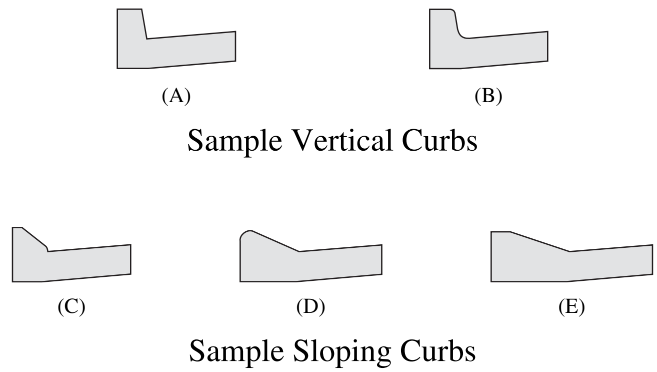
Physical features immediately adjacent to the travelway are the first objects encountered when an errant vehicle exits the road. These features can include curbs, shoulders, channelized islands, medians, and roadside grading. This section reviews each feature and known safety issues regarding each item.

Curbs

General information. Much of the rural research regarding pavement edge treatments evaluates the influence of graded or paved shoulders on safety performance at the time a vehicle enters the roadside environment. In an urban environment, very few road edge treatments include roadway shoulders as a transition from the travel lanes to the adjacent roadside environment. Instead, curb is commonly used in urban environments as it can help direct storm drainage (thereby reducing the need for roadside ditches and wider right-of-ways) and provides visual channelization to help delineate the pavement edge. There is, therefore, a need to understand the safety of curbs in the urban environment.

An important issue of concern for addressing roadside safety at curbed locations is the influence that various curb types may have in causing vehicles to trip or launch during a run-off-road event where the "first harmful" object the vehicle encounters is the roadside curb. The vertical curb has an almost vertical face and is generally between 150 to 225 mm (6 to 9 in.) in height above the driving surface of the adjacent pavement. The vertical curb is used as a means for discouraging motorists from intentionally leaving the roadway. A sloping curb has an angled surface, a height of 150 mm (6 in.) or less, and is designed for use on higher-speed roadways (greater than 70 km/h [approximately 45 mph]) or at locations where a vehicle may need to leave the roadway for emergency purposes. The sloping curb is designed so that a vehicle can traverse the curb without damaging the vehicle (*30*). Curbs "A" and "B" in Figure 2 depict example vertical curbs, while Curbs "C" through "E" represent various sloping curb configurations.

The AASHTO publications *A Policy on Geometric Design of Highways and Streets* (referred to hereafter as the *Green Book,* [*37*]) and the *Roadside Design Guide* (*1*) both indicate that a vertical curb, struck at higher speeds, may cause an errant vehicle to mount and/or launch. The *Roadside Design Guide*



Graphic adapted from *A Policy on Geometric Design of Highways and Streets, 4th ed.* (*37*).

Figure 2. AASHTO example curbs.

currently provides the following recommendations for the design of vertical curbs (*1*, p. 10–7):

> At speeds over 40 km/h (25 mph), a vehicle can mount the curb at relatively flat angles. Consequently, when sidewalks or bicycle paths are adjacent to the traveled way of high-speed facilities, some provision other than curbing may need to be made for the safety of pedestrians and bicyclists.

The *Roadside Design Guide* further suggests provision of a minimum horizontal clearance of 0.5 m (1.5 ft) beyond the face of curbs to any obstructions. This distance is the operational offset previously discussed.

The *Green Book* recommends the use of curbing on roadways with speeds of approximately 73 km/h (45 mph) or less (*37*). The *Green Book* further notes that when vertical curbs are used on these lower-speed roadways, placement of vertical curb will preferably be offset 0.3 to 0.6 m (1 to 2 ft) from the edge of the travelway. The *Green Book* recommends against the use of curbs along high-speed arterials such as freeways, but indicates that when used on these facilities, a curb "should be of the sloping type and should not be located closer to the travelway than the outer edge of the shoulder." (*37*, p. 322)

A Guide for Achieving Flexibility in Highway Design (*31*) also indicates that vertical face curbs at low-speed (40 km/h [25 mph] or less) locations have limited redirectional capabilities for errant vehicles. For speeds above 40 km/h (25 mph), the curb can influence driver behavior, but does not provide a vehicle redirection function.

Safety research. The research supporting the statements summarized above and found in common design guidelines spans curb crash testing and computer modeling over a period of many years. However, crash testing standards, computer modeling capabilities, and typical study vehicles have changed during this period. In general, researchers have performed testing on vertical curbs, sloping curbs, and curbs with adjacent barriers such as guard rails. In 1972, Dunlap et al. (*38*) performed several roadside curb evaluations including tests for five standard curbs and eight curb/guardrail combinations. In 1974, Olson et al. (*39*) evaluated curbs using crash testing combined with computer simulation. These two research studies were among the first to suggest the following commonly accepted concepts regarding curb safety:

- Curbs 150 mm (6 in.) tall or less do not redirect vehicles at speeds above 73 km/h (45 mph) and should therefore not be used for high-speed roads,
- Impacting curbs 150 mm (6 in.) tall or less will generally result in either no injury or minor injuries only, and
- Combinations of lower speeds and small approach angles produce the greatest effect on vehicle path correction.

A study performed in the 1970s at the Texas Transportation Institute evaluated curb placement in conjunction with traffic barriers and sloped medians (*40*). The researchers concluded that the traffic barriers should not be immediately adjacent to curbs as vehicles may vault or underride the barrier. They also concluded that grading the median or roadside level with the top of the curb will help reduce problems with barriers and guardrail interactions near curbs.

An evaluation performed for the Nebraska Department of Roads (NDOR) included crash tests as well as simulations of sloping curbs and curb-guardrail combinations (*41*). The researchers' evaluation included various degrees of impact and vehicle trajectory. They concluded that the three sloping curbs tested (two NDOR standard curbs and one AASHTO standard curb) were traversable for a wide range of impact conditions and had very little likelihood of causing vehicle rollovers. The researchers further determined that the chance that a vehicle could underride a guardrail was slight, and the chance that a vehicle would be vaulted by the curb-guardrail combination was greatest when the barrier was located anywhere from 0.45 to 3.7 m (1.5 to 12.1 ft) behind the curb. This range of offset values applied to both a small and a large test vehicle.

A report commissioned by the Florida Department of Transportation (*42*) simulated the trajectories of three design vehicles hitting sloped (125 mm [5 in.] tall) and vertical (150 mm [6 in.] tall) curbs at approach speeds of approximately 57, 73, and 90 km/h (35, 45 and 55 mph) and impact angles ranging from 3 to 15 deg. The model results found that the vertical curbs would deflect the Ford Festiva test vehicle for all approach speeds at angles of impact up to 12 deg. For a Chevy C2500 pickup, the vertical curb would deflect vehicles operating at 90 km/h (55 mph), but only when the angle of impact was 3 deg or less. The sloping curb was not shown to redirect the vehicle under any combination of approach speed or angle. None of the impacts were shown to result in a rollover or substantial vertical displacement of the vehicle, nor were the events shown to result in more than minor damage to the vehicle.

The AASHTO *Highway Safety Design and Operations Guide* (*30*) indicates that the potential for vehicle vaulting or rollover for curbs higher than 100 mm (4 in.) is a factor of the vehicle's weight, speed, suspension system, angle of impact, and vehicle lane tracking. As a result, small cars are generally overrepresented in serious curb-related crashes. The potential for a vehicle to vault precludes the exclusive use of a curb as sufficient protection for pedestrian facilities or roadside elements.

In 2005, Plaxico and colleagues published *NCHRP Report 537: Recommended Guidelines for Curb and Curb-Barrier Installations* in which they evaluated roads with operating speeds of 60 km/h (40 mph) or greater and the potential influence of curb or curb-barrier combinations at these locations (*43*). They determined that the most significant factor influencing vehicle trajectory is curb height. As a result, shorter curbs with flatter sloping faces should be used at higher speed locations. They also determined that a lateral distance of approximately 2.5 m (8.2 ft) is needed for a traversing vehicle to return to its predeparture vehicle suspension state. As a result, guardrails should not be placed closer than 2.5 m (8.2 ft) behind curbs on roads where vehicle speeds are greater than 60 km/h (40 mph). As the research performed by Plaxico and colleagues did not focus on low-speed roads, the placement of guardrails behind curbs for speeds lower than 60 km/h (40 mph) is not known.

In summary, curbs can provide positive (visual) guidance for drivers, but curbs do not have the ability to redirect errant vehicles upon impact (unless the vehicle speed is quite low and the vehicle impact angle is extremely small). If an errant vehicle approaches the curb at a small deflection angle, the impact of the curb is unlikely to be the cause of serious injury to the vehicle occupants; however, the curb may affect a vehicle's trajectory, resulting in impact with a second, more substantial roadside hazard. A barrier or guardrail must be placed behind the curb in such a way as to avoid vaulting the errant vehicle.

Strategy summary. A variety of strategies have been proposed, applied, and/or tested for safe application of curb treatments. Common strategies are as follows:

Purpose	Strategy
Prevent curb from vaulting vehicles	• Use appropriate curb heights with known influences on vehicle trajectories (P) • Locate barriers behind curbs an appropriate distance to improve curb-barrier interactions (P) • Grade adjacent terrain flush with the top of the curb (P)

Shoulders

General information. The common edge treatment for urban roads is a curb or curb with gutter; however, many roads exist in urban environments with a graded or paved shoulder instead of a curb located immediately adjacent to the travelway. The purpose of a shoulder is to provide a smooth transition from the travelway to the adjacent roadside while facilitating drainage and promoting various other shoulder functions (as listed in Table 6). The shoulder width is included as part of the clear zone width; therefore, the values shown in Table 6 should not be confused with clear zone requirements. There are many recommendations regarding appropriate shoulder widths for lower speed roads. These widths vary depending on the function of the shoulders as well as the available right-of-way. Table 6 shows suggested shoulder widths from the AASHTO publication *A Guide for Achieving Flexibility in Highway Design* (*31*). This information was first compiled for a 1982 NCHRP study (*44*). These widths are recommended for shoulder functional use and do not reflect identified widths for safety purposes.

Because right-of-way costs are high in urban environments, the use of paved or graded shoulders in these environments often is the result of previously rural roads being incorporated into urbanized land use without the companion roadway improvements. Often the road with a shoulder will have a drainage ditch located parallel to the road, so care must be taken to maintain traversable conditions in the event that an errant vehicle exits the road, travels across the shoulder, and then encounters the roadside grading.

There are many research studies that have evaluated the safety benefits of shoulders and companion shoulder widths. Several of these studies are included in the safety research section that follows.

Safety research. The research regarding shoulder safety has been generally divided into three categories—safe shoulder width, pavement edge treatments, and safety of paved versus graded shoulders. The research regarding these three areas of shoulder safety is summarized in the following:

- **Safe shoulder width.** Much of the research into the appropriate width of shoulders focuses on the high-speed rural condition. Early research indicated that crash frequency tended to increase with shoulder width. For example, Belmont published a paper on rural shoulder widths in 1954 and a subsequent paper in 1956 (extending the study to lower volume rural roads) and suggested that wider shoulders for higher speed, high-volume rural roads resulted in increased crash rates, while the trend appeared reversed for lower volume, high-speed roads (*45, 46*). Subsequent to these early studies, numerous researchers have studied the shoulder width question. In an unpublished critical review of research in this area (*47*), Hauer re-evaluated many of the original shoulder width studies using the original data and concluded that shoulder width safety is a sum of several opposing tendencies. These can be summarized as follows:
  – The shoulder is even and obstacle free and available for drivers of errant vehicles to use to regain control of their vehicles, correct for their error, and resume normal travel;

Table 6. Acceptable shoulder widths for shoulder functions.

Shoulder Function	Functional Classification Arterial m (ft)	 Collector and Local m (ft)
Drainage of Roadway and Shoulder	0.3 (1)	0.3 (1)
Lateral Support of Pavement	0.45 (1.5)	0.3 (1)
Encroachment of Wide Vehicles	0.6 (2)	0.6 (2)
Off-tracking of Wide Vehicles	0.6 (2)	0.6 (2)
Errant Vehicles (Run-off-road)	0.9 (3)	0.6 (2)
Bicycles	1.2 (4)	1.2 (4)
Pedestrians	1.2 (4)	1.2 (4)
Emergency Stopping	1.8 (6)	1.8 (6)
Emergency Vehicle Travel	1.8 (6)	1.8 (6)
Garbage Pickup	1.8 (6)	1.8 (6)
Mail and Other Deliveries	1.8 (6)	0.6 (2)
Emergency Call Box Services	2.4 (8)	1.8 (6)
Law Enforcement	2.4 (8)	1.8 (6)
Parking, Residential	2.4 (8)	2.1 (7)
Routine Maintenance	2.4 (8)	1.8 (6)
Major Reconstruction and Maintenance	2.7 (9)	2.7 (9)
Parking, Commercial	3.0 (10)	2.4 (8)
Parking, Trucks	3.0 (10)	N/A
Slow-Moving Vehicles	3.0 (10)	2.7 (9)
Turning and Passing at Intersections	3.0 (10)	2.7 (9)

Sources: Adapted from *A Guide for Achieving Flexibility in Highway Design* (*31*) and *NCHRP Report 254: Shoulder Geometrics and Use Guidelines* (*44*).

– Wide shoulders may induce voluntary stopping and therefore place a hazard immediately adjacent to the travelway;
– Wide shoulders may entice drivers to use them as additional lanes or for passing maneuvers on the right; and
– Wider shoulders may encourage higher operating speeds.

Evaluation of crash data without comprehensively considering these four contrasting tendencies may permit researchers to arrive at a variety of conclusions regarding shoulder width safety. In general, on roads with wider shoulders, travel speeds are higher and crashes are more severe. However, wider shoulders result in fewer run-off-road crashes, and therefore this benefit must be included.

- **Pavement edge treatments.** A common problem with roadway shoulders is that they may not be flush either with the travelway pavement surface (for the case of graded shoulders) or with the adjacent roadside grading (for the case of paved shoulders). There are many reasons that pavement drop-offs may develop in the shoulder region. Erosion of the soil next to the pavement, rutting by frequent tire wear, and pavement overlay maintenance are examples of how, over time, a pavement drop-off may develop. When a drop-off is encountered by an errant vehicle, the vehicle's tires may have difficulty mounting the extra pavement lip, causing the vehicle to further lose control.

  In the late 1970s and early 1980s, researchers at Texas A&M University performed a series of evaluations on pavement edge drop-offs (*48, 49*). They determined that vertical drop-offs as small as 7.6 cm (3 in.) could result in a severe crash if encountered by an errant vehicle. The Texas A&M researchers developed pavement edge shapes to provide a more beveled edge and determined that for speeds up to 90 km/h (55 mph), a 45-deg angle could be applied to the drop-off. This sloped edge would then enable errant vehicles to regain access to the travelway safely. Currently, the Federal Highway Administration promotes a pavement edge treatment called the safety edge that uses a similar 45-deg angle with construction standards that permit compaction to provide pavement edge stability.
- **Safety of paved versus graded shoulder.** The safety of paved versus graded shoulders is less controversial than the pavement width consideration. Several studies have indicated that the addition of any paved shoulder will help with crash reduction. Zegeer, Deen, and Mayes concluded that increasing the width of a paved shoulder for rural roads by 0.3 m (1 ft) would reduce crashes by approximately 6 percent (*50*). They also concluded that paving at least 0.3 m (1 ft) of a shoulder would reduce crashes by 2 percent. More recently, McLean found that for Australian roads the application of sealed shoulders with widths from 1.5 to 2 m (5 to 6.6 ft) would result in a decrease in crash rates and, therefore, be a cost-effective treatment (*124*).

Strategy summary. Common shoulder treatment strategies are as follows:

Purpose	Strategy
Discourage run-off-road crashes	Provide wider shoulders suitable for shoulder function (P)
Provide traversable transition for errant vehicles	• Eliminate pavement drop-offs (P) • Add a pavement safety edge (T) • Provide a paved or sealed shoulder (P)

Channelization/Medians

General information. The separation of traffic movements by the use of a raised median or turning island is often referred to as channelization. For the purposes of this review, a flush or traversable median or island is considered part of the roadway, while a raised median and raised turn island are considered part of the roadside.

Channelized islands are generally used to reduce the area of pavement at an intersection while providing positive guidance to turning vehicles. Channelized islands can be used for pedestrian refuge and traffic control device placement, and they can also be planted with landscaping treatments that contribute to an improved visual environment (*15*). For a raised island to be visible, it should have a minimum size of 5 m^2 (50 ft^2) for urban conditions (*37*). The orientation of the curb on a raised island should be slightly skewed to the adjacent travel lane to give an illusion of directing vehicles into the travel lane. Other cross-sectional characteristics of raised islands are similar to those of raised medians.

The raised median provides the primary function of separating opposing directions of vehicle travel. This physical separation has the added benefit of improving access management (restricting frequent left turns into driveways), providing a location for pedestrian refuge (assuming the median has adequate width), and providing road edge delineation during inclement weather conditions (particularly snow). A median may simply be raised using a vertical or sloped curb. In urban regions, median width can vary dramatically depending on the proposed function of the median. As suggested in the Maryland publication, *When Main Street Is a State Highway: Blending Function, Beauty and Identity*, the use of a median can dramatically improve the visual quality of a facility (*51*).

Safety research. Many of the recent research studies about raised median safety focus on the influence of the median on access management and the resulting reduction of crashes due to restricted left-turn movements. Although this crash reduction strategy falls outside the scope of this literature review, it is worth noting that the median condition has added safety benefits that should be considered in a comprehensive crash evaluation. In this review, however, the evaluation will be focused on median crashworthiness for the purposes of roadside safety.

In general, median research (excluding access management studies) has focused on the crash condition with specific attention to the following questions:

- Do medians prevent pedestrian cross-median crashes? What is the influence of a median barrier that completely prohibits pedestrian crossing?
- Do medians reduce the number of crashes and crash severity?
- Can landscaping and trees be safely located in medians?
- Should median barriers be used to improve median safety?

A median barrier review is included later in this chapter in the section on safety issues, so this section focuses on the influence of a median on crashes and landscaping treatments. Several researchers have weighed the merits of a raised median (divided highway) versus no median or a flush median. Unfortunately, in most of the before-after research studies, a jurisdiction was implementing a median improvement in conjunction with other improvements, such as road widening, lane narrowing, and so forth. As a result, the influence of divided versus undivided has resulted in a wide variety of crash observations. Harwood (*52*) studied several median conversion configurations from undivided to divided operations. After controlling for a variety of variables, he concluded that the influence of the median on safety was small. Many studies have resulted in similar observations, that is, that raised medians have a negligible effect on crash frequency. Crash severity varies depending upon the median width (wider medians reduce the chance for head-on collisions), the use of median barrier (to be discussed later), and the placement of rigid objects in the median area.

The issue of landscaping and the specific evaluation of tree placement are further discussed in the landscaping section; however, a recent three-phase study performed at California Polytechnic State University (*53*) specifically evaluated the placement of large trees in raised medians on urban and suburban highways. They evaluated sites with and without large trees and determined that at a 95-percent level of statistical confidence, an increased number of fatal or injury crashes were associated with the presence of median trees. The association between median tree crashes and left-side-only crashes, however, was only marginally significant. The three-phase study also indicated that median trees on urban and suburban highways were associated with an increase in collision frequency. Study researchers were not able to identify any systematic relationships between the left-side crash rates and median widths or tree setbacks. They also found that with the increase in fixed-object collisions came a decrease in head-on and broadside collisions. Finally, the researchers found non-intersection locations with median trees were positively associated with hit-pedestrian collision.

Another common application for raised medians is as one element in a gateway treatment at transition locations between rural and urban areas. The raised median studies for the purpose of use as gateway strategies are reviewed later in this chapter in the section discussing traffic calming applications.

Research into appropriate median widths for safety purposes are focused primarily on the high-speed rural condition. Similar median width studies for urban environments are not available.

Strategy summary. Common channelized island and median strategies are as follows:

Purpose	Strategy
Reduce likelihood of run-off-road collision	Widen median (T)
Reduce crash severity	• Place only frangible items in channelized island or median (P) • Shield rigid objects in median (P)

Roadside Grading

General information. The terrain adjacent to an urban road should be relatively flat and traversable. In general, the placement of common urban roadside features such as sidewalks and utilities tends to create a flatter urban roadside. The primary risk for irregular terrain adjacent to the travelway is that an errant vehicle will either impact a rigid obstacle or that the terrain will cause the vehicle to roll over. Rollovers were responsible for 20 percent of the fatal crashes in 2002, and the largest number of rollovers occurred after a vehicle impacted an embankment or a ditch (*25, 54*). The principal cause of rollovers is a vehicle "tripping" on an element of the roadside environment, such as a ditch or an embankment; nevertheless, sharp pavement drop-off on the shoulder may also lead to vehicle tripping for roads without a curb. To prevent vehicle tripping, the grade of ditches, slopes, and embankments should be minimized as much as possible, and pavement drop-offs must be kept to a minimum.

These strategies are potentially more relevant to rural and suburban environments than to urban ones, however. In urban areas, the roadside is typically characterized not by shoulders and embankments, but by curb and gutter applications and by adjacent roadside development. This is evidenced when one compares the absolute number of rollover crashes in urban environments with the number of rollover crashes in rural environments. In 2002, there were roughly 1,800 rollover crashes in urban areas, compared with over 6,200 for rural regions. Accounting for exposure, roughly one rollover per billion miles of travel occurs in urban areas whereas almost six rollovers per billion miles of travel occur in rural environments.

While the conditions that lead to rollover crashes are not clear, crash data analyses indicate that these crash types are generally associated with high-speed travel. Of the roughly 8,000 rollovers that occurred in 2002, only about 600 occurred on roadways classified as urban minor arterials, collectors, and locals.

The sideslope of an urban road should, in general, slope from the edge of the right-of-way toward the curb of the road. This slope will prevent any road drainage from encroaching on adjacent property and enables the drainage to be contained within a closed drainage system. As a result, the slope is often quite flat (1V:6H typically) for curbed urban roads. For roads without a curb, the design guidelines for rural roadside conditions should be applied. That is, the terrain, including drainage channels, should be safely traversable by a motor vehicle, and the placement of obstacles such as headwalls must be flush with the ground surface and designed to be navigated by an errant vehicle.

Safety research. The research team was not able to locate research specific to the urban roadside slope and safety implications associated with this terrain. Most of the studies applicable to the urban condition focused on the presence of roadside obstacles rather than the companion roadside slope.

Strategy summary. Common grading strategies are as follows:

Purpose	Strategy
Minimize crash likelihood	Maintain traversable grades that are free of rigid obstacles (P)
Minimize crash severity	• Flatten grades to reduce chance of vehicle rollover (P) • Create an object setback policy (T)

Static Roadside Treatments

Mailboxes

General information. The *Roadside Design Guide* (*1*) details the preferred specifications for the design and installation of mailboxes. In general, AASHTO recommends the use of a 100-mm by 100-mm (4-in. by 4-in.) wooden post or a 38-mm (1.5-in.) light-gauge pipe for mounting mailboxes, with these posts embedded no deeper than 600 mm (24 in.) in the ground. Mailboxes should further be mounted to their supports to prevent the mailbox from separating from the post during a crash event. Also of concern is the potential hazard associated with larger mail collection boxes, a common feature in urban environments, as well as neighborhood delivery units, which are associated with apartment complexes. Crash tests of these features have shown them to fail safety requirements, and the *Roadside Design Guide* recommends placing them outside of clear recovery areas.

While making mailboxes crashworthy will satisfy safety associated with mailbox-related crashes, it is important to recognize that the placement of mailboxes may have an important impact on the overall safety of the roadway. Mailboxes should not obstruct intersection sight distance, nor should they be located directly on higher-speed roadways, where stopping associated with mail delivery and collection can lead to substantial speed differentials between vehicles on the travelway, thereby increasing the possibility of a rear-end collision. Where such conditions exist, the *Roadside Design Guide* recommends the use of a 2.4-m (8-ft) mailbox turnout lane adjacent to the travelway to allow vehicles to leave the travelway for mail collection and delivery purposes. This turnout concept does not apply to urban curbed streets. At curbed residential locations, the *Roadside Design Guide* recommends that the minimum distance from the roadside face of the mailbox to the face of the curb should be 150 mm (6 in.), with a preferred offset ranging from 200 to 300 mm (8 to 12 in.).

A common issue regarding the placement of mailboxes in an urban environment is that the governing jurisdiction (often a city or county) may not adopt the guidelines commonly accepted by state departments of transportation. Many urban jurisdictions allow home owners to construct a mailbox of their choosing. In areas in which mailbox vandalism is common, home owners have begun to erect increasingly rigid (less forgiving) mailbox units. A rigid brick mailbox is a common site along many urban residential roadways. The problem of rigid mailbox units is compounded by the general placement of such mailboxes adjacent to a driveway (to make it easy for the home owner to retrieve mail). Since the curb has a secondary function of delineating the edge of the roadway, a mailbox placed on the departure side of a driveway (where a curb cut interrupts the roadway delineation) is particularly vulnerable to errant vehicles that exit the road to the right.

Safety research. *NCHRP Report 350* provides recommended procedures to ensure roadside features such as mailboxes are crashworthy (*36*). Since mailboxes are a common fixed object adjacent to urban streets (particularly residential), they warrant particular attention when reviewing urban roadside safety. Many urban jurisdictions do not require crashworthy mailboxes. There are several yielding mailbox designs approved for the National Highway System (NHS) that could be incorporated in an urban setting. Chapter 11 of the *Roadside Design Guide* (*1*) provides a comprehensive summary of the safe placement of mailboxes. The use of yielding mailboxes is promoted in the *Roadside Design Guide*. This permits convenient mailbox placement adjacent to the road. Mailbox placement for urban commercial locations is not included in the chapter and is a less common problem. In addition to yielding mailbox support design, some jurisdictions promote the placement of reflective object markers on the mailbox or post to improve nighttime visibility (*55*).

Strategy summary. Common mailbox safety strategies are as follows:

Purpose	Strategy
Minimize crash likelihood	• Remove or relocate mailboxes to safe locations (P) • Add reflective object markers to improve nighttime visibility (T)
Minimize crash severity	• Develop policies to require crashworthy mailboxes in urban environments (P) • Shield rigid mailboxes where practical (P)

Landscaping, Trees, and Shrubs

General information. Several types of roadside landscaping are commonly employed to enhance the aesthetics of roadside environments. These treatments may include the placement of shrubs, street trees, or alternative treatments such as landscape berms. In addition to the concern of traversability in the event that an errant vehicle encounters roadside landscaping, a common safety issue of adjacent landscape treatments is sight distance and the impact landscape treatments may have for intersection, driveway, and stopping sight distance considerations. Regional jurisdictions often have landscaping design guidelines, landscaping policies, and street tree master plans. These documents address a variety of landscaping issues including plant type, maintenance, and plant placement. Since trees, in particular, can vary from small, flexible species up to more rigid varieties, the careful selection of tree species is critical. In addition, different tree species can have substantially different root systems. Species selection should also focus on the potential for the tree system to adversely impact road surface and pedestrian facilities due to pavement heave and cracking.

Placement criteria, in some cases, is based on the functional purpose or posted speed limits of adjacent roads. Common landscape placement issues addressed in jurisdiction plans include the following:

- Proximity to intersections,
- Proximity to driveways,
- Maintaining a clear vision space,
- Lateral offset placement of trees and landscaping,
- Longitudinal placement of trees and landscaping,
- Median planting strategies, and
- Strategic placement strategies for visual perception.

These specific placement strategies are further described in the following:

- **Proximity to intersections.** Sight distance should be maintained in the proximity of intersections. As a result, many landscape guidelines restrict tree placement in the immediate vicinity of intersections. The North Carolina *Traditional Neighborhood Development (TND) Guidelines* (*56*) and the City of Seattle *Street Tree Planting Procedures* (*57*), for example, recommend that trees should be located no closer than 9 m (30 ft) from intersection corners. *Landscape Design Guidelines* for the City of Simi Valley (*58*) requires a clearance distance of 10.7 m (35 ft) from the extended curb at the near side of the cross street curb.

  Another approach to intersection clearance is based on street type and intersection configuration. For example, the Montgomery, Alabama, *Street Tree Master Plan* (*59*) uses street type and traffic control to determine tree offsets from intersections. Example minimum tree placement guidelines at intersections for Montgomery are depicted in Table 7.

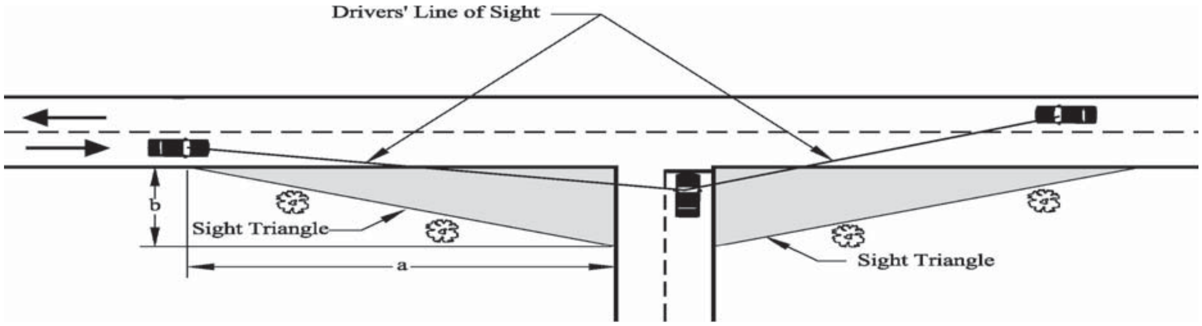
  Figure 3 is based on an FHWA publication and demonstrates the sight triangle that is required to be free of trees at an example intersection (*60*). Higher-speed vehicles that do not stop at the intersection require more sight distance than stopped vehicles, as shown.

  Guidelines for Tree Planting and Maintenance on Urban Roads, published by the Traffic Authority of New South Wales, further recommends that skewed intersections,

Table 7. Guidelines for minimum tree placement offsets at intersections for Montgomery, AL.

Intersection Control	Major Street	Neighborhood Street
Traffic Light	9.1 m (30 ft)	--
Four-Way Stop	9.1 m (30 ft)	4.6 m (15 ft)
Major Street Two-Way Stop	12.2 m (40 ft)	--
Neighborhood Street Two-Way Stop	9.1 m (30 ft)	4.6 m (15 ft)–Stops 9.1 m (30 ft)—Does Not Stop

Source: Adapted from *Montgomery Street Tree Master Plan* (*59*).



Graphic adapted from *Trees in Hazardous Locations (60)*.

Figure 3. Intersection sight triangles.

locations with high turning speeds, or locations where fast-approaching vehicles veer into the left lane to avoid impacting right-turning vehicles are all locations where cluster run-off-road crashes can be expected and where additional space free of roadside objects such as trees should be provided (*61*).

- **Proximity to driveways.** The placement of trees near driveways poses similar sight distance issues as those identified for intersections. As an example, the City of Simi Valley guidelines requires a 1.5-m (5-ft) clearance between trees and driveway edges (*58*). By contrast, the Montgomery recommendations indicate that trees should not be placed within 4.6 m (15 ft) of driveways (*59*). The City of Seattle, in *Street Tree Planting Procedures*, requires maintaining a minimum distance between trees and driveways of 2.3 m (7.5 ft) with a recommended distance of 3.0 m (10 ft) (*57*).

  Many landscape policies do not directly stipulate tree placement near driveways, but use an approach similar to the New South Wales guidelines, which simply state that drivers exiting driveways should be able to see approaching traffic and pedestrians (*61*). As an example, the attractive landscaping depicted in Figure 4 seems reasonable upon initial inspection; however, at this location the intersecting roadway is characterized by a horizontal curve. With the landscaping placement close to the driveway, the driver of an exiting vehicle cannot detect approaching vehicles without edging into the active travel lane; therefore, these roadside treatments encroach on the required sight distance. As can be viewed in the photo, the adjacent property owner also positioned large "ornamental" rocks at the corner, thereby adding a rigid obstacle in the immediate vicinity of the roadway.

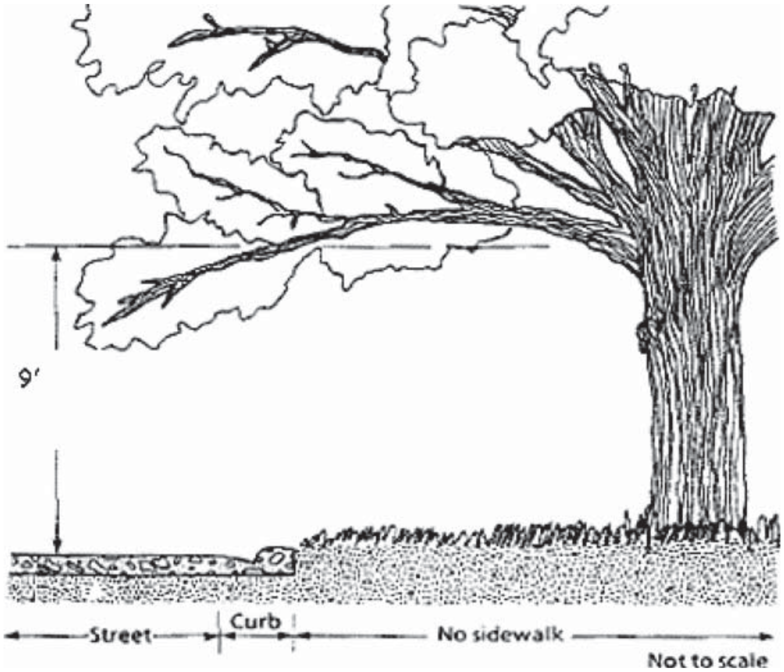
Photo by Karen Dixon.

Figure 4. Landscaping in sight triangle for driveway.

- **Maintaining a clear vision space.** *Traditional Neighborhood Development (TND) Guidelines* recommends that vertical space ranging from 0.6 to 2.1 m (2 to 7 ft) above ground be maintained to preserve lines of sight (*56*). The AASHTO publication *Highway Safety Design and Operations Guide* (*30*) recommends that the vertical "clear vision space" range from 1 to 3 m (3.3 to 10 ft) to ensure clear sight distance for drivers in low-riding sports cars as well as drivers in high trucks and buses. This vertical clear space is common to many regional landscaping plans. The "clear vision space" is essentially the space above shrub growth and below tree overhang. A low tree overhang can also create an obstacle for pedestrian access, as shown in Figure 5.

  Figure 6 depicts another type of encroachment into the vertical clear vision space. Often landscape berms are used to screen adjacent parking from the roadway. The photo on the left shows a longitudinal landscape berm and the effect it has on horizontal sight distance. At the location shown, the road has a horizontal curve to the right (in the direction the vehicle shown is traveling) and has numerous driveways that are not easily visible due to the berm height. The photo on the right depicts the same location but more clearly shows that the height of the berm exceeds the height of a typical passenger car. This type of landscape treatment is a common roadside treatment in many urban areas.

- **Lateral offset placement of trees and landscaping.** *Traditional Neighborhood Development (TND) Guidelines*



Graphic reprinted from *Vegetation Control for Safety. A Guide for Street and Highway Maintenance Personnel*, FHWA-RT-90-003 (*120*).

Figure 5. Overhead object hazard.

recommends that planting strips located between the curb and sidewalk should be at least 1.8 m (6 ft) wide (*56*). This resource further suggests that for streets with design speeds at or below 32 km/h (20 mph) or for streets that permit on-street parking, small street trees can be planted within 0.9 m (3 ft) of the back of curb or along the approximate centerline of the planting strip. The Seattle planting procedures permit tree planting 1.1 m (3.5 ft) from the face of curb (*57*). The Montgomery, Alabama, plan recommends that at neighborhood street locations trees should be installed at a point equidistant between the pavement edge and the right-of-way limits or, for residential neighborhoods, equidistant between the pavement edge and the edge of the sidewalk (*59*). For major street locations, trees should not be located closer to the edge of pavement than two-thirds of the distance from the pavement edge to the right-of-way limits. The Georgia Department of Transportation *Online Policy and Procedure System* (*62*) recommends that in an urban environment, trees with diameters less than 100 mm (4 in.) should be laterally positioned 1.2 m (4 ft) for posted or design speeds of 56 km/h (35 mph) or less, 2.4 m (8 ft) for posted or design speeds of 64 to 72 km/h (40 to 45 mph), and outside the clear zone for speeds greater than 72 km/h (45 mph). For larger trees, the minimum lateral

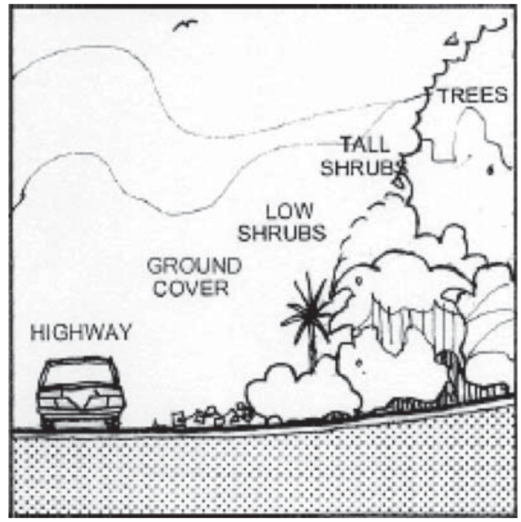
Photos by Karen Dixon.

Figure 6. Landscape berm that blocks horizontal sight distance.

placement should be 2.4 m (8 ft) from the curb or 1.2 m (4 ft) from the outside shoulder in central business districts or commercial locations for posted or design speeds of 56 km/h (35 mph) or less. Similarly, for speeds of 64 km/h (40 mph) the lateral clearance of 3.0 m (10 ft) should be maintained. For speeds of 72 km/h (45 mph), a lateral offset of 4.3 m (14 ft) is recommended. The Georgia Department of Transportation further requires that large trees be placed beyond the clear zone limits for speeds greater than 72 m/h (45 mph).

AASHTO (*30*) suggests that landscape design include consideration of the mature size of trees and shrubs and how they will influence safety, visibility, and maintenance costs as they mature. In addition, if on-street parking is permitted, the landscape border area needs to be wide enough to accommodate the planned landscaping and still permit access to parked vehicles.

New Zealand's *Guidelines for Highway Landscaping* (*20*) recommends plant layering, an approach in which plants are grouped according to height, as depicted in Figure 7.



Reprinted from *Guidelines of Highway Landscaping* (*20*)

Figure 7. Example of plant layering.

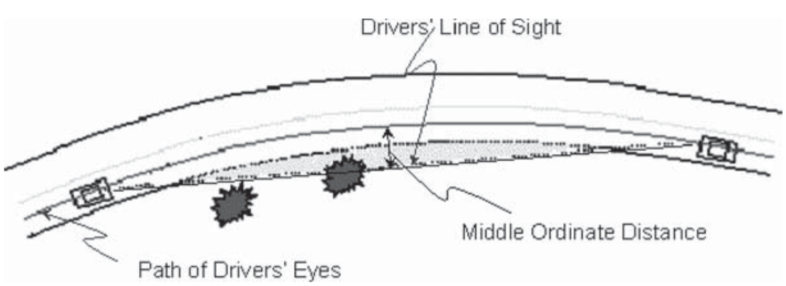
This plant layering approach permits the use of roadside landscaping and, as indicated in the guide, will do the following:

– Allow wider clear zones for rigid objects,
– Permit the inclusion of large trees in the roadside design,
– Allow appropriate sight distance, and
– Permit visually appealing plant compositions.

Finally, at horizontal curve locations the lateral offset of landscaping features must not obstruct sight distance, as shown in Figure 8.

- **Longitudinal placement of trees and landscaping.** In addition to lateral offset placement standards and constraining the placement of trees near intersections or driveways, longitudinal placement strategies include placement to help develop tree canopies and placement to help avoid conflicting obstacles. One source recommends that trees be spaced so that mature tree canopies grow within 3 m (10 ft) of each other to help provide shade (*63*). This placement results in tree spacing from 7.6 to 15.2 m (25 to 50 ft) depending on the tree type. The City of Montgomery plan suggests tree placement approximately 9.1 m (30 ft) on center, but also emphasizes that canopy trees should not be positioned under service wires (*59*).

  Other placement constraints in the Seattle procedures include space separating trees from underground utility lines of 1.5 m (5 ft), a minimum space of 3.0 m (10 ft) separating trees from power poles (4.6 m [15 ft] recommended), and a space of 6.1 m (20 ft) separating trees from street lights or other existing trees (*57*). The City of Simi Valley requires a separation of 4.6 m (15 ft) between trees and street light standards, 3.0 m (10 ft) between trees and fire hydrants and alleys, and 1.5 m (5 ft) between trees and water meters or utility vaults (*58*).
- **Median planting strategies.** Many jurisdictions maintain similar lateral offset guidelines as for the right side of the roadside (in the direction of travel). The New South Wales guidelines note that where planting is required in a median, trees should be located a minimum lateral distance from the nearest travelway of 2.5 m (8.2 ft) (*61*). The City of Simi Valley guidelines suggest that median tree spacing can vary based on tree type (*58*). Shrubs should have a mature



Graphic reprinted from *Trees in Hazardous Locations* (*60*)

Figure 8. Sight distance around a horizontal curve.

height of 0.8 m (2.5 ft), and ground cover should be set back from the curb edge a minimum of 0.5 m (1.5 ft).

- **Strategic placement strategies for visual perception.** One report from Denmark suggests that the traffic-related feature of roadside plantings may be due to the visual narrowing of the driver's field of view, which results in speed reductions (*15*). This speed reduction hypothesis is echoed in other literature, but it has not yet been empirically substantiated.

Safety research. There is considerable anecdotal information in the literature that supports the potential benefits of roadside landscaping placement for health and driver well-being. Similarly, impact with a rigid object, such as a large tree, is a known hazard, and this danger has been consistently reinforced in rural roadside research. While shrubs are often classified with trees for the purposes of analyzing crash data, it is important to consider the safe placement of shrubs separately from that of trees and other landscaping elements, as many types of landscaping elements are considered frangible.

The majority of roadside landscape safety literature has focused on the safety condition of street trees. The placement or removal of street trees is often one of the most contentious elements with respect to the design of roadsides in urban areas. Urban stakeholders often seek to incorporate street trees in the design of urban roadsides; however, when trees are placed adjacent to the travelway, they can become rigid, fixed-object hazards. Current practice discourages the placement of trees with mature-tree caliper widths greater than 100 mm (4 in.) along the roadside (*1, 37*). This maximum tree size is based on the crash tests of 100 by 100 mm (4 by 4 in.) wooden signposts. A tree, unlike a wood signpost, has a root system; however, the wood post used for sign supports has long been the reference for tree size on the assumption that if the wooden signpost is safe, then a tree of a similar size should also be safe (*64, 65*).

In 1986, the FHWA commissioned a study to reduce hazards due to trees (*66*). Although the study focused generally on the rural environment, the researchers found that for fatal tree crashes, the median tree diameter at breast height was 508 mm (20 in.), whereas the median tree diameter for nonfatal tree crashes was 381 mm (15 in.). FHWA's *Roadside Improvements for Local Roads and Streets* further notes that trees with multiple trunks, groups of small trees, or a combination of a small tree and another fixed object can act as a potential hazard and should be considered collectively (*67*). For combined effects, the cross section should not exceed 83.87 sq cm (13 sq in.).

A 1990 study performed by Turner and Mansfield evaluated urban tree safety in Huntsville, Alabama, based on a study of tree crashes (*7*). The study presents aggregate information on the characteristics of urban run-off-road crashes into trees, but did not include information on the specific road characteristics of the environments in which these crashes occurred. The authors concluded that mature trees with diameters larger than 10 cm (4 in.) should not be permitted within a roadside clear zone region. The authors further suggested that if the trees are needed for aesthetics or environmental reasons, the tree location should be behind a barrier, ditch, or retaining wall.

A 1999 study conducted in Washington State examined both rural and urban environments and developed models for both conditions as well as models combining the urban and rural data (*68*). The researchers determined that the variable representing the number of isolated trees in a section had a negative sign (indicating a decrease in accident frequency) for urban areas. This same variable had a positive sign (indicating an increase in accident frequency) for rural locations. The authors also evaluated crash severity. The models they developed predicted that in an urban environment isolated trees can be expected to result in possible injury while the presence of tree groups can be expected to result in disabling injuries or fatalities. The authors had a similar finding for tree groups in rural environments. The authors attributed the reduction of accident frequency due to isolated trees in urban environments to the fact that there are fewer trees in urban environments than in rural ones.

In 1999, Kloeden and colleagues published a study of crashes that occurred between 1985 and 1996 in Southern Australia (*69*). The researchers did not separate the crashes into urban and rural categories; however, they did perform evaluations based on the speed zones associated with the crash locations. Table 8 depicts the distance to roadside hazards for fatalities that occurred during the study period for speed zones of 80 km/h (50 mph) or less. The offset values shown in this table are rounded to the closest meter. This Australian study found that 58.6 percent of roadside hazard fatalities were due to vehicle impacts into trees.

A study published in 2003 evaluated five arterial roadways in downtown Toronto and sought to understand the safety impacts of placing landscape elements, such as mature trees, adjacent to the travelway. The sites were selected because all five sites were undergoing various environmental and aesthetic improvements due to community concerns associated with major road reconstruction projects. The sites were tracked from 1992 to 1995 as they underwent these improvements. This study found a statistically significant reduction in mid-block crashes from the pre- to post-test conditions, although the authors did not elaborate on the nature of the crashes that were investigated as part of the study (*70*). These results, however, cannot be uniquely attributed to trees since the projects involved major reconstruction.

Researchers from Monash University Accident Research Centre in Australia published a study in 2003 that evaluated roadside safety issues in Victoria from 1996 to 2000 (*71*). They determined that 4.1 percent of collisions with roadside trees resulted in a fatality, compared with only 2.3 percent of other roadside object crashes. They also noted that the likelihood of

Table 8. Offsets to roadside hazards in fatalities.

Distance of Roadside Hazard from Road (m)(ft)	Number of Crashes	Percentage (%)	Cumulative Percentage (%)
0 (0)	34	22.2	22.2
1 (3)	38	24.8	47.1
2 (7)	30	19.6	66.7
3 (10)	18	11.8	78.4
4 (13)	12	7.8	86.3
5 (16)	5	3.3	89.5
6 (20)	3	2.0	91.5
7 (23)	1	0.7	92.2
8 (26)	3	2.0	94.1
9 (30)	1	0.7	94.8
10 (33)	3	2.0	96.7
14 (46)	2	1.3	98.0
15 (49)	2	1.3	99.3
16 (52)	1	0.7	100.0
Total	**153**	**100.0**	

Source: Adapted from *Severe and Fatal Car Crashes Due to Roadside Hazards* (*69*).
Note: Crashes involving multiple fatalities are only counted once in this table.

a fatality is greater for collisions at higher speeds and that the most frequently impacted roadside hazards were trees, poles, fences, and embankments.

A study published in 2005 by Bratton and Wolf performed an analysis using national crash data and concluded that crash frequency is generally higher and injury level more severe in higher speed rural areas (*72*). They also noted that crashes involving trees are more injurious than all crashes in general. Bratton and Wolf were not able to identify a significant difference between tree collision rates in urban and rural areas. Although they noted that trees, as fixed objects, statistically increase the likelihood of injury in accidents, trees are involved in a small overall percentage of these crash events. The authors went on to note that since the clear zone concept does not appear to be a feasible notion for the urban environment, designers should develop a way of safely integrating trees into the urban roadside environment.

Researchers at California Polytechnic State University performed a three-phase study completed in 2004 (with interim reports in 2002 and 2003) in which they evaluated the street tree application specifically for the urban median condition (*53*). In the initial stages of the research, the researchers performed a literature review and noted the wide variety of anecdotal evidence and conflicting empirical evidence produced for previous studies into the roadside safety of the urban street tree. They noted that there are a variety of clearance standards used throughout the United States for recommended offset values to roadside hazards such as large trees (defined as trees with diameters greater than 100 mm [4 in.] for their study) and very little direction regarding appropriate placement of trees in medians. As a result, Phases 2 and 3 of the study were focused on evaluating urban street trees in curbed urban and suburban highway medians with a variety of median widths, including narrow medians. The researchers concluded that large trees located in medians are associated with more total crashes as well as more fatal and injury crashes. The presence of median trees was statistically significant for the severity model developed for the study. The researchers also found a positive relationship between median trees and hit-pedestrian crashes at non-intersection locations. The median width results were inconclusive.

Strategy summary. A variety of strategies have been proposed, applied, and/or tested for safe application of landscaping and tree placement adjacent to the roadside. The safety of these strategies in some cases is well known; in other cases, strategies hold promise but their exact influence on safety is unknown. Common strategies are as follows:

Purpose	Strategy
Prevent large trees from growing in hazardous locations	• Restrict/Refine planting guidelines regarding tree and landscaping placement (T) • Implement plant layering strategies (T)
Eliminate hazardous tree conditions	• Remove or shield isolated large trees (diameter of 100 mm [4 in] or more) (P) • Shield tree groups (P) • Establish urban lateral offset guidelines for large trees (T) • Delineate hazardous trees to improve visibility (E)
Minimize level of severity	Reduce travel speed on adjacent road (P)

Street Furniture

General information. In many urban areas, the use of street furniture is a common approach to improving the aesthetic quality of a street. Street furniture includes items placed adjacent to the road that are there to improve the adjacent land use or to improve the transportation operations. In some jurisdictions, street lights and signs are included in the category of street furniture; however, for the purposes of this review, street furniture is considered to be supplemental items such as benches, public art, trash receptacles, phone booths, planters, bollards, fountains, kiosks, transit shelters, bicycle stands, and so forth. Often the placement of these devices can obscure sight distance, so their location should not occur in the sight triangles of intersections or driveways. Many street furniture items are placed along the right-of-way by property owners, as in the case of the placement of a sidewalk cafe in front of a restaurant, and are thus largely outside the engineer's control. Transit shelters are provided to protect transit riders from inclement weather and must be located close to the curb to facilitate short bus dwell times.

One interesting way that some jurisdictions manage the placement of street furniture by land owners is by a permitting process that requires vendors or property owners to acquire liability insurance for street furniture located adjacent to the road. Seattle is one city with this insurance requirement. Other jurisdictions restrict the placement of private street furniture by a permitting process complemented by a tax for each square meter or square foot of public right-of-way used. Dublin, Ireland, is one city that uses this approach.

Safety research. The research team for this project was not able to locate any research evaluating the relative hazard that may be posed by street furniture. Nevertheless, street furniture can potentially create sight distance obstructions when located near an intersection, particularly when large numbers of people congregate as a result of the street furniture. It is also important that the sight distance of pedestrians be maintained when placing street furniture proximate to the roadway.

Strategy summary. Common street furniture safety strategies are as follows:

Purpose	Strategy
Minimize likelihood of crash	• Locate street furniture as far from street as possible (P) • Restrict street furniture placement to avoid sight distance issues for road user (P)
Minimize crash severity	Develop street furniture that meets basic crashworthy standards (E)

Utility Poles, Luminaires, and Signposts/Hardware

General information. In both the national and international literature, the placement of utility poles, light poles, and similar vertical roadside treatments and companion hardware is frequently cited as an urban roadside hazard. For example, Haworth and Bowland have noted that while impacts with trees were more common outside the Melbourne, Australia, metropolitan area, single-vehicle crashes with poles or posts were more common within the metropolitan region (*73*). A 1998 study by the European Transport Safety Council identified collisions with utility poles or posts as one of the top two roadside hazards for Finland, Germany, Great Britain, and Sweden (*74*).

Safety research. This section discusses the research literature for utility poles, lighting supports, and signposts/roadside hardware.

- **Utility poles.** Utility poles are prevalent in urban environments and can pose a substantial hazard to errant vehicles and motorists. A study of utility pole crashes, for example, found that crash frequency increases with daily traffic volume and the number of poles adjacent to the travelway (*33*). Utility poles are more prevalent adjacent to urban roadways than rural highways, and demands for operational improvements coupled with limited street right-of-way often lead to placing these poles proximate to the roadway edge (see Figure 9).

  The absolute number of fatalities related to utility poles has remained around 1,200 since the mid 1980s (see Figure 10) (*75*). Utility poles are involved in the second highest number of fixed-object fatalities (trees are involved in the highest number of fixed-object fatalities). In a statistical study performed by Washington State Department of Transportation researchers, utility poles were identified as one of the roadside features that can significantly affect the injury level or severity of run-off-road crashes (*68*).

  The literature regarding crashes related to utility poles has identified utility poles as being principally an urban hazard, with urban areas experiencing 36.9 pole crashes per 161 km (100 mi) of roadway, compared with 5.2 pole crashes per 161 km (100 mi) of roadway for rural areas (*76*). Zegeer and Parker found that the variable that had the greatest ability to explain crashes related to utility poles was the average daily traffic (ADT) along the roadway (*33*). The significance of ADT as the critical variable explains the importance of vehicle exposure to understanding run-off-road crashes with utility poles.

  A common recommendation for addressing the utility pole safety issue is to place utilities underground and thereby remove the hazardous poles. The removal of all

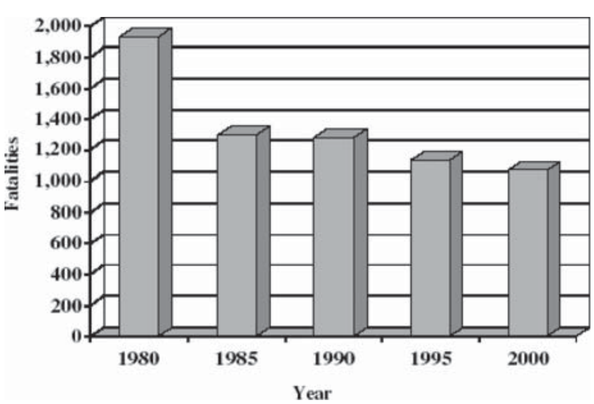
Photos by NCHRP Project 16-04 research team.

Figure 9. Road widening resulting in utility pole hazards.

poles in the urban roadside environment is not practical as these poles often function as the supports for street lights and other shared utilities. There are, however, several known utility pole hazardous locations that should be avoided when feasible. In general, utility poles should be placed in the following locations:

– As far as possible from the active travel lanes,
– Away from access points where the pole may restrict sight distance,
– Inside a sharp horizontal curve (as errant vehicles tend to continue straight toward the outside of curves), and
– On only one side of the road (*66, 77*).

State of the Art Report 9: Utilities and Roadside Safety summarizes categories for utility pole safety solutions as the following: changing the pole position; using safety devices (crash cushions, safety poles, guardrail, and barriers);



Graphic reprinted from *State of the Art Report 9: Utilities and Roadside Safety* (*75*).

Figure 10. Fatalities related to crashes with utility poles (1980–2000).

or warning motorists of the obstacles (*78*). The report includes several initiatives in which pole relocation or removal is currently targeted as a safety strategy.

Additional ways to minimize utility pole crashes are placing utilities underground (where feasible), using shared poles to reduce pole density, and relocating poles to less vulnerable locations. The delineation of poles using reflective tape or buttons may also help an alert driver identify a utility pole and avoid it; however, this delineation treatment may also act as an attractor for impaired drivers who are attempting to guide their vehicles by road edge delineation. The Land Transport Safety Authority in New Zealand recommends that utility poles and large trees be highlighted using a uniform method that cannot be removed, such as reflectorized markers or paint markings (*79*).

Increasing the lateral distance of utility poles from the travel lanes appears to be a promising improvement strategy. Many jurisdictions maintain an operational offset of 0.5 m (1.5 ft), but several agencies are seeking to increase the pole placement offset in urban regions. Haworth and colleagues (*80*) observed that in metropolitan Melbourne, Australia, poles involved in fatal crashes were most often less than 2 m (6.6 ft) from the edge of the road. The Clear Roadside Committee established by the Georgia Utilities Coordinating Council suggests that for curbed sections, poles should be placed as far as is practical from the face of the outer curbs, with the following goals:

– Lateral clearance of 3.6 m (12 ft) from the face of the curb to the face of the pole.
– For speed limits greater than 56 km/h (35 mph) but not exceeding 72 km/h (45 mph), a lateral clearance of 2.4 m (8 ft).

– For roads with posted speed limits less than or equal to 56 km/h (35 mph), a lateral clearance of 1.8 (6 ft) (*81*).

Similar to the Georgia policy, the Maine Utility Pole Location Policy suggests that offsets should be greater than 2.4 m (8 ft) for roadways with posted speed limits of 40 to 55 km/h (25 to 35 mph) and that offsets should be greater than 4.3 m (14 ft) on roadways with posted speed limits of 65 to 70 km/h (40 to 45 mph) (*82*).

In Sweden, emphasis is placed on system level improvements. Based on the idea that the transportation system itself is unsafe, Sweden is redeveloping the system to reduce user errors that lead to injury or death. One of the strategies to achieve this goal is to modify the system to ensure that users are not exposed to impact forces that can kill or severely injure the users (*71*).

Finally, some utility pole literature suggests the use of breakaway poles. In the event that an errant vehicle impacts a breakaway pole, the pole will swing upward and then back down (thereby permitting the impacting vehicle to travel safely under the pole). One concern with breakaway utility poles has been whether they pose a threat to pedestrians when they swing back down after swinging up to avoid a crash. A 1970s series of case studies performed in Australia by McLean, Offler, and Sandow evaluated crashes in the proximity of Stobie poles (utility poles with two rolled-steel joists separated by concrete) (*83*). In evaluating the risk to pedestrians, the researchers determined that there were no cases in their studies where a pedestrian was in the immediate vicinity of a collision between a car and a Stobie pole.

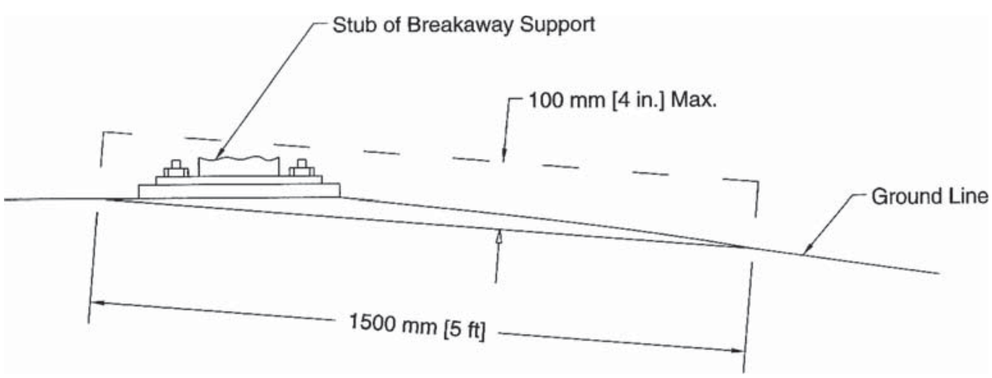
- **Lighting and visibility.** The design of luminaire posts is directed by *NCHRP Report 350*, and substantial research has been devoted to designing these light poles to be yielding upon impact (using breakaway bolts) (*36*). Multiple designs for these posts are included in the current edition of the *Roadside Design Guide* (*1*), and specifications for evaluating these features are contained in AASHTO's *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (*84*).

  An important issue in addressing roadside safety is the role of lighting in making potentially hazardous roadside environments visible to the road users (motor vehicle drivers, bicyclists, and pedestrians), particularly during nighttime hours. Other issues with roadside lighting, as cited in the literature, include frequency and spacing of lights (*56*) and lighting color and associated visibility (*85*). These issues are beyond the scope of this study.

- **Signposts and roadside hardware.** The design of signposts is directed by *NCHRP Report 350*, and there has been substantial research devoted to designing these features to be traversable (*36*). Multiple designs for these features are included in the current edition of the *Roadside Design Guide* (*1*), and specifications for evaluating these features are contained in AASHTO's *Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals* (*84*).

  Crash severity can be minimized through the use of traversable hardware, such as break-away light posts, mailboxes, and utility poles. The current standard for breakaway hardware, as contained in the *Roadside Design Guide* and *NCHRP Report 350*, is that breakaway features function omni-directionally to ensure that the features do not constitute a hazard from any impact direction (*1*, *36*). To prevent vehicle snags, the stub height after breakaway should not exceed 100 mm (4 in.) (see Figure 11).

  While an unobstructed and traversable roadside is preferred, it may be necessary at some locations to use breakaway features, which will minimize the severity of the initial impact by an errant vehicle. Breakaway poles and similar features must be designed to prevent intrusion on the passenger compartment of the vehicle, either by minimizing the weight and load of such features, or by providing a secondary hinge, at least 2.1 m (7 ft) above the ground, that permits the vehicle to pass safely beneath the post upon impact. The current edition of the *Roadside Design Guide* provides specifications for these devices and suggests that the concern for pedestrians in urban areas has led to a trend of using fixed supports for some urban locations (*1*).



Graphic reprinted from *Roadside Design Guide* (*1*) with permission.

Figure 11. Stub of a breakaway support.

Strategy summary. Common strategies for utility poles, lighting supports, and signposts/roadside hardware are as follows:

Purpose	Strategy
Treat individual high risk pole locations	• Remove or relocate poles (P) • Place poles on inside of horizontal curves and avoid placement on outside of roudabouts or too close to intersection corners (P) • Use breakaway or yielding poles (T) • Shield poles (P) • Improve pole visibility (E)
Treat multiple poles in high risk locations	• Establish urban clear zone offset guidelines for pole setback distances from curb (P) • Place utilities underground while maintaining appropriate nighttime visibility (P) • Combine utilities/signs onto shared poles (reduce number of poles) (P) • Replace poles with building-mounted suspended lighting (where suitable) (E) (*86*)
Minimize level of severity	Reduce travel speed on adjacent road (P)

Safety Barriers

Roadside barriers are subject to *NCHRP Report 350* testing criteria (*36*). There are several types of safety barriers that may be present in an urban environment. These include the following:

- Barriers (flexible, semi-rigid, and rigid);
- Bridge railings; and
- End treatments (crash cushions and end terminals).

Generally, most of the research on safety barriers has been oriented toward the design of barriers and their placement to shield vehicles from hazardous roadside conditions. The *Roadside Design Guide* and *NCHRP Report 350* provide considerable information on placement and design of safe barrier systems (*1*, *36*). FHWA maintains a roadside hardware website that provides information about specific roadside hardware that has been tested (see http://safety.fhwa.dot.gov/roadway_dept/road_hardware/index.htm).

In the urban environment, many of the safety barriers common to rural environments may not be suitable due to constraints regarding space available for flared end treatments, the constraining influence of safety barriers on pedestrian activity, and the potential obstruction of sight distance at the many intersections and driveways in the urban environment. Also, in locations with bicycle activity, safety barriers located immediately adjacent to the road may expose cyclists to unnecessary risks because the barriers may give a sensation of "squashing" the cyclist between the barrier and an adjacent motor vehicle (*79*).

Safety research. Considerable research has been performed on a variety of traffic barriers. *NCHRP Report 490: In-Service Performance of Traffic Barriers* includes an extensive literature review that discusses the evolution of traffic barrier crashworthiness (*87*). The following summaries briefly review the application of these tested barriers (barriers, bridge rails, and end treatments) in an urban environment.

- **Barriers.** Barriers can be categorized as flexible (cable barriers and W-beam guardrail with weak post), semi-rigid (thrie beam and W-beam guardrail with strong post), and rigid (concrete barrier system such as the New Jersey barrier).

  Because guardrails are most typically associated with rural and higher speed environments, the use of guardrails in urban environments is often restricted to protection of bridge approaches and departures. In fact, the conventional use of guardrail is to shield roadside objects from impact that pose a greater threat than impact to the guardrail itself. Since the placement of guardrails at locations with frequent driveways is problematic due to the numerous breaks in the barrier treatment and the adverse effect of the guardrail on driveway and intersection sight distance, the use of conventional guardrail is minimal in urban low-speed corridors. AASHTO indicates that for very low traffic volume locations, traffic barriers are not generally cost-effective (*32*). This recommendation is confirmed by research performed by Stephens (*88*) and Wolford and Sicking (*89*). In the event that an engineer does endorse the use of a barrier in an urban environment, factors in addition to the lateral offset, deflection distance, terrain effects, flare rate, and length of need (common to rural placement design) must be supplemented by consideration of corner sight distance, pedestrian activity (with particular attention to the needs of persons with disabilities), and bicycle activity (*1*).

  When the use of a protective barrier is warranted in the urban environment, the application of aesthetic barrier treatments may be considered. These treatments perform the same general function as a guardrail (shield hazardous environments) while enhancing the aesthetics of a roadway.

  The use of barriers in an urban environment can be to shield roadside obstacles (such as rigid utility poles), separate motorized and nonmotorized traffic, and provide a physical separation between the active travel lanes and pedestrian activity. For barriers with a shielding objective, several different barriers may be considered. For example, the

California Department of Transportation published a report in 2002 with a focus on suitable aesthetic barriers (*90*). This report includes the status of crash testing as well as the advantages and disadvantages of each treatment. Candidate barriers for urban environments include concrete barriers with textured and patterned surfaces, timber guardrail, precast concrete guardwall, and stone masonry guardwall.

The placement of barrier in the vicinity of a median is a common strategy in rural environments to help prevent head-on collisions by errant vehicles. Washington State, for example, performed an evaluation of median treatments for multi-lane, divided state highways with full access control (*91*). The researchers determined that the placement of a barrier for medians up to a width of 15 m (50 ft) is cost-effective. In an urban environment, the median width is narrow and often serves the combined functions of separating opposing directions of travel and acting as pedestrian refuge at certain locations. Currently, concrete Jersey barriers are used most commonly for medians in urban locations.

The placement of barriers adjacent to the road introduces a new roadside hazard. For example, use of rigid barriers tends to result in a greater number of minor crashes, but dramatically reduces the number of serious or fatal head-on and run-off-road crashes (*92*). Lee and Mannering (*68*) determined that for urban environments, guardrails are significantly associated with an increase in crash frequency, but the severity of these crashes is likely to result in possible injury only.

In locations where aesthetics are important and a barrier is required, jurisdictions may develop crash-tested options such as the Vermont-approved stone masonry system shown in Figure 12 (in addition to the various aesthetic barriers identified in the California report previously indicated [*90*]).

- **Bridge rails.** In both urban and rural environments, bridges should be equipped with rails that do not permit vehicles to penetrate the space beyond the rail (i.e., structural adequacy). Transitions to guardrails must be located at both the approach and departure end of all bridge rails. Bridge rails must be designed to retain a large passenger car at the legal driving speed for local streets and roads (*94*). The bridge rails must, therefore, be structurally designed and maintain their structural integrity after impact.
- **End treatments.** For locations where the end of the barriers cannot be adequately flared or protected, it is necessary to use an end treatment such as a barrier terminal or crash cushion. Aesthetic enhancements to end treatments have not received much attention, so conventional treatments are necessary in the urban environment. These treatments should not allow a vehicle to penetrate, vault, or roll upon impact. They should have the strength and redirectional qualities of a standard barrier.

Photo reprinted from *Guardrail Study* (*93*).

Figure 12. Stone masonry barrier.

Dynamic Roadside Conditions

Bicycle Facilities

General information. Bicycle facilities consist of road and roadside features intended for bicycle operation. These facilities may include standard lanes, wide outside lanes, bicycle lanes, and off-road bicycle paths. Accompanying bicycle facilities may be bicycle hardware located along the roadside, such as bicycle racks. In general, the literature regarding the relationship between bicycle facilities and roadside safety is limited. Wide shoulders and bicycle lanes provide an additional "clear" area adjacent to the travelway, so these features could potentially provide a secondary safety benefit for motorists, provided bicycle volumes are low. These bicycle facilities will also further separate the motor vehicle from any roadside obstructions and improve the resulting sight distance for motor vehicle drivers at intersecting driveways and streets.

A second area of consideration is the placement of bicycle-supportive hardware, such as bicycle racks, adjacent to the travelway. Bicycle racks are commonly made of steel or other metals and are typically bolted to the ground to secure locked bicycles from potential theft. These features are not designed to be yielding should a run-off-road event occur. To date, there has been little evaluation of the potential roadside hazard posed by such treatments, although they can clearly present a potential fixed-object hazard. Making such features yielding would potentially minimize the core function of these features—providing a secure location for locking up bicycles. Thus, a potentially more desirable alternative may be to encourage the placement of these features outside of the clear zone.

Safety research. Most of the bicycle research focuses on specific bicycle safety issues such as safety helmets and training. Several studies have developed and reviewed previous bicycle suitability or compatibility criteria (*95*, *96*). The criteria for determining bicycle suitability include available lane width, traffic volume, and vehicle speeds. One best practices review has suggested that road safety for cyclists could be enhanced by increased law enforcement to ensure that cyclists do not ride in the wrong direction (against traffic) or at night without adequate lighting (*97*). This best practices review also noted that the use of extruded curbs to separate a bike lane from traffic should be avoided.

Since the focus of this research effort is roadside safety for the urban environment, it is helpful to understand the magnitude of the safety risk to cyclists as they encounter roadside environments. One FHWA report using hospital emergency department data noted that 70 percent of reported bicycle injury events did not involve a motor vehicle and 31 percent occurred in non-roadway locations. For bicycle-only crashes, a total of 23.3 percent of the recorded crashes occurred at sidewalk, driveway, yard, or parking lot locations (*98*). Stutts and Hunter (*99*) evaluated bicycle–motor vehicle crashes and determined that some factors associated with the crash were variables such as age, gender, impairment, and time of day. Roadside variables (sidewalk, parking lot, and driveways) were not statistically significant in their model.

Strategy summary. Common strategies to improve bicycle safety as well as bicycle–motor vehicle interactions are as follows:

Purpose	Strategy
Reduce likelihood of crash	• Use wider curb lanes (P) • Increase bicycle enforcement (T) • Increase operational offsets (P)
Reduce severity of crash	Locate bicycle racks as far away from road as possible (T)

Parking

General Information. In many urban environments, limited off-street parking often necessitates the use of on-street parking to address the needs of local businesses and stakeholders. As noted in the *Green Book* (*37*), cars typically park 150 to 305 mm (6 to 12 in.) from the curb and have a normal width of roughly 2.1 m (7 ft). Thus, approximately 2.4 m (8 ft) are needed to comfortably accommodate on-street parking. One common strategy in larger cities is to design wider outside parking lanes, such as 3 m (10 ft), and convert them to travel lanes during peak periods and anticipated high-volume conditions.

On-street parking can potentially have mixed results on a roadway's safety performance. On the one hand, these features narrow the effective width of the roadway and may result in speed reductions, thereby leading to a reduction in crash severity. Conversely, on-street parking may also lead to an increase in collisions associated with vehicles attempting to pull in or out of an on-street parking space.

In addition to vehicle conflicts, on-street parking serves as a physical buffer between the motor vehicle path and pedestrian facilities. The added safety buffer provided to the pedestrian, however, can be countered by the pedestrian who elects to cross the street mid-block in areas not designated for pedestrian crossing. The parked vehicles may act as a shield to prevent proper sight distance for the drivers of adjacent motor vehicles, often resulting in new conflicts between motor vehicles and pedestrians stepping between parked cars. Similarly, there is an inherent conflict between the motor vehicle and drivers exiting or entering their parked vehicles on the traffic side of the roadway.

An additional concern often cited regarding on-street parking is the effect it may have on reducing emergency services' response rate. Often the narrowing effect of on-street parking can be compounded by illegal parking too close to critical locations such as intersections. The Local Government Commission released a publication called *Emergency Response Traffic Calming and Traditional Neighborhood Streets* (*100*) that suggests that the adverse effects of on-street parking can be mitigated by implementing the following strategies:

- Placing a double set of driveways periodically (per fire department recommendation) to enable local access;
- Placing alleys on short blocks across from each other;
- Placing mailbox clusters, curb extensions, or similar treatments where residents will find it inappropriate to park; and
- Enforcing parking criteria to minimize illegal parking.

Finally, the severity of a roadside hazard constituted by a collision between a parked vehicle and a moving vehicle is minimal. Since on-street parking is generally parallel to the moving vehicles, the impact by a moving vehicle is likely to be a sideswipe crash. This is one of the less severe crash types. For locations with head-in or reverse-in parking, the crash severity likelihood is increased as the moving vehicle may impact a vehicle in reverse. Proper sight distance and separation of parked vehicles from the active travel lane (often by the use of a bulb-out at the intersection) will help minimize safety risks between moving and parked or parking vehicles. As indicated in the previous section, curb extensions or bulb-outs can pose a hazard to bicyclists by forcing them into the active travel lane. In the event that the parking lanes are not occupied, the extension could also create a hazard for drivers unfamiliar with it. On-street parking is generally not considered appropriate for higher speed roads such as suburban to urban transitional arterials.

Strategy summary. Common on-street parking strategies are as follows:

Purpose	Strategy
Reduce likelihood of crash	Restrict on-street parking to low-speed roads (P)
Reduce crash severity	Where parking is appropriate, use parallel parking rather than angular parking (P)

Sidewalks and Pedestrian Facilities

General information. Sidewalks and pedestrian facilities, in general, do not pose a particular hazard to motorists. The safety concern about locating these facilities adjacent to the road is the risk to the pedestrians using the facilities. Providing safe facilities for pedestrians is an obvious strategy for increasing pedestrian safety. While shared streets may be appropriate if vehicle speeds and volumes are kept extremely low (see Figure 13), for most roads in urban areas, vehicle speeds warrant the use of sidewalks (*21, 101, 102*). The *Green Book* (*37*) recommends the use of sidewalks on urban streets, with sidewalk widths ranging between 1.2 and 2.4 m (4 and 8 ft) depending on the roadway classification and nearby land use characteristics (see Table 9).

Of the roughly 75,000 pedestrian-related crashes that occur each year, almost half occur while the pedestrian was at a non-intersection, on-roadway location (see Table 10).

The conventional approach to examining pedestrian and bicycle safety is to examine crash records to determine the non-motorized user's action prior to a crash event. Complete and accurate motor vehicle crash data for pedestrian crashes can be difficult to find. Stutts and Hunter evaluated police-reported pedestrian crashes and compared these to hospital emergency room records (*99*). They found that crash events that occurred in parking lots, driveways, and other off-road locations were reported less frequently than those occurring in the roadway. A 1999 FHWA study (*98*) also reviewed hospital emergency room records and determined that 11 percent of the pedestrian–motor vehicle events recorded occurred at roadside locations (sidewalk, parking lot, and driveway).

Of the data for which pre-crash action is known, improper crossings were the largest single crash category, accounting for 20 percent of the total crashes. The categories that have the most direct relationship to the roadside fell into the four categories most strongly related to the design of roadsides: jogging, walking with and against traffic, and miscellaneous activity.

Photo reprinted from walkinginfo.org (*121*).

Figure 13. Low-speed shared street.

As shown in Table 11, approximately 13,600 crashes were classified as "darting into road" crashes, which is where a pedestrian rushes into the street and is struck by a motor vehicle. The majority of individuals involved in "darting-into-road" crashes were children between the ages of 5 and 9, who may have been using the street for play activities (*103*). As Whyte has indicated, the street is often the preferred play location for children, even when parks and other recreational amenities may be available (*104*).

An additional feature of the roadside environment is a pedestrian buffer area. The pedestrian buffer is a physical distance separating the sidewalk and the vehicle travelway. Buffer areas typically serve a host of secondary purposes as well—they provide locations for on-street parking, transit stops, street lighting, and planting areas for landscape materials, as well as a location for a host of street appurtenances, such as seating and trash receptacles. Buffer strips may be either planted or paved. The *Green Book* supports the use of buffer strips on urban arterials, collectors, and local streets (*37*).

Table 9. *Green Book* sidewalk specifications (*37*).

Road Class	Side of Street	Specification
Urban Arterials	Both	Border area (buffer plus sidewalk) should be a minimum of 2.4 m (8 ft) and preferably 3.6 m (12 ft) or more.
Collector	Both sides of street for access to schools, parks, and shopping. Both sides of streets desirable in residential areas.	1.2 m (4 ft) minimum in residential areas. 1.2 to 2.4 m (4 to 8 ft) in commercial areas.
Local	Both sides of street for access to schools, parks, and shopping. Both sides of streets desirable in residential areas.	1.2 m (4 ft) minimum in residential areas. 1.2 to 2.4 m (4 to 8 ft) in commercial areas, although additional width may be desirable if roadside appurtenances are present.

Source: Developed from *A Policy on Geometric Design of Highways and Streets*, 4th ed. (*37*).

Table 10. Pedestrian location during a crash (2002).

Pedestrian Location	Number	Percent
Intersection - In Crosswalk	14,674	19.7
Intersection - On Roadway	15,319	20.6
Intersection - Other	1,391	1.9
Intersection - Unknown Location	810	1.1
Non-intersection - In Crosswalk	381	0.5
Non-intersection - On Roadway	35,785	48.0
Non-intersection - Other	3,518	4.7
Non-intersection - Unknown Location	173	0.2
In Crosswalk - Unknown if Intersection	16	0.0
Other Location	1,830	2.5
Unknown Location	595	0.8
Total	**74,492**	**100.0**

Source: *General Estimates System* (*122*).

Safety research. Several studies have evaluated potential countermeasures to improve pedestrian safety. Generally, these studies were based on case studies, statistical models, or subjective evaluation. Landis and colleagues (*105*) modeled several roadside walking environment variables to evaluate the pedestrian's perception of risk versus actual risk. The researchers expected that as the number of driveways increased they would observe a decrease in pedestrian safety, but this hypothesis was determined not to be statistically significant. They did find that motor vehicle volume and vehicle speeds were significant factors in pedestrian safety. Corben and Duarte evaluated the high number of pedestrian injuries along Melbourne's arterial roads and recommended the adoption of three practices:

- Reduce traffic volumes,
- Reduce road widths, and
- Reduce vehicle speeds (*106*).

Corben and Duarte further suggested that strategies for reducing the vehicle speed can include public awareness and enforcement campaigns; gateway treatments (such as road narrowing, changing pavement texture, and implementing roundabouts); and streetscape improvements (*106*). Gateway treatments are addressed in the traffic calming section of this document, which follows this section. Cottrell reviewed a variety of options for improving pedestrian safety in the State of Utah (*107*). Many of his recommendations are similar to those already reviewed; however, he also included improving sidewalk security and visibility with street lights as an important issue. Cottrell further noted that the failure to remove snow from sidewalks during winter conditions may result in pedestrians entering the street either to cross it or to walk along the cleared road. The document that to date most exhaustively summarizes strategies for improving pedestrian safety is *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan—Volume 10: A Guide for Reducing Collisions Involving Pedestrians* (*123*). This document includes methods for enhancing pedestrian safety in the road as well as adjacent to the road. The recommendations in the document are consistent with those of the research studies summarized in this review.

Table 11. Pedestrian crashes by type (2002).

Pedestrian Crash Type	No. of Crashes	Percent
No Action	23,502	31.6
Darting into Road	13,594	18.3
Improper Crossing	15,344	20.6
Inattentive	521	0.7
Jogging	211	0.3
Pushing Vehicle	103	0.1
Walking with Traffic	1,746	2.3
Walking against Traffic	1,184	1.6
Playing, Working, etc. in Roadway	8,074	10.8
Other	5,964	8.0
Unknown	4,249	5.7
Total	**74,492**	**100.0**

Source: *General Estimates System*. (*122*).

Strategy summary. Common strategies for eliminating or minimizing motor vehicle–pedestrian crashes at roadside locations are as follows:

Purpose	Strategy
Reduce motor vehicle-pedestrian crash likelihood at roadside locations	• Provide continuous pedestrian facilities (P) • Install pedestrian refuge medians or channelized islands (see previous section on medians and islands) (P) • Offset pedestrian locations away from travelway with pedestrian buffers (P) • Physically separate pedestrians from travelway at high-risk locations (P) • Improve sight distance by removing objects that obscure driver or pedestrian visibility (T) • Maintain pedestrian facilities free of leaves, snow, or tree roots (T) • Improve visibility by installing illumination for nighttime conditions (T) • Enforcement and public awareness campaigns (T)
Reduce severity of motor vehicle-pedestrian crashes at roadside locations	Reduce roadway design speed/ operating speed in high pedestrian volume locations (T)

Traffic Calming Applications—Gateway Treatments

Although traffic calming applications have been prevalent throughout Europe for several decades, traffic calming is relatively new in the United States, first emerging in the late 1990s as a strategy for addressing community livability concerns associated with high vehicle traffic volumes and speeds. The practice of traffic calming applications has sparked a substantial debate regarding the safety and appropriateness of these applications, particularly when applied to roadways intended for higher volumes and/or higher operating speeds, such as minor arterial roadways (*23, 108, 109*).

Traffic calming applications come in a variety of forms, including partial and full road closures and alterations in the design of intersections and curb lines. This report is specifically focused on traffic calming strategies deployed at arterial transitions from higher speed rural conditions to locations with lower speed arterial characteristics. This transitional traffic calming strategy is known as a gateway and is reviewed in the following summary.

General information. The traffic calming strategy known as a gateway is defined by Burden as "a physical or geometric landmark on an arterial street which indicates a change in environment from a major road to a lower speed residential or commercial district (*110*)." Burden goes on to suggest that gateways can be a combination of street narrowings, medians, signs, arches, roundabouts, or other features. The objective of a gateway treatment is to make it clear to a motorist that he or she is entering a different road environment that requires a reduction in speed.

Drivers need a certain transitional speed zone with the explicit guidance and roadway features to inform and encourage them to gradually slow down before they reach the urban residential area for a safe entry. A transitional speed zone can also help drivers to speed up within a certain timeframe when leaving an urban area. This transition area is extremely important for drivers who are not familiar with the urban area. They rely on the roadway features to indicate changes in surroundings that require an adjustment in their driving speed and behavior.

The gateway concept was presented in a 1998 paper by Greg Pates in which he depicted the region between a rural area and a fringe area (transitioning into urban use) as the gateway location where travel speed should be reduced and motorists should become more alert (*111*).

Safety research. Little information exists on the safety performance of gateway treatments. At present, such treatments have not been subject to extensive crash testing, undoubtedly because of the large degree of variation in the design and materials used in the construction of such features. Nevertheless, as noted in Skene, such features are often used by Canadian and British transportation professionals in speed transition zones to provide the driver with visual cues of a forthcoming change in safe operating conditions (*108*). In the United States, these gateway treatments are typically aimed at delineating the boundaries of specific communities.

Most of the research regarding gateway treatments focuses on their influence on operating speed or road users' perceptions of gateway treatments and their understanding that they are, in fact, transitioning into a different and slower speed environment.

In a 1997 study in the United Kingdom, researchers at the Transport Research Laboratory performed a before-after evaluation of a series of traffic calming strategies on major roads (*112*). The traffic volume on candidate roads was greater than 8,000 vehicles per day, and at least 10 percent of the traffic was composed of heavy vehicles. Speeds at inbound gateways were reduced at eight out of nine locations tested. Mean speed reductions ranged from 5 to 21 km/hr (3 to 13 mph). The study evaluated a variety of treatments, including speed reduction signage, narrowings, dragon teeth marking, speed cushions, colored pavement, and advanced signing. The researchers determined that the signing provided a high visual impact and resulted in large speed reductions. Physical devices such as the speed cushions resulted in a greater level of speed reduction than signing alone. The use of colored bands placed laterally across the road and placed in a series seemed to result in some speed reduction, but did not result in large decreases in speed. The researchers did not test the speed reduction signs and so could not comment on the effectiveness of these devices. Dragon-teeth marking, identified as one of the strategies, is depicted as a schematic and a photograph in Figure 14.

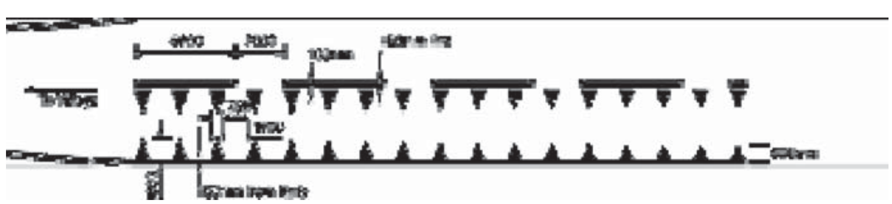


Photo and graphic reprinted from *Traffic Calming on Major Roads* (*112*) under the terms of the Click-Use License.

Figure 14. Dragon-teeth marking.

Berger and Linauer describe the operating speed influence of five raised island configurations used as gateway treatments from high-speed rural locations in Austrian villages (*113*). The five gateway island configurations are shown in Figure 15. The most dramatic influence on speeds occurred for Island Number 5, where the path of the approach lane was shifted dramatically. Table 12 demonstrates the range of speed reductions observed in this Austrian study, and Figure 16 shows the speed profile for Island Number 5.

A study performed for traffic calming strategies deployed from 1993 to 1996 in Ireland evaluated the transition zone as the area between a high-speed and low-speed road (*114*). The researchers evaluated the gateway transition from rural to urban environments in two phases:

- From the "Traffic Calming Ahead" sign to the "Do Not Pass" sign and
- From the "Do Not Pass" sign to the gateway treatments in the form of raised islands.

In the first phase, the researchers observed that the "Traffic Calming Ahead" sign at the beginning of the transition zone reduced inbound traffic speed. They determined this by comparing the speed reduction results in the transition zone with and without a "Traffic Calming Ahead" sign. With the "Traffic Calming Ahead" sign present, the 85th percentile speeds ranged between 90 and 100 km/hr (56 and 62 mph) at the start of the transition zone. The 85th percentile speeds at the "Do Not Pass" signs were reduced by 6 to 8 km/hr (4 to 5 mph). At locations without the traffic calming signs, the 85th percentile speeds were observed to be reduced by only 2 to 3 km/hr (1.2 to 1.9 mph) at the same approach location.

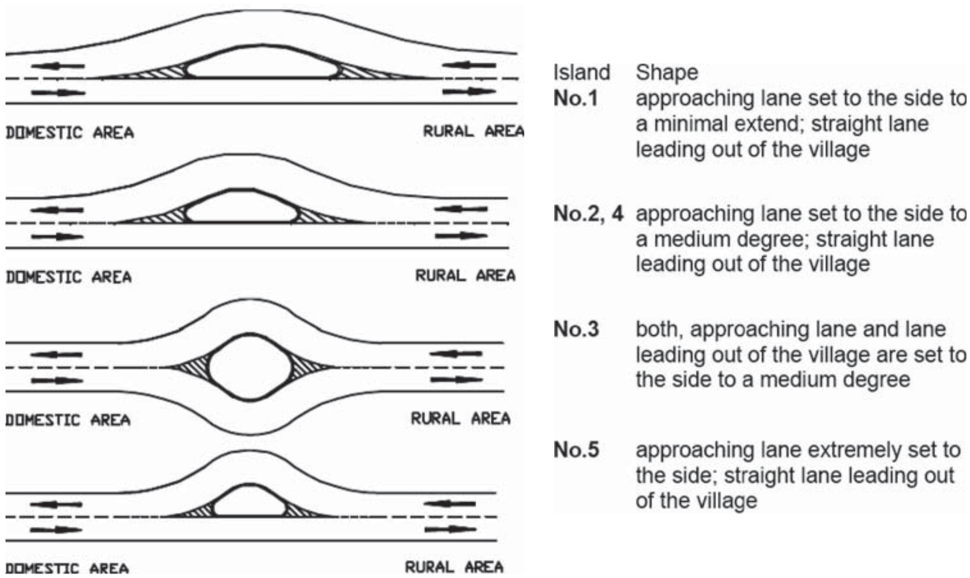
In the second phase, the speed reduction analysis results indicated that the gateway with raised traffic islands was an effective traffic calming treatment. They found that speed reductions of approximately 14 km/hr (9 mph) relative to the speed recorded at "Do Not Pass" signs were achieved at gateways with raised islands compared with a reduction of only 10 km/hr (6 mph) at gateways without raised islands.

A case study performed in Canada evaluated traffic calming strategies on an arterial road connecting two residential areas (*115*). Mohawk Road is a two-lane road with a 50-km/hr (31-mph) speed limit and was originally designed to service rural conditions. Speeding is very common on this road, and the test data showed that about 67 percent of the vehicles were exceeding the speed limit at the test location. After evaluating several alternatives, the jurisdiction finally elected to implement a series of landscaped speed control medians of various dimensions to help slow traffic down. Based on a before-after site evaluation, the speed reduction at control sections (where the strategies were not deployed) ranged from 85 percent to 88 percent for initially observed speeds, while the speeding percentage reduction in test sections ranged from 47 percent to 67 percent of the original speeds. This 20-percent speeding reduction was determined to be statistically significant at a 99-percent confidence level. The researchers were not able to compare corresponding crash data for the site.

Ewing reviewed a highway reconstruction project deployed in Saratoga Springs, New York (*116*). The case road transitioned from a four-lane, semi-rural highway with a flush, painted median and a speed limit of 88 km/hr (55 mph) to a three-lane urban road with a raised median and a posted speed limit of 48 km/hr (30 mph). The length of road available for this transition was 550 m (1,800 ft). Because the road passes the Saratoga Spa State Park, the Lincoln Baths, and the Museum of Dance, local representatives wanted a gateway for the transition of the road. The three photos shown in Figure 17 depict the gateway transition ultimately constructed for this facility.

Roundabouts are another commonly recommended gateway treatment. Pates has discussed how Norwegian trial projects using roundabouts experienced average speed reductions of 10 km/hr (6 mph) (*111*). Ewing (*23*) and Zein and Montufar (*92*) identify roundabouts as safe traffic calming alternatives to conventional intersections that can serve as both psychological and physical indicators of a transition from a rural high-speed environment to the lower speed urban street. Ewing also indicates that the center islands of the roundabouts can be landscaped and possibly include sculptures or monuments. Although the research team was unable to locate published research regarding the use of street art in roundabout medians, they did speak with researchers from both the United Kingdom and Australia. Representatives from both countries suggested that the application of street art in roundabouts is generally hazardous if these items are placed in the center of the first roundabout encountered by the driver on a rural road. The use of a series of roundabouts as a transition, with the street art located in the subsequent roundabouts, however, is a common practice and appears to be a safe strategy for these transitional regions.

The evaluation of gateway treatments is a new area of research for transportation and, as a result, very little is known about crashworthiness issues. As reviewed in this summary, the focus in using gateway treatments has been on the resulting speed reduction (thereby reducing ultimate crash severity).



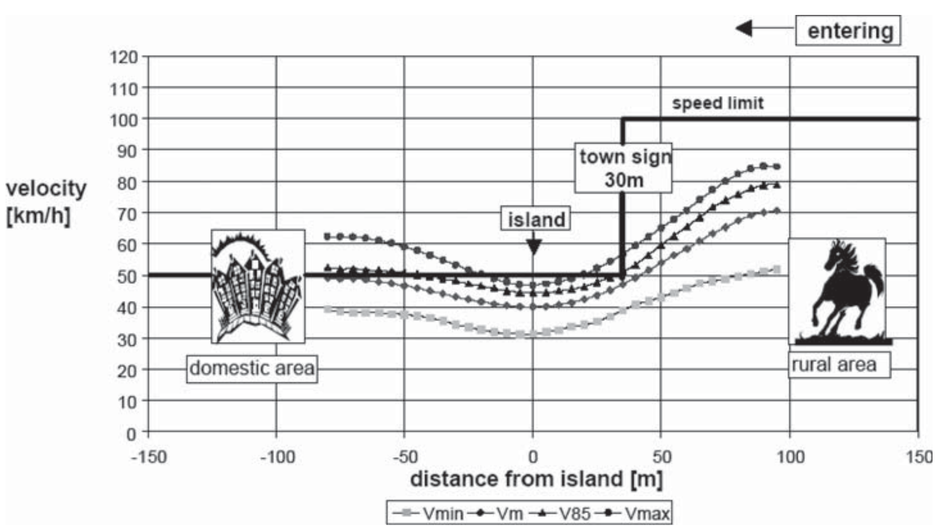
Graphic reprinted from "Raised Traffic Islands at City Limits—Their Effect on Speed" (*113*).

Figure 15. Gateway islands used in an Austrian study.

Table 12. Gateway median speed results from Austrian study (*113*).

Speed		Island Number 1	2	3	4	5
V_{mean} (km/h)	Previous	54.0	58.0	60.0	65.0	65.0
	Subsequent	54.1	48.4	44.1	47.2	40.1
V_{85} (km/h)	Previous	62.0	67.0	70.0	76.0	77.0
	Subsequent	61.0	54.5	50.5	55.2	44.6
V_{max} (km/h)	Previous	70.0	88.0	86.0	95.0	97.0
	Subsequent	76.2	59.3	56.1	65.8	46.9

Source: Adapted from "Raised Traffic Islands at City Limits—Their Effect on Speed" (*113*).



Graphic reprinted from "Raised Traffic Islands at City Limits—Their Effect on Speed" (*113*).

Figure 16. Island Number 5 speed profile.

Photos courtesy of Reid Ewing © (*116*)

Figure 17. Example of gateway transition in Saratoga Springs, NY.

Strategy summary. Common traffic calming gateway strategies are as follows:

Purpose	Strategy
Reduce likelihood of run-off-road crash	Apply speed reduction signs, pavement markings, and other gateway treatments (T)
Reduce severity of run-off-road crash	• Construct gateway raised median treatments (T) • Construct roundabouts with traversable island centers in initial islands (T)

Literature Review Conclusion

This review has examined the knowledge and practice of roadside safety as they relate to the design of roadsides in urban areas. A brief review of roadside crash statistics demonstrates that roads in the urban environment, although generally lower speed facilities than their rural counterparts, nevertheless suffer from run-off-road collisions with roadside hazards. The operational offset concept for curbed urban roadways should, therefore, not be mistaken as a safety standard, and urban setback policies should be considered for future adoption.

Although they are not the focus of this research, the strategies used in urban environments to help prevent errant vehicles from leaving the travelway and encountering a fixed roadside object are briefly reviewed in this report.

Finally, this review has summarized common urban roadside objects and known safety issues associated with these roadside objects. A collection of safety strategies (experimental, tried, and proven) for each set of roadside hazards is included.

In general, this review makes it clear that the safety implications of many roadside features (such as curbs, signs, and utility poles) are well understood; however, there are significant gaps in understanding how many urban roadside features (such as landscape buffers, trees, and lighting) should be addressed for safe urban roadside development.

CHAPTER 3

Findings and Applications

The goals of this research effort are to develop design guidelines for safe and aesthetic urban roadside treatments and ultimately to develop a toolbox of effective treatments that balance the needs of all roadway users while accommodating community values. Of particular interest is the design of urban roadways that carry substantial volumes of traffic and are designed for higher operating speeds, thus often raising additional roadside safety concerns.

To accomplish these goals, the research team performed two specific tasks. These two research tasks were as follows:

- Developing a systematic analysis approach (referred to as an Urban Control Zone Assessment) to enable jurisdictions to better target hazardous urban roadside locations and
- Developing before-after case studies for a variety of urban roadside treatments.

These two tasks are described in detail in the sections that follow, with specific case information included in Appendixes A and B, available online at http://trb.org/news/blurb_detail.asp?id=9456. Appendix C (included herein) includes a toolbox that generally summarizes the safe application of roadside elements in an urban environment. A supplemental product of this research effort is draft language for possible inclusion in the urban roadside chapter of the AASHTO *Roadside Design Guide*. This document is included in Appendix C.

Urban Control Zone Assessment

Experimental Design

Many urban roadside environments are crowded with potential hazards. The task of identifying which objects pose the greatest risk to users of the road can be daunting for a jurisdiction with limited resources. In 1999, the Florida Department of Transportation (FDOT) developed a document called the *Utility Accommodation Manual* (*117*). This document's purpose was to provide direction for ways to reasonably accommodate utilities in state transportation facility rights-of-way. FDOT included a concept in this document called "Control Zones" for consideration at facilities with limited or no access control. Although the emphasis of FDOT's document was utility pole placement, the concept of control zones can be expanded and is a promising approach for evaluating an urban roadside environment in its entirety. FDOT's *Utility Accommodation Manual* defines control zones as the following:

> Areas in which it can be statistically shown that accidents are more likely to involve departure from the roadway with greater frequency of contact with above ground fixed objects. (*117*)

Example control zones include those that contain objects hit more than two times within three consecutive years, objects located within the return radii and object horizontal offset distance at an intersecting street, objects located within 1 m (3 ft) of a driveway flare, and objects located along the outside edge of a horizontal curve for roads with operating speeds greater than 56 km/h (35 mph).

The research team performed a systematic evaluation of crash data to define common control zones for urban roadside environments. To accomplish this task, the research team evaluated urban crash data for four different locations. Study areas included urban corridors located in Atlanta, Georgia; Orange County and San Diego County, California; Chicago, Illinois; and Portland, Oregon. Although not all sites were within the same city limits for a regional study, they were all characterized by urban corridors where fixed-object crashes occurred along the corridor (often in cluster configurations). The sources of the crash data varied. The Georgia Department of Transportation (GDOT) provided Atlanta crash data and road characteristic information. The Oregon Department of Transportation (ODOT) provided Portland crash data and road information. For corridors located in Illinois and California, the research team used data from the Highway Safety Information System (HSIS) database maintained by FHWA. The research team specifically targeted higher speed urban roads in each of the regions, although some of the corridors included transitions to lower speeds.

Comprehensive crash data can be informative, but the research team supplemented this information by collecting corridor video data for both directions of travel. The team then used this video data to determine the type and placement of roadside objects, adjacent land use, access density, and so forth. Table 13 shows the actual corridors evaluated for this task. The initial goal developed by the research team was a sample of 16 to 32 km (10 to 20 mi) of urban arterial per city; however, due to select long corridors with frequent fixed crashes, the California and Illinois data collection considerably exceeded this initial data goal. As a result, 244.9 km (152.3 mi) of urban arterial from a total of four states are included in this analysis.

The goal of this task was to identify urban control zones that can be then applied to other regional analyses for project priority and evaluation. These zones are summarized in the sections that follow.

Findings and Recommendations

The various corridors the research team evaluated for identification of potential urban control zones included a wide variety of speed limits, physical features, and types of crashes. In Appendix A, each site is described in detail including observed roadway conditions as well as crash type and crash severity information. In addition, the research team performed a cluster crash analysis to identify locations with an overrepresentation of fixed-object crashes. A spot map for each site is also included in the Appendix A summary. Common fixed-object crash features for each site are further identified in Table 14. As members of the research team evaluated fixed-object crashes at each site, recurring road features emerged at fixed crash locations. Many of these are locations where roadside crashes can be anticipated; however, the information included in Table 14 helps demonstrate the frequency of these road conditions at the study locations.

The 6-year crash summaries included in Appendix A present total crash type information for each study corridor. As is often the case along an urban corridor, a large number of crashes occurred at intersections and driveways. Crashes at these locations are generally angle, head-on, rear-end, and, in some instances, sideswipe crashes. In addition, intersection-related crashes often involve more than one vehicle. As a result, crash severity at each study corridor location is further presented in Table 15, in which crash severity percentages for all crashes are contrasted with crash severity of fixed-object crashes only. The average per state for the study corridors representing the percent injured varied from 22.5 percent to 46.1 percent for all crashes (with an overall average of 34.6 percent), while fixed-object injury crashes ranged from 22.2 percent to 38.3 percent (with an overall average of 29.2 percent). By contrast, fixed-object crash fatalities at all locations were a larger percentage than for all crashes with a total average of 1.1-percent fatal crashes for all reported fixed-object crashes compared with only 0.3-percent fatal crashes for all crash types (the "all crashes" statistic includes the fixed-object crashes). Table 16 further depicts the total percentage of fixed-object crashes and pedestrian crashes for the study corridors. The urban fixed-object crashes were approximately 6.7 percent of all crashes observed for the four state study corridors.

The nature of the roadside crashes at these corridor locations pointed to a common set of frequently hit objects resulting

Table 13. Urban control zone sites evaluated in this study.

California Sites		Georgia Sites	
Study Corridor Name	Length km (mi)	Study Corridor Name	Length km (mi)
S. H. Route 1	11.3 (7.0)	Alpharetta Highway	3.5 (2.2)
S. H. Route 39	29.3 (18.2)	Briarcliff Road	4.2 (2.6)
S. H. Route 74	3.2 (2.0)	Candler Road	5.6 (3.5)
S. H. Route 75	5.3 (3.3)	14th St / Peachtree St	4.8 (3.0)
S. H. Route 76	11.3 (7.0)	Franklin Road	3.7 (2.3)
S. H. Route 78	6.4 (4.0)	Moreland Avenue	6.4 (4.0)
S. H. Route 90	8.0 (5.0)	Roswell Road – 1 (Cobb)	3.2 (2.0)
Subtotal:	**74.8 (46.5)**	Roswell Road – 2 (Cobb)	3.2 (2.0)
		Roswell Road (Fulton)	3.5 (2.2)
		Subtotal:	**38.1 (23.8)**
Illinois Sites		**Oregon Sites**	
Study Corridor Name	Length km (mi)	Study Corridor Name	Length km (mi)
Route 6	11.9 (7.4)	Beavercreek Rd	3.2 (2.0)
Route 14	16.6 (10.3)	Brookwood Ave	5.5 (3.4)
Route 19(Cook)	9.2 (5.7)	Cascade Hwy	1.6 (1.0)
Route 19(Dupage)	12.1 (7.5)	Evergreen Pkwy	4.3 (2.7)
Route 25	13.7 (8.5)	Farmington Rd	2.7 (1.7)
Route 31	14.0 (8.7)	Foster Rd	9.3 (5.8)
Route 41	16.6 (10.3)	McLoughlin Blvd	2.4(1.5)
Subtotal:	**94.1 (58.4)**	185th Ave	8.9 (5.5)
		Subtotal:	**37.9 (23.6)**

Table 14. Urban control zone corridor overview.

Case No.	Corridor Description	Lane merge with object offsets 2–6 ft	Lane merge with object offsets > 6 ft	Channelization island very small with poles	Driveway / intersection with obstacles located on far side	Median at horizontal curve with obstacle offsets 4–6 ft	Roadside at horizontal curve with obstacles 4–6 ft	Numerous roadside obstacles within 1–2 ft (on tangent)	Roadside ditch with non-traversable headwalls	Uneven roadside with obstacles (offset varies)	Corridor clear zone not maintained at right-turn lanes	Guardrail wrapped around curb return	Longitudinal barrier/guardrail offset 2–6 ft	Scenic / tourist location with close obstacles
UCZ-CA-1	SH 1, Orange County, CA	x		x	x									x
UCZ-CA-2	SH 39, Orange County, CA				x			x						
UCZ-CA-3	SH 74, Orange County, CA						x			x				
UCZ-CA-4	SH 75, San Diego County, CA					x	x			x				x
UCZ-CA-5	SH 76, San Diego County, CA	x								x				
UCZ-CA-6	SH 78, San Diego County, CA	x			x					x				
UCZ-CA-7	SH 90, Orange County, CA	x			x			x						
UCZ-GA-1	Alpharetta Highway, Fulton County, GA				x									
UCZ-GA-2	Briarcliff Rd., DeKalb County, GA	x			x		x		x					
UCZ-GA-3	Candler Rd., DeKalb County, GA				x					x		x		
UCZ-GA-4	14th St./Peachtree St., Fulton County, GA				x			x						
UCZ-GA-5	Franklin Rd., Cobb County, GA				x		x							
UCZ-GA-6	Moreland Dr., DeKalb County, GA				x		x	x						
UCZ-GA-7	Roswell Rd. (1), Cobb County, GA								x		x			
UCZ-GA-8	Roswell Rd. (2), Cobb County, GA									x				
UCZ-GA-9	Roswell Rd., Fulton County, GA				x		x	x						
UCZ-IL-1	Route 6, Will County, IL				x			x						
UCZ-IL-2	Route 14, Cook County, IL			x				x						
UCZ-IL-3	Route 19, Cook County, IL			x	x			x						
UCZ-IL-4	Route 19, DuPage County, IL							x		x				
UCZ-IL-5	Route 25, Kane County, IL				x		x	x		x				
UCZ-IL-6	Route 31, Kane County, IL			x	x			x		x				
UCZ-IL-7	Route 41, Cook County, IL				x		x	x			x	x	x	x
UCZ-OR-1	Beavercreek Rd., Clackamas County, OR		x	x										
UCZ-OR-2	Brookwood Pkwy., Washington County, OR						x	x	x	x				
UCZ-OR-3	Cascade Hwy., Clackamas County, OR	x		x				x		x				
UCZ-OR-4	Evergreen Pkwy, Washington County, OR					x		x						
UCZ-OR-5	Farmington Rd., Washington County, OR				x	x		x						
UCZ-OR-6	Foster Rd., Multnomah County, OR				x		x	x	x					
UCZ-OR-7	McLoughlin Blvd., Clackamas County, OR		x					x	x					
UCZ-OR-8	185th Ave., Washington County, OR												x	

from these crashes, with varying severity levels. Commonly hit fixed objects included the following:

- Poles and posts,
- Light standards,
- Traffic signals,
- Trees and landscaping,
- Mailboxes,
- Walls and fences,
- Barrier or guardrail, and
- Embankment.

In addition, roadside furniture may have been impacted, but the crash databases classified this type of roadside object as "other unidentified object."

As shown in Table 14, the primary locations for fixed-object crashes were characterized by several common road and roadside configurations. Often, locations with these configurations

Table 15. Summary of crash severity distributions for study corridors.

Case No.	All Crashes			Fixed-Object Crashes		
	Percent No Injury or Unknown	Percent Injured	Percent Fatal	Percent No Injury or Unknown	Percent Injured	Percent Fatal
UCZ-CA-1	57.27	42.48	0.26	77.66	21.32	1.02
UCZ-CA-2	55.28	44.13	0.59	74.66	24.80	0.54
UCZ-CA-3	70.30	29.70	0.00	64.29	35.71	0.00
UCZ-CA-4	66.39	33.33	0.28	62.30	37.70	0.00
UCZ-CA-5	29.79	69.09	1.12	56.52	39.13	4.35
UCZ-CA-6	31.72	66.42	1.87	56.41	41.03	2.56
UCZ-CA-7	62.64	37.21	0.14	76.62	23.38	0.00
Average (CA)	53.34	46.05	0.61	66.92	31.87	1.21
UCZ-GA-1	79.48	20.47	0.05	75.00	23.61	1.39
UCZ-GA-2	81.46	18.48	0.06	73.86	26.14	0.00
UCZ-GA-3	75.63	24.25	0.12	74.63	24.63	0.75
UCZ-GA-4	80.23	19.72	0.05	64.02	35.37	0.61
UCZ-GA-5	72.76	27.16	0.08	76.79	23.21	0.00
UCZ-GA-6	75.46	24.43	0.11	71.69	28.31	0.00
UCZ-GA-7	78.33	21.52	0.15	86.49	13.51	0.00
UCZ-GA-8	73.11	26.78	0.11	84.21	15.79	0.00
UCZ-GA-9	80.56	19.31	0.13	72.09	27.91	0.00
Average (GA)	77.45	22.46	0.10	75.42	24.28	0.31
UCZ-IL-1	72.75	26.95	0.30	79.07	18.60	2.33
UCZ-IL-2	79.09	20.64	0.27	78.57	19.05	2.38
UCZ-IL-3	71.63	28.12	0.25	75.68	22.52	1.80
UCZ-IL-4	74.37	25.51	0.12	75.81	24.19	0.00
UCZ-IL-5	68.69	30.78	0.54	72.09	25.58	2.33
UCZ-IL-6	74.35	25.51	0.14	84.00	15.00	1.00
UCZ-IL-7	73.20	26.32	0.49	67.28	30.51	2.21
Average (IL)	73.44	26.26	0.30	76.07	22.21	1.72
UCZ-OR-1	55.91	44.09	0.00	60.00	40.00	0.00
UCZ-OR-2	55.26	44.74	0.00	70.59	29.41	0.00
UCZ-OR-3	46.20	53.80	0.00	50.00	50.00	0.00
UCZ-OR-4	53.90	45.35	0.74	50.00	44.44	5.56
UCZ-OR-5	61.49	38.30	0.21	69.23	30.77	0.00
UCZ-OR-6	58.40	41.13	0.47	44.44	51.85	3.70
UCZ-OR-7	56.79	43.21	0.00	73.33	26.67	0.00
UCZ-OR-8	61.82	38.03	0.15	66.67	33.33	0.00
Average (OR)	56.22	43.58	0.2	60.53	38.31	1.16
Average (4 States)	65.11	34.59	0.30	69.74	29.17	1.10

experienced clustered crashes while much of the roadside along the corridor remained free of crashes. The road and roadside configurations that are often involved in fixed-object crashes can be generally grouped into the following:

- Obstacles in close lateral proximity to the curb face or lane edge;
- Roadside objects placed near lane merge points;
- Lateral offsets not appropriately adjusted for auxiliary lane treatments;
- Objects placed inappropriately in sidewalk buffer treatments;
- Driveways that interrupt positive guidance and have objects placed near them;
- Three kinds of fixed-object placement at intersections;
- Unique roadside configurations associated with high crash occurrence; and
- Roadside configurations commonly known to be hazardous.

Each of these potential Urban Control Zones is discussed in the sections that follow.

Obstacles in Close Lateral Proximity to the Curb Face or Lane Edge

Historically, a lateral offset (referred to as an operational offset) of 0.5 m (1.5 ft) has been considered the absolute minimum lateral (or perpendicular) distance between the edge of an object and the curb face. As previously indicated, this offset value enabled vehicle access, that is, a person could open a car door if the vehicle were stopped adjacent to the curb. **This operational offset was never intended to represent an acceptable safety design standard,** although it was sometimes misinterpreted as being one. The urban environment limits lateral offset distances simply because of the restricted right-of-way widths common to an urban setting.

Table 16. Summary of crash type distributions.

Case No.	Percent Fixed-Object Crashes	Percent Pedestrian Crashes	Percent Others
UCZ-CA-1	10.1	1.1	88.8
UCZ-CA-2	5.4	2.6	92.0
UCZ-CA-3	8.5	1.2	90.3
UCZ-CA-4	17.1	0.8	82.1
UCZ-CA-5	6.4	0.7	92.9
UCZ-CA-6	14.6	3.0	82.4
UCZ-CA-7	5.5	0.9	93.6
Average (CA)	9.7	1.5	88.9
UCZ-GA-1	1.9	0.5	97.6
UCZ-GA-2	2.6	0.4	97.0
UCZ-GA-3	3.9	1.5	94.6
UCZ-GA-4	2.8	1.0	96.2
UCZ-GA-5	4.7	1.3	94.0
UCZ-GA-6	5.9	1.6	92.5
UCZ-GA-7	5.6	0.8	93.6
UCZ-GA-8	10.7	0.0	89.3
UCZ-GA-9	2.9	1.6	95.5
Average (GA)	4.6	1.0	94.5
UCZ-IL-1	6.4	1.6	92.0
UCZ-IL-2	3.8	1.3	94.9
UCZ-IL-3	4.7	0.8	94.5
UCZ-IL-4	3.6	0.5	95.9
UCZ-IL-5	6.6	2.1	91.3
UCZ-IL-6	4.8	0.4	94.8
UCZ-IL-7	14.8	1.8	83.4
Average (IL)	6.4	1.2	92.4
UCZ-OR-1	2.7	0.0	97.3
UCZ-OR-2	14.9	0.0	85.1
UCZ-OR-3	7.6	0.0	92.4
UCZ-OR-4	6.7	1.1	92.2
UCZ-OR-5	2.8	1.3	95.9
UCZ-OR-6	3.2	1.6	95.2
UCZ-OR-7	9.3	0.0	90.7
UCZ-OR-8	1.8	1.4	96.8
Average (OR)	6.1	0.7	93.2
Average (4 States)	6.7	1.1	92.3

The research team for this project observed several objects located within inches of the edge of the road for the selected study corridors. In general, these items were utility poles, light standards, street signposts, and trees. **Evaluation of the role of trees in crashes was difficult because the types of trees in the selected study corridors varied dramatically and included mature rigid trees as well as small-caliper ornamental trees.** Due to the varying nature of the tree placement along the corridors (and the wide range of their frangible tendencies), the research team often could not identify a specific tree involved in the crashes recorded in the crash database. Actual crash reports were not available for most of the locations, so unless a tree exhibited scars, it was not feasible to determine actual tree types involved in crashes.

Poles, posts, and light standards, however, were easier to evaluate. The lateral placement of these items was generally consistent along short corridor segments. The research team, therefore, further evaluated crash locations on the basis of crash records for crashes involving poles, posts, and light standards to determine common lateral offsets and crash frequency. Posts (which could, in some instances, be classified as breakaway) were included in this assessment because these items are often coded as "poles or posts," so posts could not always be evaluated separately in the analysis.

To evaluate fixed-object crashes associated with poles, posts, and light standards, the research team viewed the corridor videos (for both travel directions) and for each location recorded data for the characteristics listed in Table 17.

For the study corridors extending over the 6-year period, a total of 503 crashes into poles, posts, or light standards occurred. Of these, 389 occurred during dry weather, 78 during wet weather, 4 during ice, 4 during fog, 19 during snow, and 9 during unknown weather conditions. Table 18 depicts the distribution of these weather-related crashes on the basis of corridor speed limit. Most crashes occurred during dry and wet conditions on roads with posted speed limits of 48 to 72 km/h (30 to 45 mph).

To evaluate lateral offset to the objects that were hit, Table 19 further shows these crashes aggregated by the posted speed limit and lateral distance category. (The lateral offset was the

Table 17. Pole/post/light-standard variables.

Description	Available Options
Curb:	Yes or No
Continuous Edge line Present:	Yes or No
Bike Lane Present:	Yes or No
Driveway Immediately Upstream of Object Hit:	Yes or No
Night Hours (10 p.m. to 6 a.m.):	Yes or No
Weather at Time of Crash:	Dry Wet Ice Fog Snow Other or Not Stated
Lateral Distance from Curb Face (when present) or Lane Edge (when no curb):	Less than 1' 1' – 2' 2' – 4' 4' – 6' 6' – 8' 8' – 10' 10' – 15' 15' – 20' Greater than 20'

distance from the curb face or lane edge [at locations without curb].) Only a small subset of these urban crashes occurred at locations where curb was not present. As a result, Table 20 depicts the 456 sites where curb was present at the pole, post, or light-standard crash location. The cumulative percentage demonstrates that, for curb locations, 93.4 percent of all fixed-object pole/post/light standard crashes occurred within 1.8 m (6 ft) of the curb face while 82.5 percent of these occurred within 1.2 m (4 ft) of the curb.

This observation, combined with a tendency for clustered crashes (for poles, these occurred along short road segments with objects laterally positioned close to the road), suggests that in an urban environment the placement of rigid objects should ideally be more than 1.8 m (6 ft) from the curb face and no closer than 1.2 m (4 ft) wherever possible.

In addition, the frequency of object impact was greater at locations where objects were in close proximity to the road and located on the outside of a horizontal curve. These crashes occurred at locations where objects were placed on the right edge of the road and at locations where objects were placed on medians. This suggests that the lateral offset placement of objects at horizontal curves should be increased wherever possible.

Roadside Objects Placed Near Lane Merge Points

The placement of roadside objects in the vicinity of lane merge points increases the likelihood of vehicle impact with these objects. The research team identified several cluster crashes at these lane merge locations: lane drop locations, acceleration taper ends, and bus bay exit transitions. As shown in Table 14, six sites included cluster crashes at taper point locations where fixed objects were laterally located less than 1.8 m (6 ft) from the curb face or lane edge (for locations where curb was not present). Cluster crashes occurred at two additional sites where these objects were located more than 1.8 m (6 ft) laterally. Longitudinal placement of objects within approximately 6.1 m (20 ft) of the taper point increased the frequency of these crashes. Figure 18 shows two example crash locations with a pole located at lane merge tapers. This increased likelihood of fixed-object crashes at lane merge tapers suggests that an object-free buffer zone at taper points on urban roadways would eliminate or reduce roadside crashes at these locations and allow drivers to focus solely on merging into the traffic stream.

Table 18. Poles/post/light-standard crashes for speed limit thresholds.

	Speed Limit km/h (mph)							
Weather	40 (25)	48 (30)	56 (35)	64 (40)	72 (45)	80 (50)	89 (55)	Total
Dry	0	72	152	29	104	19	13	389
Wet	1	18	26	7	22	2	2	78
Ice	0	0	3	0	1	0	0	4
Fog	0	2	0	0	2	0	0	4
Snow	1	2	1	0	4	1	0	9
Other or Not Stated	1	8	6	2	2	0	0	19
Total:	3	102	188	38	135	22	15	503

Table 19. Lateral distance to objects that were hit for all corridors.

Lateral Distance m (ft)	Speed Limit km/h (mph) 40 (25)	48 (30)	56 (35)	64 (40)	72 (45)	80 (50)	89 (55)	Total	Percent	Cumulative Percent
0–3 (0–1)	0	35	71	2	19	1	1	129	25.6	25.6
3–7 (1–2)	2	29	44	16	50	13	3	157	31.2	56.8
7–13 (2–4)	0	26	32	2	32	2	3	97	19.3	76.1
13–20 (4–6)	1	6	23	8	18	1	0	57	11.3	87.4
20–26 (6–8)	0	3	11	1	11	0	0	26	5.2	92.6
26–33 (8–10)	0	3	4	3	2	4	2	18	3.6	96.2
33–49 (10–15)	0	0	0	3	2	0	6	11	2.2	98.4
49–66 (15–20)	0	0	3	3	1	1	0	8	1.6	100
Total:	3	102	188	38	135	22	15	503	100	

Lateral Offsets Not Appropriately Adjusted for Auxiliary Lane Treatments

At many of the study corridors, roadside objects, such as utility poles, were placed a considerable distance from the active travel lane. Often lateral offsets of 3.7 to 4.3 m (12 to 14 ft) existed at mid-block locations; however, at locations with auxiliary lanes, such as extended-length, right-turn lanes developed for driveway or intersection turning movements, the lateral location of the objects remained unchanged, resulting in an effective lateral offset that was often less than 0.6 m (2 ft). Two of the corridors depicted in Table 14 consistently included cluster crashes at these turn-lane configurations. In addition, crashes at many of the other corridor sites occurred periodically (but not always in clusters) at similar turn-lane locations. This observation suggests that increased lateral offsets should be consistently maintained at extended-length, left-turn lane locations. When a lane is added that functions as a higher speed turn lane or a through lane, the roadside objects should be shifted laterally as well.

Other auxiliary lane locations can include bike lanes. At these locations, the higher speed motor vehicles are further separated from the roadside environment, so the width of the clear zone should include the bike lane. This does not, however, modify the recommended minimum lateral offset from the curb face.

Objects Placed Inappropriately in the Sidewalk Buffer Treatment

The placement of roadside objects immediately adjacent to active travel lanes at some corridor sites increased when a sidewalk was physically separated from the curb by a

Table 20. Lateral distance to objects that were hit for corridors with curb only.

Lateral Distance m (ft)	Speed Limit km/h (mph) 40 (25)	48 (30)	56 (35)	64 (40)	72 (45)	80 (50)	89 (55)	Total	Percent	Cumulative Percent
0–3 (0–1)	0	35	71	2	19	1	1	129	28.3	28.3
3–7 (1–2)	2	29	44	16	50	13	3	157	34.4	62.7
7–13 (2–4)	0	26	27	2	30	2	3	90	19.7	82.5
13–20 (4–6)	1	6	23	2	18	0	0	50	11.0	93.4
20–26 (6–8)	0	3	10	1	9	0	0	23	5.0	98.5
26–33 (8–10)	0	3	1	2	0	0	0	6	1.3	99.8
33–49 (10–15)	0	0	0	0	0	0	1	1	0.2	100
49–66 (15–20)	0	0	0	0	0	0	0	0	0.0	100
Total:	3	102	176	25	126	16	8	456	100	

Photo by Karen Dixon.

Figure 18. Pole placed at lane merge.

buffer strip that contained fixed objects. Interestingly, crashes varied dramatically at these locations. At locations with buffer strips 0.9 m (3 ft) wide or narrower, objects were systematically hit. Wider buffer strips containing mature trees with large-diameter trunks placed within 0.9 to 1.2 m (3 to 4 ft) of the curb showed a significant increase in the number of severe crashes with the trees. At locations with smaller, ornamental trees located in the center of a buffer strip, the number of severe crashes into trees was dramatically reduced. By contrast, utility poles and light standards were frequently hit at locations where these objects were placed in the center of the buffer strip. At several sites, however, the research team observed smaller, more forgiving objects, such as landscaping with small-caliper trees, positioned near the center of the buffer strip and the more rigid poles and light standards positioned immediately adjacent to the sidewalk and as far from the active travel lane as possible. The crash analysis at these staggered-object-placement buffer strips showed very few roadside crashes.

This research suggests that the placement of rigid objects on sidewalk buffer strips 1.2 m (4 ft) wide or narrower should be avoided. For wider buffer strips, placement of the more forgiving roadside items close to the road and placement of the more rigid objects at a greater lateral offset of 1.2 m (4 ft) or more from the curb face is recommended. Figure 19 depicts recommended buffer strip object placement scenarios.

Driveways Interrupt Positive Guidance/Objects Placed Near Driveways

Many rural roads have a white edge line delineating the right edge of the travelway. In urban environments, a continuous white line is often not included at locations with a curb as the curb itself functions to delineate the edge of the road. During nighttime or inclement weather conditions, the need for positive guidance along the right edge of the road may be heightened due to reduced visibility. In addition, impaired or fatigued drivers may depend more heavily on this delineation to help them keep their vehicle within the boundaries of the travelway. For a few of the observed corridors, a continuous white line occurred either at the edge of the gutter pan or a few feet from the gutter pan to delineate a separate bicycle lane. When this white line was not present, single-vehicle crashes tended to occur more frequently at driveway locations. In particular, objects positioned on the far side of driveways were hit more often than objects located away from driveways or objects that were located on the near side of driveways. This observation is not a surprise because the curb line may no longer provide positive guidance to vehicles at driveway entry points, and the driveway configuration certainly does not provide a re-direction function when a vehicle drifts from the road. Figure 20 shows an example crash location with a pole located at the far side of a driveway. The placement of the pole within the sidewalk is, of course, also not recommended.

Of the 456 pole/post/light crashes that occurred at locations with curb (see Table 20), 181 occurred at driveways, so this location accounted for approximately 40 percent of all of these crashes. Of the 181 driveway-associated, fixed-object crashes, 155 occurred at locations with no supplemental positive guidance such as a white edge line, approximately 86 percent of these crashes. This percentage of the crashes associated with driveways that did not provide additional positive guidance could simply be an artifact of how many sites did not have an edge line, but this high a number of crashes certainly warrants future research. Regardless, avoiding

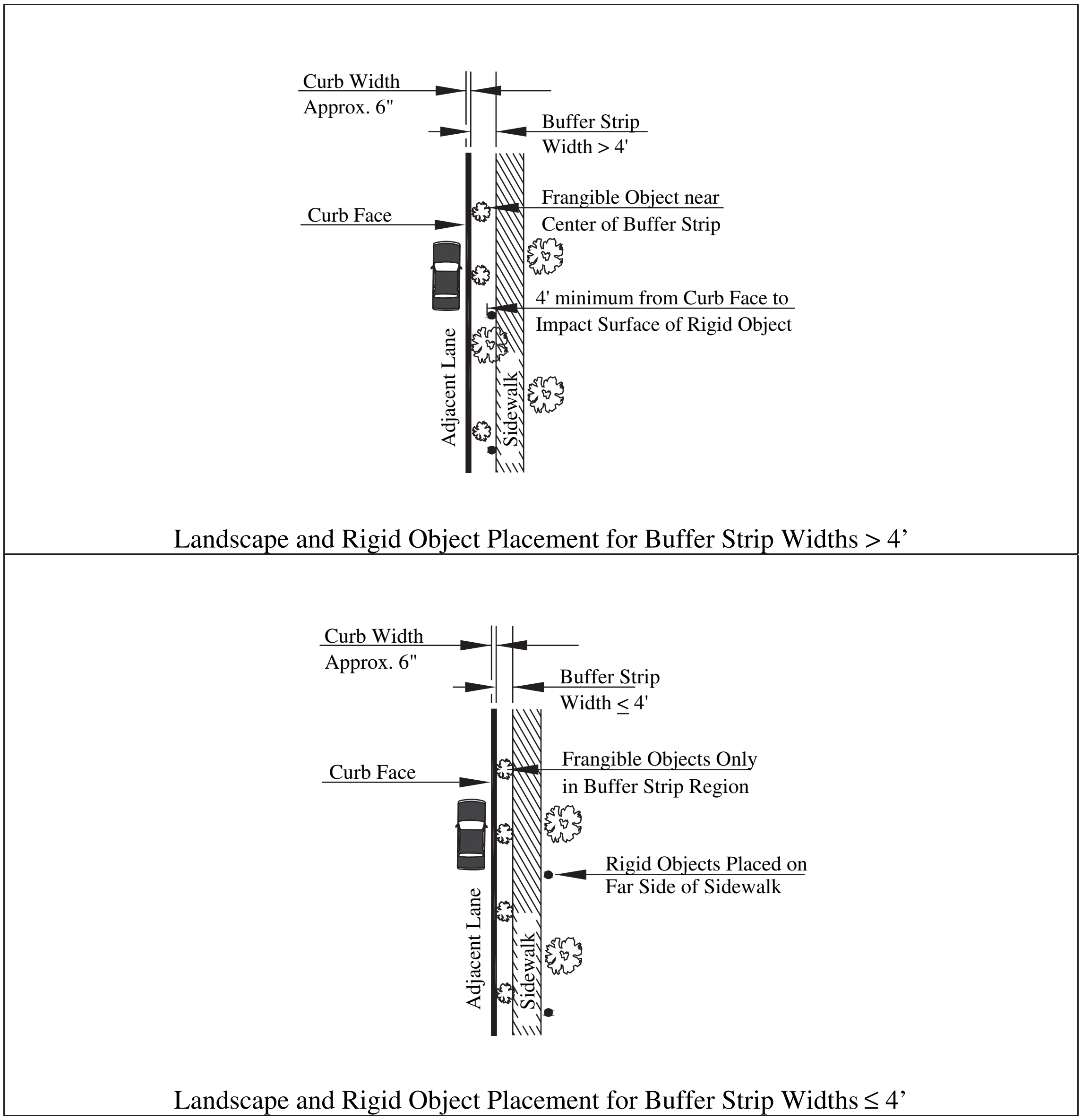


Figure 19. Object placement at buffer strips.

the placement of poles on the immediate far side of driveways will help to reduce the number of crashes. It is important to remember that placing poles on the immediate far side of a driveway may sometimes be the result of trying to avoid putting an object on the near side of the driveway in the visibility triangle for drivers of vehicles exiting the driveway, so relocation of the pole should avoid this critical location as well.

Three Kinds of Fixed-Object Placement at Intersections

Crashes at intersections often occur between vehicles; however, several intersection crashes in which vehicles hit roadside objects were also noted in the corridor analysis. In some cases, the crash occurred because a driver attempted to avoid hitting another vehicle; however, several single-vehicle crashes were also observed at intersection locations. In general, these single-vehicle, fixed-object crashes at intersections fell into one of the following three categories:

- Impacted small channelization islands (often these islands included signs, traffic signals, or poles). This intersection crash type occurred at six of the study corridors (see Table 14).
- Impacted objects positioned close to the lane edge. These objects often interfered with turning movements when vehicles veered from their turning path.
- Impacted objects where pedestrian ramps at intersection corners were oriented in such a way as to direct errant

Photo by Karen Dixon.

Figure 20. Lack of positive guidance at a driveway.

Photo by Karen Dixon.

Figure 21. Object orientation with access ramp.

vehicles toward roadside objects. Figure 21 shows one crash location where this occurred. This crash condition is similar to the driveway crash condition with no positive guidance discussed previously.

Unique Roadside Configurations Associated with High Crash Occurrence

Several of the study corridors were characterized by high crash numbers at a specific location. Often this peak in crash statistics resulted from a physical road feature unique to the site. For example, at corridor UCZ-IL-1 a disproportionately large number of crashes involved an underpass structure. When members of the research team inspected the site, they determined that sometime in its past, a two-way road with one lane under each side of the underpass wall had been converted into a two-lane, one-way road. This modification occurred at two separate locations due to the creation of a one-way pair configuration. As a result, the approach to the underpass required vehicles to shift in an effort to avoid the wall now located between the lanes in the same direction of travel. The crashes occurred when a vehicle did not safely navigate this required lane shift. This crash cause was evident due to a scarred underpass wall.

Locations of this type are unique and should be considered individually for crash mitigation treatments. The creation of simple crash spot maps (as shown in Appendix A) can enable an agency to quickly identify cluster crash locations of this nature.

Roadside Configurations Commonly Known to Be Hazardous

Several roadside crashes occurred at locations where they would be expected. These sites exhibited characteristics known to result in potentially hazardous conditions. For example, locations with roadside ditches, nontraversable headwalls and culverts (often at driveways), or uneven roadside grading were common roadside crash locations. In addition, crashes occurred at high-speed locations where sloping curb delineated the roadside edge, but adequate clear zone was not available. Finally, three of the corridors were located in the vicinity of scenic or tourist attractions. At these locations, roadside objects were hit more frequently even when lateral offsets to the objects were similar to those at other crash-free sites. Regardless of the cause, additional lateral offset to objects in these or similar locations seems prudent to minimize the risk of hazardous run-off-road crashes for unfamiliar drivers.

Case Study Task and Summary of Findings

Experimental Design

The individual projects selected as part of this case study task were used to identify strategies where safety and aesthetics were incorporated into the roadway's design. The research team identified several recent beautification or roadside improvement projects to use as indicators for the influence of improvements on crash conditions. Ideally, a project where only one item is changed (such as moving trees to the far side of sidewalks) would be perfect for this task; however, the research team could not identify projects of this nature because, in general, transportation agencies implement multiple improvements in each project. As a result, the data analysis for this case study task can provide general indications about the safety impacts of beautification or roadside improvement projects, but cannot be used to explicitly evaluate individual features and their associated hazards.

Initially, the research team proposed two levels of case studies (one with comparison sites); however, the NCHRP Project 16-04 panel requested the stand-alone case studies (locations without comparison sites) so as to evaluate as many projects as possible. The stand-alone case studies include crash type summaries, crash severity summaries, and before-after crash analysis for a specific improvement corridor with data developed and provided by local jurisdictions. The research team attempted to solicit candidate projects from a variety of geographically distributed jurisdictions.

Inclusion of a case study project required that the project have a focus on median or roadside improvements as well as having available most, if not all, of the requested data. The research team attempted to collect crash data for 3-year periods before and after the project was implemented. This level of crash information was not available for all sites. In select cases, projects with a minimum of 1 year of data were included; projects with less than 1-year's worth of post-reconstruction data were excluded. The construction period is indicated in the case study summaries included in Appendix B.

More specifically, the research team collected data in the following five areas for the case study analysis:

1. **Crash frequency**—the absolute number of crashes occurring before and after the context-sensitive improvement.
2. **Crash rates**—raw crash volumes considered in relation to the traffic volume carried by the roadway.
3. **Crash severity**—the proportion of crashes involving serious injury or death compared with property-damage-only (PDO) crashes.
4. **Crash type**—changes in specific types of crashes that have occurred as a result of the improvement.
5. **Average daily traffic (ADT)**—the average number of vehicles per day using the roadway.

In addition to crash type summary information and crash severity summary information, Appendix B includes a simple before-after crash summary comparison for each site. Often before-after analyses are limited because researchers study corridors where safety issues are prominent and so the resulting improvements can be dramatic; however, for the beautification and roadside enhancement projects the focus is not on operations and safety but rather on aesthetics and livability. As a result, the before-after analysis can provide a useful indication about possible safety implications of a change to the road environment. Table 21 demonstrates the basic type of data included in the before-after analysis for each case study included in Appendix B.

Findings and Recommendations

Table 22 illustrates the individual case study elements included in Appendix B as well as the general observed safety trend for each project. The research team attempted to exclude projects in which entire lanes were added as the observed safety results because these types of projects provide confounding information; nonetheless, a few of the projects had some lane widening (often due to realignment) and are so noted in the table. The crash trends identified in Table 22 show (1) when crash frequency increased by more than one crash per year (or by more than 5 percent), (2) when crash frequency decreased by more than one crash per year (or by more than 5 percent), or (3) when change in crash frequency was minimal (within one crash per year on average or within 5 percent of the original crash rate). These crash trends are a summary of the before-after analysis documented in Table 21 and the individual case studies included in Appendix B.

Table 21. Evaluation matrix for case study sites.

			Comparison	
Analysis Category	**Candidate Street -- Before**	**Candidate Street -- After**	**Crash Reductions**	**Standard Deviation**
Crash Frequency				
Crash Rate				
Severe and Fatal Crash Frequency				
Single-Vehicle Crash Frequency				
ADT				

Table 22. Case study project elements versus before-after crash trends.

	Streetscape Project Elements														Before-After Crash Trends*			
Case No.	Curb & Gutter	Curb Extensions	Sidewalk Additions / Improvements	Landscape Buffer Next to Road & Sidewalk	Add Landscaping / Street Trees	Trees Removal / Relocation	Improve Roadside Grading/Ditch Removal	Relocate Utility Poles	Add or Enhance Street Lights	Bus Stops / Bays	Enhanced Pedestrian Crossings / Access	Median Islands / Raised Islands	Bicycle Lanes	Widening of Road > 8'	Frequency of All Crashes	Crash Rate	Frequency of Severe Crashes	Frequency of Single-Vehicle Crashes
CS-AZ-1	x		x	x	x		x				x	x			⇓	⇓	⇓	⇔
CS-AZ-2	x	x	x	x	x		x			x					⇑	⇑	⇔	⇑
CS-AZ-3	x	x	x	x											⇓	⇔	⇑	⇔
CS-CA-1	x		x		x		x						x		⇑	⇑	⇔	⇑
CS-CA-2	x		x				x					x			⇑	⇔	⇔	⇔
CS-CA-3	x		x	x	x			x	x			x		x	⇓	⇓	⇔	⇔
CS-MN-1	x		x	x	x							x		x	⇓	⇓	⇔	⇓
CS-MT-1	x		x	x											⇑	⇑	⇔	⇔
CS-MT-2	x	x	x		x						x				⇑	⇑	⇔	⇑
CS-NC-1	x		x	x	x							x			⇓	⇓	⇔	⇑
CS-NC-2	x		x	x	x	x		x					x	x	⇓	⇓	⇓	⇓
CS-NC-3	x		x									x			⇓	⇓	⇓	⇑
CS-NC-4	x		x	x		x		x	x				x		⇓	⇔	⇔	⇔
CS-NC-5	x		x	x	x							x			⇓	⇓	⇔	⇔
CS-NC-6	x		x	x	x							x	x	x	⇓	⇓	⇔	⇓
CS-NC-7	x		x									x			⇓	⇑	⇔	⇓
CS-OR-1	x		x	x			x					x			⇑	⇑	⇑	⇔
CS-OR-2	x		x	x	x			x			x	x			⇑	⇑	⇑	⇔
CS-OR-3		x			x						x				⇓	⇓	⇔	⇔
CS-OR-4		x									x				⇓	⇓	⇔	⇑
CS-OR-5	x	x	x		x				x			x			⇓	⇓	⇔	⇔
CS-OR-6		x	x		x						x				⇓	⇓	⇔	⇓
CS-OR-7		x			x					x	x		x		⇓	⇓	⇔	⇑
CS-UT-1		x	x								x				⇓	⇓	⇔	⇔
CS-UT-2	x		x												⇓	⇓	⇓	⇑
CS-UT-3	x		x								x				⇓	⇓	⇔	⇓
CS-UT-4	x		x								x				⇑	⇑	⇔	⇔

*Before-After symbols depict the following:
⇑ ≡ Crash frequencies increased by more than one crash per year; crash rates increased by more than 5 percent.
⇓ ≡ Crash frequencies decreased by more than one crash per year; crash rates decreased by more than 5 percent.
⇔ ≡ Crash frequencies for the "After" condition were within one crash per year of the "Before" condition; crash rates for the "After" condition were within 5 percent of the "Before" condition crash rates.

In Table 22, the before-after crash trends are represented by the four statistics:

- Frequency of all crashes at a site,
- Crash rate,
- Frequency of severe crashes at a site, and
- Frequency of single-vehicle crashes.

Ideally, a reduction in all four trend statistics would be observed, clearly demonstrating enhanced safety at a site; however, in many cases, an increase occurred for one before-after crash trend statistic while others remained constant or decreased. For all candidate improvement projects, a designer seeks to reduce the number of severe crashes at a site. Severe crashes, for the purposes of the values shown in the case study tables, generally include incapacitating injuries or fatalities. Only three of the case study sites exhibited an increase greater than one additional severe crash per year. All three of these case study sites included sidewalk improvements with buffer strips, but several similar improvement projects resulted in little change to a reduction in severe crashes.

Since the focus of this research effort is roadside crashes, and these frequently are single-vehicle crashes, an increase in these kinds of crashes may be of concern. Single-vehicle crashes increased by more than one crash at eight of the sites. In general, these sites included pedestrian enhancement improvements; however, as was the case with the sites of severe crashes discussed above, there were many pedestrian enhancement projects that resulted in reduced single-vehicle crashes.

Since inspection of the individual before-after crash trends provides confounding results, a more effective approach may be to examine all four before-after crash trends collectively.

At 10 of the sites, crashes were reduced or remained constant. At nine additional sites, three of the four crash trends were reduced or remained similar during the "after" period. This results in 19 of the 27 sites having a general trend of crash reduction. None of the sites exhibited an increase in all four crash trend statistics, and only five sites exhibited an increase in three of the four crash trends evaluated. As a result, specific case study assessments (see Table 22 and Appendix B) provided inconclusive results and should be used simply as indicators of the expected outcomes for similar improvement projects.

General Recommendations

The use of corridor video analysis combined with historic crash statistics provided meaningful insight into urban roadside crash conditions and locations where roadside objects should not be located, if possible. Conversely, the use of roadside improvement or beautification case studies did not directly help to address specific roadside safety issues, but these case studies can be used by an agency proposing similar projects to determine expected overall safety performance of these improvements.

This research clearly shows that there are specific locations prone to roadside crashes where agencies should avoid the placement of rigid objects. For jurisdictions with limited roadside safety improvement funds, urban control zones can be used to help agencies establish spending priorities for incremental roadside safety improvement on their urban corridors. The research suggests the following:

- Avoid locating rigid obstacles in close proximity to a curb face or lane edge (at curb locations where it is possible, increase the lateral offset to rigid objects to 1.8 m [6 ft] from the face of the curb and do not allow the distance of this offset to be less than 1.2 m [4 ft]);
- Restrict the placement of rigid objects at lane merge locations (avoid placing rigid objects within 3.0 m (10 ft) longitudinally of the taper point, which will provide a 6.1-m (20-ft), object-free length);
- Maintain offsets at selected higher speed auxiliary lane locations, such as extended-length, right-turn lanes (maintain the lateral offset from the curb face at these locations);
- Maintain careful object placement within the sidewalk buffer treatment (avoid rigid objects in buffers 0.9 m (3 ft) in width or less and strategically position objects in wider buffers); and
- Avoid placing rigid objects in the proximity of driveways (avoid placing rigid objects on the immediate far side of the driveway and do not place any objects within the required sight triangle for the driveway).

In addition, roadside crashes occurred frequently at intersections; at unique configurations (e.g., a one-way lane split at an underpass); and known hazardous roadside conditions, such as roadside ditches, non-traversable headways, and so forth.

CHAPTER 4

Conclusions and Suggested Research

Conclusions

The urban roadside environment is complex. Due to the constrained nature of this built environment, it is difficult for a designer to achieve an acceptable clear zone, free of objects. As a result, a lateral offset that enhances roadway operations may be used, but this offset does not represent a safe placement for rigid roadside objects.

This research identified known safety characteristics and placement strategies for urban roadside objects by means of a comprehensive literature review. Following this state-of-the-practice identification, the research team further evaluated roadside safety conditions using two approaches.

First, the research team videotaped over 241 km (150 mi) of urban corridors and compared their 6-year crash history and crash locations to the various roadside features observed on these corridors. The result of this assessment was the identification of several potential urban control zones. These locations are shown to have a greater likelihood of crashes and, as a result, should be kept free of rigid objects whenever possible. These urban control zones include locations with the following:

- Obstacles in close lateral proximity to the curb face or lane edge;
- Roadside objects placed near lane merge points;
- Lateral offsets not appropriately adjusted for auxiliary lane treatments;
- Objects placed inappropriately in sidewalk buffer treatments;
- Driveways that interrupt positive guidance and have objects placed near them;
- Three kinds of fixed-object placement at intersections;
- Unique roadside configurations associated with high crash occurrence; and
- Roadside configurations commonly known to be hazardous.

Each of these urban control zones is reviewed in detail in Chapter 3. The recommendations that are the result of this research effort are the following:

- Where possible at curb locations, provide a lateral offset to rigid objects of at least 1.8 m (6 ft) from the face of the curb and maintain a minimum lateral offset of 1.2 m (4 ft).
- At lane merge locations, do not place rigid objects in an area that is 3.0 m (10 ft) longitudinally from the taper point. This will result in a 6.1-m (20-ft), object-free length at the taper point. The lateral offset for this 6.1-m (20-ft) section should be consistent with the lane width, typically 3.7 m (12 ft).
- Although many auxiliary lanes, such as bus lanes or bicycle lanes, have low volumes and may be included as part of a clear zone in the urban environment, higher speed auxiliary lane locations, such as extended length right-turn lanes, are common locations for run-off-road crashes. A lateral offset of 1.8 m (6 ft) from the curb face to rigid objects is preferred, and 1.2-m (4-ft) minimum lateral offset should be maintained.
- At locations where a sidewalk buffer is present, rigid objects should not be located in the buffer area when it has a width of 0.9 m (3 ft) or less. For buffer widths greater than 0.9 m (3 ft), lateral offsets from the curb face to rigid objects should be maintained with a minimum offset of 1.2 m (4 ft). At these wider buffer locations, other frangible objects can be strategically located to help shield any rigid objects.
- Rigid objects should not be located in the proximity of driveways, and care should be taken to avoid placing rigid objects on the immediate far side of a driveway. In addition, objects should not be located within the required sight triangle for a driveway.

A second component of this research included a case study assessment for roadside enhancement or beautification projects. At these locations, the governing agencies incorporated a variety of urban roadside changes to improve the aesthetic quality of the roadside and enhance the functional use of the space, often with particular emphasis on pedestrian facilities. Although the findings of this task were inconclusive, the individual case studies can be used by agencies to help determine general safety trends for similar future projects.

Suggested Research

This research effort creates a foundation for better understanding on how urban roadside configurations can influence safety. As with any such effort, the questions answered by this research also help to identify knowledge gaps. The gaps could substantially benefit from future research efforts.

Specifically, the research team identified five specific issues that merit additional research. The first issue is the influence of positive guidance at driveway and intersection locations. This issue appeared to contribute to crash conditions; however, the disproportionate number of sites where positive guidance in the form of a white edge line was not present prohibited the researchers from drawing definitive conclusions regarding this issue.

The second issue of interest is the evaluation of auxiliary lanes and their role in roadside safety. In some instances, the inclusion of a bicycle lane provided an additional offset to roadside objects. At these locations, the number of roadside crashes appeared to be reduced. This observation suggests that the bicycle lane can be included as part of the available clear zone and that at locations where this occurs, the white stripe that separates the motor vehicle lane from the bicycle lane could serve as the edge of the clear zone. Alternatively, some of the sites studied included what appeared to be an almost continuous right-turn lane (referred to in the report as an extended right-turn lane). At these locations, turn movements were channelized by pavement markings only. A large number of crashes occurred when these auxiliary turn lanes functioned similarly to through lanes, yet lateral offsets were not increased. At locations where upstream or downstream lateral offsets were approximately 4.3 m (14 ft), these offsets were reduced to less than 0.6 m (2 ft) adjacent to the turn lanes. The number of roadside crashes dramatically increased as a result. Future research should investigate when an auxiliary lane should be treated as another motor vehicle lane. For example, could a short right-turn pocket be treated like a bicycle lane and this width be included in the clear zone or should any lane designed for motor vehicles, regardless of its function, be treated similarly?

A third issue for future research is the definition of a hazardous tree. Although this study identified some recommended tree placement strategies, the concept of a tree as a rigid object requires further definition. Historically, a tree with a caliper width of 4 in. or more has been considered a rigid object, but the literature review indicated that this dimension was based on wooden pole crash tests. The influence of tree type (soft wood versus hard wood), tree size, root system configuration, and similar issues merits further consideration.

A fourth issue for further research resulting from this evaluation is the influence of moving light standards farther from the travel lane and how this change in location might affect nighttime visibility. At the study corridors, numerous light standards located close to the road were hit by vehicles, so the recommendation to move these lights closer to the near side of the sidewalk or even to the far side of the sidewalk would probably improve safety as it relates to roadside hazards. The effect of this relocation of the street lights on safety as it relates to visibility merits further evaluation for light pedestals that do not include mast arm configurations that can be easily lengthened.

The fifth issue for further research is roadside improvements at intersections where pedestrian access ramps appear to direct an errant motor vehicle toward a rigid object (often a signal pole). It seems like a minor issue to shift the pole so that this conflict is minimized; however, often a pedestrian button is located on the pole, and this relocation could adversely affect operations for the pedestrian. As a result, the placement of traffic signal poles in relation to access ramps, roadside safety, and pedestrian usability should be assessed.

Finally, the research team identified one additional item that is not included in the five research issues but appears to warrant further evaluation. For the corridor analysis task, the research team attempted to identify corridors with relatively high operating speeds (as higher speed crashes generally result in greater injury severity). A few of these corridors transitioned into lower speed corridors with on-street parking and curb extensions. The curb extensions generally were positioned to help define intersections and to enable shorter pedestrian crossing distances. Since the number of sites with this lower speed configuration was limited, the research team could not comprehensively evaluate these curb extension locations. However, at the few locations where the research team did observe these extensions, roadside crashes appeared to peak during nighttime hours, presumably when on-street parking was limited. Due to the small sample size, the research team could not draw any definitive conclusions; therefore, the team strongly recommends that roadside safety at curb extensions be the subject of future research.

References

1. American Association of State Highway and Transportation Officials. *Roadside Design Guide*. Washington, DC (2002).
2. National Highway Traffic Safety Administration. *Traffic Safety Facts 2005: A Compilation of Motor Vehicle Crash Data from the Fatality Analysis Reporting System and the General Estimates System*. DOT HS 810 631. U.S. DOT, Washington, DC (2006).
3. Neuman, T. R., Pfefer, R., Slack, K. L., Raub, R., Lucke, R., and Wark, R. *NCHRP Report 500*: *Guidance for Implementation of the AASHTO Strategic Highway Safety Plan—Volume 1: A Guide for Addressing Aggressive-Driving Collisions*. Transportation Board of the National Academies, Washington, DC (2003).
4. Bureau of Transportation Statistics. *National Transportation Statistics 2005*. U.S. DOT, Washington, DC (2005).
5. Bryer, T. E. "Safety Management." *The Traffic Safety Toolbox: A Primer on Traffic Safety*. Institute of Transportation Engineers, Washington, DC (1993) pp. 11–23.
6. Zeigler, A. J. *Guide to Management of Roadside Trees. Users Manual*. FHWA-IP-86-17. Michigan DOT, FHWA, U.S. DOT, Washington, DC (1986).
7. Turner, D. S. and Mansfield, E. R. "Urban Trees and Roadside Safety." *ASCE Journal of Transportation Engineering*, Vol. 16, No. 1 (1990) pp. 90–103.
8. Chowdhury, M. A., Warren, D. L., Bissell, H., and Taori, S. "Are the Criteria for Setting Advisory Speeds on Curves Still Relevant?" *ITE Journal* (February 1998) pp. 32–45.
9. Kubilins, M. A. "Designing Functional Streets That Contribute to Our Quality of Life." *Transportation Research E-Circular E-C019: Urban Street Symposium Conference Proceedings*. Transportation Research Board, National Research Council (December 2000). http://onlinepubs.trb.org/Onlinepubs/circulars/ec019/ec019.pdf.
10. Fitzpatrick, K., Carlson, P., Brewer, M., and Wooldridge, M. D. "Design Speed, Operating Speed, and Posted Speed Limit Practices." *Transportation Research Board 82nd Annual Meeting Compendium of Papers* (CD-ROM). Transportation Research Board of the National Academies, Washington, DC (2003).
11. Fitzpatrick, K., Shamburger, B., and Fambro, D. "Design Speed, Operating Speed, and Posted Speed Survey." *Transportation Research Record 1523*. Transportation Research Board, National Research Council, Washington, DC (1996) pp. 55–60.
12. Tarris, J. P., Mason, Jr., J. M., and Antonucci, N. "Geometric Design of Low-Speed Urban Streets." *Transportation Research Record: Journal of the Transportation Research Board, No. 1701*. Transportation Research Board, National Research Council, Washington, DC (2000) pp. 95–103.
13. Al-Madani, H. and Al-Jahani, A. R. "Assessment of Drivers' Comprehension of Traffic Signs Based on Their Traffic, Personal, and Social Characteristics." *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 5, No. 1 (2002) pp. 63–76.
14. Recarte, M. A. and Nunes, L. "Mental Load and Loss of Control Over Speed in Real Driving. Towards a Theory of Attentional Speed Control." *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 5, No. 2 (2002) pp. 111–122.
15. Herrstedt, L., Kjemtrup, K., Borges, P., and Anderson, P. *An Improved Traffic Environment, a Catalogue of Ideas*. Report 106. Road Data Laboratory, Road Standards Division, Road Directorate, Denmark Ministry of Transport (1993).
16. Brewer, J., German, J., Krammes, R., Movassaghi, K., Okamoto, J., Otto, S., Ruff, W., Sillan, S., Stamatiadis, N., and Walters, R. *Geometric Design Practices for European Roads*. FHWA-PL-01-026. FHWA, U.S. DOT, Washington, DC (2001).
17. Lynch, K. *The Image of the City*. MIT Press, Cambridge, MA (1960).
18. Sivak, M. "Recent Psychological Literature on Driving Behaviour: What, Where, and by Whom?" *Applied Psychology: An International Review*, Vol. 46, No. 3 (1997) pp. 303–310.
19. Groeger, J. A. and Rotherngatter, J. A. "Traffic Psychology and Behavior." *Transportation Research Part F: Traffic Psychology and Behaviour*, Vol. 1, No. 1 (1998) pp. 1–9.
20. Transit New Zealand. *Guidelines for Highway Landscaping*. SP/M/020. Version 2. (PDF). (2006). www.transit.govt.nz/technical/view_manual.jsp?content_type=manual&=edit&primary_key=31&action=edit#about.
21. City of Las Vegas. "Streets: A Users' Manual—Your Guide to the Las Vegas Neighborhood Traffic Management Program." Las Vegas, NV (2001).
22. Land Transport Safety Authority. *Guidelines for Urban-Rural Speed Thresholds: RTS 15*. Wellington, NZ (2002).
23. Ewing, R. *Traffic Calming: State of the Practice*. Institute of Transportation Engineers, Washington, DC (1999).
24. FHWA. *Synthesis of Shoulder Rumble Strip Practices and Policies* (2000). http://safety.fhwa.dot.gov/fourthlevel/exec_summary.htm. Accessed May 17, 2004.
25. Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., Council, F., McGee, H., Prothe, L., and Eccles, K. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan—Volume 6: Guide for Addressing Run-Off-Road Collisions*. Transportation Research Board of the National Academies, Washington, DC (2003).

26. FHWA. "Boosting Roadway Safety with Rumble Strips." *Focus: Accelerating Infrastructure Innovations* (May 2002). www.tfhrc.gov/focus/may02/rumble.htm. Accessed May 29, 2004.
27. American Association of State Highway and Transportation Officials. *Guide for the Development of Bicycle Facilities*. Washington, DC (1999).
28. Moeur, R. C. "Analysis of Gap Patterns in Longitudinal Rumble Strips to Accommodate Bicycle Travel." *Transportation Research Record: Journal of the Transportation Research Board, No. 1705*. Transportation Research Board, National Research Council, Washington, DC (2000) pp. 93–98.
29. Mak, K. K., Bligh, R. P., and Ross, Jr., H. E. "Clear Zone Requirements for Suburban Highways." *Transportation Research Record 1500*. Transportation Research Board, National Research Council, Washington, DC (1995) pp. 119–126.
30. American Association of State Highway and Transportation Officials. *Highway Safety Design and Operations Guide*. Washington, DC (1997).
31. American Association of State Highway and Transportation Officials. *A Guide for Achieving Flexibility in Highway Design*. Washington, DC (2004).
32. American Association of State Highway and Transportation Officials. *Guidelines for Design of Very Low-Volume Local Roads (ADT ≤ 400)*. Washington, DC (2001).
33. Zegeer, C. V. and Parker Jr., M. R. "Effect of Traffic and Roadway Features on Utility Pole Accidents." *Transportation Research Record 970*. Transportation Research Board, National Research Council, Washington, DC (1984) pp. 65–76.
34. Benekohal, R. B. and Lee, M. H. "Comparison of Safety Effects of Roadside versus Road Improvements on Two-Lane Rural Highways." *Transportation Research Record 1303*. Transportation Research Board, National Research Council, Washington, DC (1991) pp. 92–102.
35. Zegeer, C. V. and Cynecki, M. J. "Determination of Cost-Effective Roadway Treatments for Utility Pole Accidents." *Transportation Research Record 970*. Transportation Research Board, National Research Council, Washington, DC (1984) pp. 52–64.
36. Ross, Jr., H. E., Sicking, D. L., Zimmer, R. A., and Michie, J. D. *NCHRP Report 350: Recommended Procedures for the Safety Performance Evaluation of Highway Features*. Transportation Research Board, National Research Council, Washington, DC (1993).
37. American Association of State Highway and Transportation Officials. *A Policy on Geometric Design of Highways and Streets*, 4th ed. Washington, DC (2004).
38. Dunlap, D. F., Grote, P., Fram, D. M., and Mashinter, W. *Investigation of the Dynamic Impact Characteristics of Roadside Structures*. UM-HSRI-PF-72-5. Highway Safety Research Institute, University of Michigan, Ann Arbor, MI (1972).
39. Olson, R. M., Weaver, G. D., Ross, Jr., H. E., and Post, E. R. *NCHRP Report 149: Effect of Curb Geometry and Location on Vehicle Behavior*. Transportation Research Board, National Research Council, Washington, DC (1974).
40. Ross, H. E., and Post, E. R. *Dynamic Behavior of an Automobile Traversing Selected Curbs and Medians.* Research Report 140-6. Texas Transportation Institute, Texas A&M University, College Station, TX (1975).
41. Holloway, J. C., Sickling, D. L., and Rossen, B. T. *Performance Evaluation of NDOR Mountable Curbs*. TRP-03-37-94. Midwest Roadside Safety Facility, University of Nebraska-Lincoln (1994).
42. Wezeker, J. and Nkunga, A. *Vehicle Trajectories Resulting from Traversing FDOT Street Curbs*. B-C352. Florida Department of Transportation (January 2003).
43. Plaxico, C. A., Ray, M. H., Weir, J. A., Orengo, F., Tiso, P., McGee, H., Council, F., and Eccles, K. *NCHRP Report 537: Recommended Guidelines for Curb and Curb-Barrier Installations*. Transportation Research Board, National Research Council, Washington, DC (2005).
44. Downs, H. G., Jr. and Wallace, D. W. *NCHRP Report 254: Shoulder Geometrics and Use Guidelines*. Transportation Research Board, National Research Council, Washington, DC (1982).
45. Belmont, D. M. "Effect of Shoulder Width on Accidents on Two-Lane Tangents." *Highway Research Board Bulletin 91*. Highway Research Board, National Research Council (1954) pp. 29–32.
46. Belmont, D. M. "Accidents versus Width of Paved Shoulders on California Two-Lane Tangents—1951 and 1952." *Highway Research Board Bulletin 120*. Highway Research Board, National Research Council (1956) pp. 1–16.
47. Hauer, E. "Shoulder Width, Shoulder Paving and Safety." http://roadsafetyresearch.com (2000). Accessed May 17, 2004.
48. Zimmer, R. A. and Ivey, D. L. *Pavement Edges and Vehicle Stability: A Basis for Maintenance Guidelines.* Texas Transportation Institute, College Station, TX (1982).
49. Olson, P. L., Zimmer, R. A., and Pezoldt, V. *Pavement Edge Drop. Final Report*. UMTRI-86-33. University of Michigan Transportation Research Institute, Ann Arbor, MI (1986).
50. Zegeer, C. V., Deen, R. C., and Mayes, J. G. "Effect of Lane and Shoulder Widths on Accident Reduction on Rural, Two-Lane Roads." *Transportation Research Record 806*. Transportation Research Board, National Research Council, Washington, DC (1981) pp. 33–43.
51. Maryland Department of Transportation. *When Main Street is a State Highway*: *Blending Function, Beauty and Identity—A Handbook for Communities and Designers*. MD (2003).
52. Harwood, D. W. *NCHRP Report 282: Multilane Design Alternatives for Improving Suburban Highways*. Transportation Research Board, National Research Council, Washington, DC (1986).
53. Sullivan, E. C. *Safety of Median Trees with Narrow Clearances on Urban Conventional Highways*. Applied Research and Development Facility, Cal Poly State University, San Luis Obispo, CA (2004).
54. Viner, J. G. "Risk of Rollover in Ran-Off-Road Crashes." *Transportation Research Record 1500*. Transportation Research Board, National Research Council, Washington, DC (1995) pp. 112–118.
55. Iowa Highway Research Board. *Iowa Traffic Control Devices and Pavement Markings: A Manual for Cities and Counties*. Center for Transportation Research and Education, Iowa State University, Ames, IA (2005).
56. North Carolina Department of Transportation. *Traditional Neighborhood Development (TND) Guidelines*. Raleigh, NC (August 2000).
57. City of Seattle. *Street Tree Planting Procedures*. www.ci.seattle.wa.us/transportation/treeplanting.htm. Accessed 2007.
58. City of Simi Valley. *City of Simi Valley Landscape Design Guidelines*. Simi Valley, CA (January 2002).
59. City of Montgomery. *Montgomery Street Tree Master Plan*. Montgomery, AL. www.montgomeryal.gov/media/1473969/street%20tree%20master%20plan%20document%20-%20final.pdf. Accessed 2007.
60. FHWA. *Trees in Hazardous Locations*. NCHRP 17-18(3). http://safety.transportation.org/htmlguides/trees/. Accessed May 7, 2007.
61. Traffic Authority of New South Wales. *Guidelines for Tree Planting and Maintenance on Urban Roads*. New South Wales, Australia (May 1987).
62. Georgia Department of Transportation. *Online Policy and Procedure System*. www.dot.state.ga.us/doingbusiness/PoliciesManuals/Pages/topps.aspx. Accessed May 7, 2007.

63. Oregon Department of Transportation and Oregon Department of Land Conservation and Development. *Main Street . . . When a Highway Runs through It: A Handbook for Oregon Communities*. (1999).
64. Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K., Lacy, K., and Zeeger, C. *NCHRP Report 500: Guidance for Implementation of the AASHTO Highway Safety Plan—Volume 3: A Guide for Addressing Collisions with Trees in Hazardous Locations*. Transportation Research Board, National Research Council, Washington DC (2003).
65. Iowa State University. *Vegetation Control for Safety. A Guide for Street and Highway Maintenance Personnel.* FHWA-RT-90-003. Office of Highway Safety, FHWA, U.S. DOT, Washington, DC (1992).
66. Zeigler, A. J. *Guide to Management of Roadside Trees. Users Manual*. FHWA-IP-86-17. Michigan DOT, FHWA, U.S. DOT, Washington, DC (1986).
67. FHWA. *Roadside Improvements for Local Roads and Streets*. U.S. DOT, Washington, DC (October 1986).
68. Lee, J. and Mannering, F. *Analysis of Roadside Accident Frequency and Severity and Roadside Safety Management*. Washington State Department of Transportation, Olympia, WA (December 1999).
69. Kloeden, C. N., McLean, A. J., Baldock, M. R. J., and Cockington, A. J. T. *Severe and Fatal Car Crashes Due to Roadside Hazards*: *A Report to the Motor Accident Commission*. NHMRC Road Accident Research Unit, University of Adelaide, Australia (1999).
70. Naderi, J. R. "Landscape Design in Clear Zone: Effect of Landscape Variables on Pedestrian Health and Driver Safety." *Transportation Research Record: Journal of the Transportation Research Board*, *No. 1851*. Transportation Research Board of the National Academies, Washington, DC (2003) pp. 119–130.
71. Delaney, A., Langford, J., Corben, B., Newstead, S., and Jacques, N. *Roadside Environment Safety* (Report to RACV). Monash University Accident Research Centre, Melbourne, Australia (2003).
72. Bratton, N. J. and Wolf, K. L. "Trees and Roadside Safety in U.S. Urban Settings." *Transportation Research Board 84th Annual Meeting Compendium of Papers* (CD-ROM). Transportation Research Board of the National Academies, Washington, DC (2005).
73. Haworth, N. and Bowland, L. *Serious Injury Single Vehicle Crashes.* Report No. 175. Monash University Accident Research Centre, Victoria, Australia (2000).
74. European Transport Safety Council. *Forgiving Roadsides.* European Transport Safety Council, Brussels. www.etsc.be/documents/bri_road5.pdf. Accessed June 15, 2005.
75. Transportation Research Board Committee on Utilities. *State of the Art Report 9: Utilities and Roadside Safety*. Transportation Research Board of the National Academies, Washington, DC (2004).
76. Mak, K. K. and Mason, R. L. *Accident Analysis—Breakaway and Non-Breakaway Poles Including Sign and Light Standards along Highways*. DOT-HS-805-605. FHWA, U.S. DOT, Washington, DC (August 1980).
77. Lacy, K., Srinivasan, R., Zegeer, C., Pfefer, R., Neuman, T. R., Slack, K. L., and Hardy, K. K. *NCHRP Report 500: Guidance for Implementation of the AASHTO Strategic Highway Safety Plan—Volume 8: A Guide for Reducing Collisions Involving Utility Poles*. Transportation Research Board of the National Academies, Washington, DC (2004).
78. Transportation Research Board Committee on Utilities. *State of the Art Report 9: Utilities and Roadside Safety*. Transportation Research Board of the National Academies, Washington, DC (2004).
79. Land Transport Safety Authority. *Urban Roadside Barriers and Alternative Treatments RTS11*. Wellington, New Zealand, 1995 (republished in 2001).
80. Haworth, N., Vulcan, P., Bowland, L., and Pronk, N. *Fatal Single Vehicle Crashes Study: Summary Report*. Report No. 122. Monash University Accident Research Centre, Victoria, Australia (1997).
81. Dixon, K., Wu, C., Geary, G., Wang, J., and Coley, M. *Analysis of Fatal Crashes at Utility Pole Locations in Georgia for 1997 and 1998*. Georgia Institute of Technology, Atlanta, GA (2000).
82. Marquis, B. *Utility Pole Crash Modeling*. Maine Department of Transportation, Augusta, ME (2001).
83. McLean, A. J., Offler, W. J., and Sandow, B. L. *Adelaide In-Depth Accident Study: 1975–1979: Part 7: Road and Traffic Factors*. Road Accident Research Unit, University of Adelaide, Australia (1981).
84. American Association of State Highway and Transportation Officials. *Standard Specifications for Structural Supports for Highway Signs, Luminaires*, *and Traffic Signals,* 4th ed. Washington, DC (2002).
85. Lewin, I., Box, P. and Stark, R. *Roadway Lighting: An Investigation and Evaluation of Three Different Light Sources—Final Report 522*. Arizona Department of Transportation, FHWA, U.S. DOT (May 2003).
86. Nilsson, G. and Wenäll, J. "Fixed Roadside Objects Cause 100 Fatalities Each Year." *Nordic Road and Transport Research*, No. 1, Swedish National Road and Transport Research Institute (1998) pp. 13–15.
87. Ray, M. H., Weir, J., and Hopp, J. *NCHRP Report 490: In-Service Performance of Traffic Barriers*. Transportation Research Board of the National Academies, Washington, DC (2003).
88. Stephens, L. B. "Guardrail Warrants for Low-Volume Roads." *Transportation Research Circular 416: Issues Surrounding Highway and Roadside Safety Management*. Transportation Research Board, National Research Council, Washington, DC (October 1993) pp. 74–84.
89. Wolford, D. and Sicking, D. L. "Guardrail Need: Embankments and Culverts." *Transportation Research Record 1599*. Transportation Research Board, National Research Council, Washington, DC (1997) pp. 48–56.
90. California Department of Transportation. *California Highway Barrier Aesthetics*. (June 2002).
91. Glad, R. W., Albin, R. B., McIntosh, D. M., and Olson, D. K. *Median Treatment Study on Washington State Highways*. WA-RD 516.1. Washington State Department of Transportation, Olympia, WA (2002).
92. Zein, S. R. and Montufar, J. *Roadway Safety Benchmarks Over Time.* Report TP 14328 E. Transport Canada, Ottawa, ON (2003).
93. Vermont Agency of Transportation. *Guardrail Study*. (2002).
94. Office of Highway Safety. *Improving Highway Safety at Bridges on Local Roads and Streets.* FHWA, U.S. DOT, Washington, DC (1998).
95. Turner, S. M., Shafer, C. S., and Stewart, W. P. *Bicycle Suitability Criteria for State Roadways in Texas.* Report No. TX-97/3988-S. Texas Transportation Institute, College Station, TX (1997).
96. Harkey, D. L., Reinfurt, D. W., Knuiman, M., Steward, J. R., and Sorton, A. *Development of the Bicycle Compatibility Index: A Level of Service Concept.* FHWA-RD-98-072. FHWA, U.S. DOT, Washington, DC (1998).
97. Litman, T., Blair, R., Demopoulos, B., Eddy, N., Fritzel, A., Laidlaw, D., Maddox, H., and Forster, K. *Pedestrian and Bicycle Planning: A Guide to Best Practices.* Victoria Transport Policy Institute, Victoria, BC (2005).
98. Sutts, J. C. and Hunter, W. W. *Injuries to Pedestrians and Bicyclists: An Analysis Based on Hospital Emergency Department Data.* FHWA-RD-99-078. Federal Highway Administration, U.S. DOT, Washington, DC (1999).

99. Stutts, J. C. and Hunter, W. W. *Police-Reporting of Pedestrian and Bicyclists Treated in Hospital Emergency Rooms.* University of North Carolina, Highway Safety Research Center, Chapel Hill, NC (1998).
100. Burden, D. and Zykofsky, P. *Emergency Response Traffic Calming and Traditional Neighborhood Streets*. Local Government Commission, Sacramento, CA (December 2000).
101. Polus, A. and Craus. J. "Planning and Geometric Aspects of Shared Streets." *Transportation Research Record 1523*. Transportation Research Board, National Research Council, Washington, DC (1996) pp. 29–33.
102. Gunnarsson, S. O. "Traffic Planning." *The Traffic Safety Toolbox: A Primer on Traffic Safety*. Institute of Transportation Engineers, Washington, DC (1999) pp. 15–37.
103. Zegeer, C. V. and Seiderman, C. B. "Designing for Pedestrians." *The Traffic Safety Toolbox: A Primer on Traffic Safety*. Institute of Transportation Engineers, Washington, DC (1999) pp. 177–196.
104. Whyte, W. H. *The Social Life of Small Urban Spaces*. The Conservation Foundation, Washington, DC (1980).
105. Landis, B. W., Vattikuti, V. R., Ottenberg, R. M., LcLeod, D. S., and Guttenplan, M. "Modeling the Roadside Walking Environment: A Pedestrian Level of Service." *Transportation Research Record: Journal of the Transportation Research Board*, *No. 1773*, Transportation Research Board, National Research Council (2001) pp. 82–88.
106. Corben, B. F. and Duarte, A. *Injury Reduction Measures in Areas Hazardous to Pedestrians—Stage 1: Countermeasure Options.* Report No. 169. Monash University Accident Research Centre, Victoria, Australia (2000).
107. Cottrell, W. D. *UDOT Report No. UT-02.10: Evaluating and Improving Pedestrian Safety in Utah.* Prepared by the University of Utah for the Utah Department of Transportation, Salt Lake City, UT (2002).
108. Skene, M. "'Traffic Calming' on Arterial Roadways?" Paper Presented at the 69th Annual Meeting of the Institute of Transportation Engineers. Las Vegas, Nevada (August 1–4, 1999).
109. Robinson, C. C. "Traffic Calming on Arterials–Con." Paper Presented at the 69th Annual Meeting of the Institute of Transportation Engineers. Las Vegas, Nevada (August 1–4, 1999).
110. Burden, D. *Streets and Sidewalks, People and Cars: The Citizens' Guide to Traffic Calming.* Local Government Commission, Center for Livable Communities, Sacramento, CA (2000).
111. Pates, G. "Improving Small City Highways: New Techniques for Improving Safety and Livability Through Technology Transfer." *Proceedings of the Sixth National Conference on Transportation Planning for Small and Medium-Sized Communities*. Washington State Department of Transportation, Olympia, WA (1999).
112. Wheeler, A. H., Abbott, P. G., Godfrey, N. S., Phillips, S. M., and Stait, R. *TRL Report 238: Traffic Calming on Major Roads: The A47 Trunk Road at Thorney, Cambridgeshire.* Transport Research Laboratory, London, UK (1997).
113. Berger, W. J. and Linauer, M. "Raised Traffic Islands at City Limits—Their Effect on Speed." *Proceedings of ICTCT Workshop 1998*. Lund Institute of Technology, Budapest, Hungary (1999).
114. Crowley, F. and MacDermott, A. *Evaluation of Traffic Calming Schemes Constructed on National Roads 1993–1996*. Road Safety Engineering, R460. National Roads Authority, Dublin, Ireland (2002).
115. Forbes, G. and Gill, T. "Arterial Speed Calming, Mohawk Road Case Study." *Transportation Research E-Circular E-C019: Urban Street Symposium Conference Proceedings*. Transportation Research Board, National Research Council (December 2000) pp. I-2/1–I-2/7. http://onlinepubs.trb.org/Onlinepubs/circulars/ec019/Ec019_i2.pdf.
116. Ewing, R. "From Highway to My Way." *Journal of Planning*, Vol. 67(1), American Planning Association, Chicago, IL (January 2001) pp. 22–26.
117. Florida Department of Transportation. *Utility Accommodation Manual*. Document No. 710-020-001-d. Tallahassee, FL (1999).
118. Fatality Analysis Reporting System (FARS). (Database). National Center for Statistics and Analysis (NCSA) and NHTSA. www-fars.nhtsa.dot.gov/Main/index.aspx.
119. Ostensen, A. G. "New Focus for Highway Safety." *Public Roads*, Vol. 68, No. 5 (2005) pp. 2–7.
120. Iowa State University Technology Transfer Center. *Vegetation Control for Safety. A Guide for Street and Highway Maintenance Personnel*, FHWA-RT-90-003. Prepared under the Rural Transportation Assistance Program Project 70, Office of Highway Safety, FHWA, U.S. DOT, Ames, IA (1990).
121. Walkinginfo.org: Pedestrian and Bicycle Information Center (website). "Shared Street (Green Street)." www.walkinginfo.org/engineering/calming-street.cfm.
122. NCSA and NHTSA *General Estimates System*. (Database).
123. Zeeger, C. V., Stutts, J., Huang, H., Cynecki, M. J., Van Houten, R. V. Alberson, B. Neuman, T. R., Pfefer, R., Slack, K. L., Hardy, K. K. *NCHRP Report 500: Guidance for Implementation of the AASHTO Highway Safety Plan—Volume 10: A Guide for Reducing Collisions Involving Pedestrians*. Transportation Research Board, National Research Council, Washington DC (2004).
124. McLean, J. *Effects of Sealed Shoulders on Road User Costs.* Project Report for Austroads Project No. BS. E. N. 042. Austroads Publication No. AP-R188/01. Sydney, Australia (2001).

APPENDIX A

Urban Control Zone Corridor Study Reports

Appendix A: Control Zone Corridor Study Reports from the contractor's final report for NCHRP Project 16-04 is available on the TRB website at http://trb.org/news/blurb_detail.asp?id=9456.

APPENDIX B

Case Study Reports

Appendix B: Case Study Reports from the contractor's final report for NCHRP Project 16-04 is available on the TRB website at http://trb.org/news/blurb_detail.asp?id=9456.

APPENDIX C

Toolkit for Urban Roadside Design

Introduction

It is a challenge to design an urban roadside environment that balances the often conflicting demands of land owners, road users, and local jurisdictions to effectively use this valuable space without dramatically compromising safety. Though there is still much to learn about how the urban roadside configuration influences the functional operation and safety of a roadway corridor, some basic design concepts can help assure the placement of roadside objects that minimize potentially hazardous conditions. This toolkit provides placement strategies, referred to as urban control zones, for a variety of urban conditions. The primary focus of this summary is roadside object placement for high speed urban roads. Roads characterized by twenty-four hour on-street parking or low speed local roads are not directly addressed in this toolkit. Following the urban control zone section are treatment details for known objects common to the urban roadside environment.

Urban Control Zones

An urban control zone is a roadside location that can be shown to pose a greater hazard for errant vehicles and as such should be given special attention regarding object placement strategies. Key urban control zones include lateral placement strategies, lane merge locations, driveways, intersections, and sidewalk configurations. In addition high crash locations and common roadside crash locations can also be identified as potential urban control zones for roadside safety.

Lateral Placement of Objects

Description. Where possible, achieve the clear zone as recommended by the *AASHTO Roadside Design Guide*. In constrained urban areas where clear zones are not feasible, the recommended lateral offset to roadside objects may vary depending on specific road features.

Object placement strategies. Object placement strategies include the following:

- Roads on tangent with vertical curb – recommend lateral offset of 6 ft (absolute minimum of 4 ft) from curb face to rigid objects [these values also apply to median locations]. Frangible objects should be positioned no closer than 1.5 ft to curb face.
- Roads at horizontal curves with vertical curb – recommend lateral offsets to objects a minimum of 6 ft from the curb face on the outside of curve face and a recommended lateral offset of 4 ft for the inside of curve locations (absolute minimum of 1.5 ft for frangible items only) from curb face [these values also apply to median locations]. For sharp curvature locations, determine an object free zone based on sight distance criteria (see *Figure* C-1).
- Roads on tangent or curve with shoulder (no curb) – adhere to clear zone guidelines where possible. If infeasible, then locate objects immediately adjacent to the right-of-way boundary to maximize lateral offset.
- Auxiliary lanes that function as higher speed lanes such as extended right-turn lanes must meet the tangent and curve criteria.
- Auxiliary lanes such as bicycle lanes can include the width of the bicycle lane in the clear zone; however, it is still recommended that lateral offset from the curb face exceed 1.5 ft where possible at these locations.

Lane Merge Locations

Description. Often acceleration lanes, lane merges, and bus bay exit points transition to the through travel lane at a taper point. At this location, the driver of the vehicle needs to focus on merging into the active traffic stream. If the driver does not judge the merge correctly, he or she may run off the road at this location. As a result, lane merge locations should be free of roadside objects where possible.

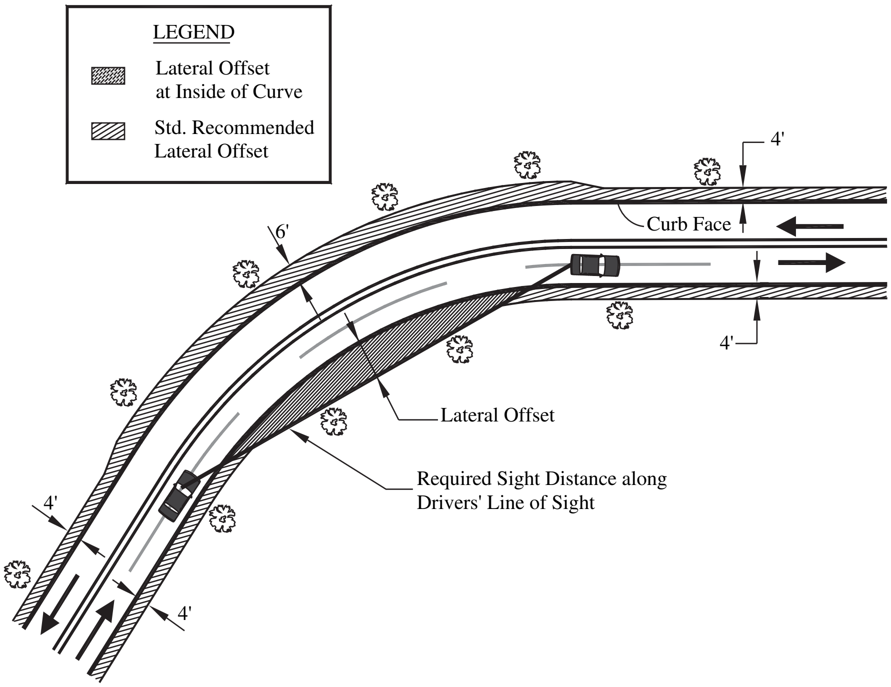


Figure C-1. Lateral placement of objects at horizontal curves.

Object placement strategies. Object placement strategies include the following:

- Lateral offset of rigid objects should be as large as possible. Since the presumption is that a vehicle unable to traverse the lane merge will continue along its current path, a lateral offset equivalent to a standard lane width should be kept free of rigid objects. Where feasible, therefore, objects should be placed at least 12 ft from the curb face so that errant vehicles unable to merge and that continue straight will not impact the object. Breakaway objects should be located 4 to 6 ft from the curb face as a minimum at the taper point locations.
- Longitudinal placement of rigid objects should not occur within 10 ft upstream or downstream of the taper point for a total length of 20 ft where feasible (see *Figure* C-2). Where this placement is infeasible, priority should be given to keeping the upstream roadside area object free.

Driveways

Description. The placement of roadside objects in the vicinity of driveways should occur in such a way as not to compromise available sight distance or provide a clear path for errant vehicles to impact a rigid object on the far side of a driveway entry.

Object placement strategies. Object placement strategies include the following:

- Downstream (far side) placement of objects should be located 10 to 15 ft from the driveway throat edge (see *Figure* C-3).
- Upstream (near side) placement of objects should be located so as to provide adequate sight distance for drivers of exiting vehicles.

Intersections

Description. Though intersections are common crash locations for multiple vehicle collisions, numerous single vehicle roadside crashes can also be expected at intersections. These collisions can occur because of the use of small islands

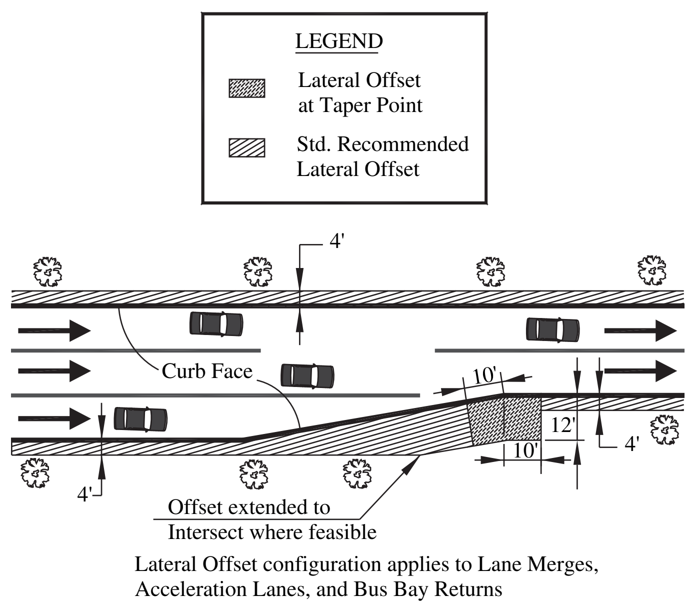


Figure C-2. Object-free zone at merge points.

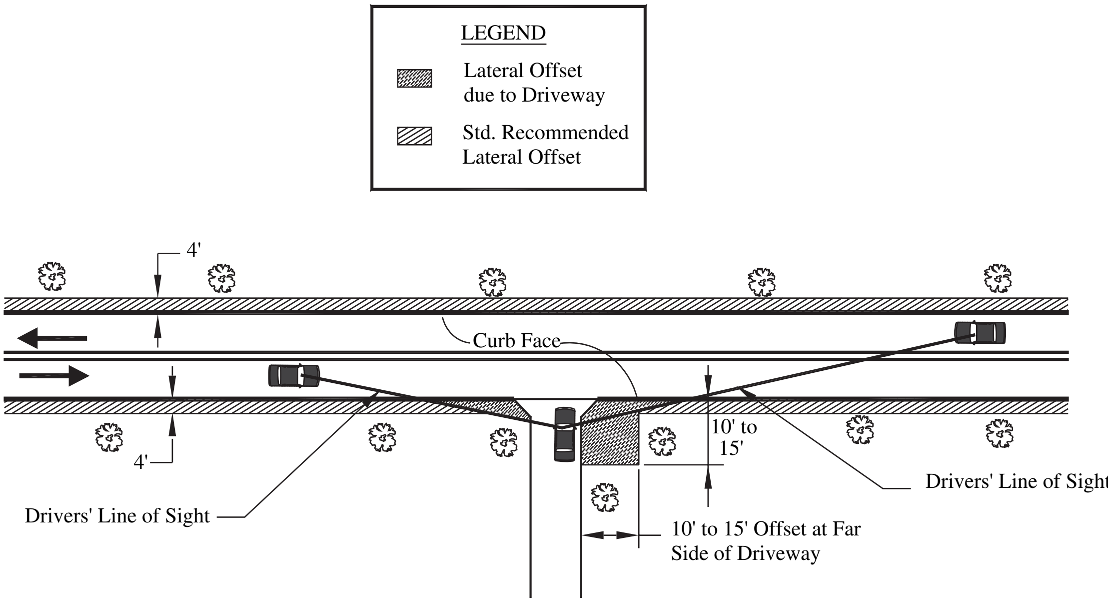


Figure C-3. Roadside object-free zones at driveways.

that are not noticeable to drivers, objects located too close to the curb in the curb return region, and objects located directly aligned with pedestrian access ramps.

Object placement strategies. Object placement strategies include the following:

- Research shows that curbs can provide a positive (visual) guidance but have very little re-directional ability; therefore, curbs should be used at raised channelization islands to assist with providing positive guidance to the driver.
- Since research shows that sloping curbs can be traversable, their use at channelization islands as a means of restricting vehicle access is not recommended.
- For intersection channelization islands (also known as corner islands), the island design should adhere to the AASHTO *Geometric Design of Highways and Streets* criteria (see their Exhibit 9-37 and 9-38). The island should be sufficiently designed so as to be conspicuous to approaching drivers and should not encroach on vehicle paths. Similarly, median noses should be conspicuous and designed so as not to impede normal traffic operations. At both the corner islands and the median noses, the placement of rigid objects should be avoided completely. Only breakaway devices should be constructed at these locations.
- Often a turning vehicle does not successfully navigate the designated turn path and strays onto the adjacent curb return or shoulder. This situation often occurs for truck turning movements. Object placement at the inside edge of intersection turning movements should be as far as practical from the curb face or lane edge. Similarly, for locations without curb these values should be as far as possible from the edge of lane as these locations do not have a curb to help the driver realize that the vehicle has strayed from the designated path.
- Many urban intersections with curb include directional pedestrian access ramps at the intersection corners. For these locations, rigid objects should not be positioned so that errant vehicles are directed towards them along the path of the access ramp. As a result, placement of pedestrian buttons should either be located on a breakaway pedestal pole adjacent to the directional ramp where possible rather than on a rigid traffic signal pole. This will enable the traffic signal pole placement to occur further away from the curb return region.

Sidewalk Configurations

Description. In urban environments, sidewalks are often attached directly to the curb. When this occurs, all fixed roadside objects should be located beyond the sidewalk. Another common sidewalk configuration includes a buffer strip between the curb and the sidewalk edge. For these locations, objects are often located within this buffer strip. Care should be taken to assure that objects placed in the buffer strip area do not become roadside hazards.

Object placement strategies. Object placement strategies include the following:

- For a buffer strip 3 to 4 ft wide, rigid objects should not be constructed. Only frangible items such as breakaway signs or forgiving landscaping treatments are appropriate for use in these narrow buffer strips.

- Buffer strips that are 5 ft wide or greater should include smaller roadside items such as forgiving landscaping treatments or ornamental trees (with canopies that do not impede on sight distance) in the region adjacent to the curb but beyond recommended lateral offsets. If it is infeasible to locate more rigid objects such as light standards or utility poles beyond the sidewalk, then their placement should be immediately adjacent to the sidewalk so as to place them as far from the active travelway as possible. Under no circumstances, however, should these objects be located within the sidewalk boundaries as this space must be kept completely object free so that pedestrians can remain on their designated path.

High Crash Locations and Common Urban Roadside Crash Locations

Description. Many urban corridors are characterized by unique physical features that may directly contribute to a roadside crash. Though the urban control zones previously identified capture most of the high roadside crash locations, a specific design or operational characteristic for a road may also be a location that merits roadside crash mitigation. These locations can be identified by creating spot maps that demonstrate cluster crash locations that do not fall within the bounds of the previously identified urban control zones.

Object placement strategies. Each high crash location that fits the above description will have roadside safety improvement strategies unique to the specific feature contributing to the high crash numbers. As a result, placement strategies can include increased lateral offset, shielding, or reconstruction for extreme cases. This must be evaluated on a case by case basis.

Roadside Treatment Details

Several roadside treatments common to an urban environment can become roadside hazards if not properly positioned. The following summaries identify these common urban roadside features and placement strategies that may help enhance safety at these locations.

Landscaping, Trees, Shrubs, and Plant Layering

General information. Several types of roadside landscaping are commonly employed to enhance the aesthetics of roadside environments. These treatments may include the placement of shrubs, street trees, or alternative treatments such as landscape berms. In addition to the concern of traversability in the event that an errant vehicle encounters roadside landscaping, a common issue regarding the safety of adjacent landscape treatments is sight distance and the impact landscape treatments may have for intersection, driveway, and stopping sight distance considerations.

Strategy summary. The placement criteria, in some cases, is based on the functional purpose or posted speed limits of adjacent roads. Common landscape placement issues include the following:

- Avoid placement in proximity to intersections as discussed in the urban control zone section.
- Avoid placement in proximity to driveways as discussed in the urban control zone section.
- At locations with isolated hazardous trees, consider removing these trees.
- At locations with known hazardous trees that cannot be relocated, shield the trees with safety barrier where possible.
- Lateral offset placement of trees and landscaping as discussed in the urban control zone section. Where practical, use plant layering in front of the more rigid items. In the event of an errant vehicle, this initial landscaping will function as an energy dissipation device and slow down the vehicle prior to impact with the more rigid tree.
- Implement median planting strategies as discussed in the lateral placement urban control zone section.
- Maintaining a clear vision space, which is a space above ground that preserves the lines of sight for drivers, bicyclists, and pedestrians. In general, this space should extend vertically 1 to 3 m [3.3 to 10 ft]. These dimensions will assure clear sight distance for drivers in low-riding sports cars as well as drivers in high trucks and buses. The "clear vision space" then is essentially the space above shrub growth and below tree overhang. A low tree overhang can also create an obstacle for pedestrian access.
- Longitudinal placement of trees and landscaping will help keep landscaping growth from encroaching on other functions of the roadside environment. In addition to longitudinal placement strategies discussed in the urban control zone section, it is advisable to prohibit landscape placement at a variety of other locations. One jurisdiction, for example, recommends that these placement strategies could include the separation of trees from underground utility lines by 1.5 m [5 ft] and a placement a minimum of 3.0 m [10 ft] from utility poles with 4.6 m [15 ft] recommended. In addition, trees could be separated from street lights by 6.1 m [20 ft], from fire hydrants and alleys a distance of 3.0 m [10 ft], and 1.5 m [5 ft] from water meters or utility vaults. Additional longitudinal placement strategies may be implemented to try and achieve uniform tree spacing. This spacing will depend on the specific tree characteristics but could range from 7.6 to 15.2 m [25 to 50 ft]. Tree canopies should not be positioned under service wires.

- The strategic placement of landscaping to influence the visual perception of a driver is a relatively new technique. Landscaping can be used to help visually delineate the downstream road and geometric features of that road. The use of landscaping for visual perception purposes can also help create visual narrowing of the driver's field by gradually tapering a tree line towards the road.

Utility Poles, Posts, Light Standards

General information. Utility poles, posts, light poles, and similar vertical roadside treatments are some of the most common urban roadside hazards. The urban environment, by its very nature, can be expected to include these common roadside objects.

Strategy summary (for utility poles). Several potential strategies can be considered for addressing roadside safety for utility pole placement. These include the following:

- Place utilities completely underground and remove the hazardous poles. The removal of all poles in the urban roadside environment may not be practical, but the placement of utilities underground, where feasible, will minimize this hazard.
- Place poles as far as possible from the active travel lanes. Recommended goals include specific pole lateral clearance based on speed limits. One jurisdiction suggested a pole offset strategy with a target goal of 3.6 m [12 ft] from face of curb to face of pole for all locations where possible. For speed limits greater than 56 km/h [35 mph] but not exceeding 72 km/h [45 mph], a lateral clearance of 2.4 m [8 ft] is acceptable. For roads with posted speed limits less than or equal to 56 km/h [35 mph], a lateral clearance of 1.8 [6 ft] is acceptable. A second jurisdiction recommends an offset greater than 2.4 m [8 ft] for roads with speed limits of 40 to 55 km/h [25 to 35 mph] and a lateral offset of 4.3 m [14 ft] for roads with speed limits of 65 to 70 km/h [40 to 45 mph].
- Locate poles away from access points where the pole may restrict sight distance or be easily impacted.
- Place poles on the inside of sharp horizontal curves (as errant vehicles tend to continue straight towards the outside of curves), but be sure pole placement conforms with the urban control zone recommendations previously shown.
- Locate poles on only one side of the road and place shared utilities on poles where possible.
- Use breakaway poles at select hazardous locations or shield them with safety barrier.

Mailboxes

General information. The placement of mailboxes in urban environments can result in new hazardous roadside objects if jurisdictions do not enforce guidelines about mailbox type and placement. There are several crashworthy mailboxes that have been tested including standard boxes mounted on a 100 mm by 100 mm [4 in by 4 in] wooden post or a 38 mm [1$^1/_2$ in] light-gauge pipe for mounting mailboxes, with these posts embedded no deeper than 600 mm [24 in] into the ground. Mailboxes should further be mounted to their supports to prevent the mailbox from separating from the post during a crash event. Standard cluster mailboxes (as approved by U.S. Postal Service Standards) can also be used in urban regions. Many of the larger mail collection boxes fail safety requirements and should be placed outside of clear recovery areas.

Strategy summary. While making mailboxes crashworthy will satisfy safety associated with mailbox-related crashes, it is important to recognize that the placement of mailboxes may have an important impact on the overall safety of the roadway. The following recommendations detail appropriate placement of mailboxes:

- Mailboxes should not obstruct intersection sight distance.
- Mailboxes should not be located directly on higher-speed roadways, where stopping associated with mail delivery and collection can lead to substantial speed differentials between vehicles on the travelway, thereby increasing the possibility of a rear-end collision. For higher-speed urban roads without curb where mailboxes are present, one option is to provide a 2.4 m [8 ft] mailbox turnout lane adjacent to the travelway that will permit vehicles to leave the travelway for mail collection and delivery purposes. Alternatively, a minimum shoulder width for these higher-speed roads of 1.8 m [6 ft] should be maintained at these locations.
- At curbed residential locations, mailboxes should be positioned so that the minimum distance from the roadside face of the mailbox to the face of the curb is 150 mm [6 in], with a preferred offset ranging from 200 to 300 mm [8 to 12 in].
- Mailbox placement at driveways should be compatible with the urban control zones previously defined.
- Shield rigid mailboxes.
- Add reflective object markers to improve nighttime visibility of mailboxes.

Safety Barriers

General information. Roadside barriers are subject to *NCHRP Report 350* testing criteria. There are several types of safety barriers that may be present in an urban environment. These include the following:

- Barriers (flexible, semi-rigid, and rigid),
- Bridge Railings, and
- End Treatments (crash cushions and end terminals).

Generally, most of the research on safety barriers has been oriented towards the design of barriers and their placement to shield vehicles from hazardous roadside conditions. The Federal Highway Administration maintains a roadside hardware website that provides information about specific roadside hardware that has been tested. This information is available at: http://safety. fhwa.got.gov/roadway_dept/road_hardware/index.htm.

Strategy summary. In the urban environment, it may be challenging to construct roadside barriers in the confined roadside space available. In locations with bicycle activity, for example, safety barriers located immediately adjacent to the road may expose cyclists to unnecessary risks as the barrier may result in a sensation of "squashing" the cyclist between the barrier and an adjacent motor vehicle. Similarly, barriers immediately adjacent to motor vehicle lanes cause vehicles to shy away from the barrier, thereby adversely impacting traffic operations. Finally, traffic barrier restricts pedestrian activity in an urban environment and requires careful design of openings for pedestrian crossings that include crashworthy barrier end treatments. Due to the wide variety of potential safety barriers that may be selected for use, the two references identified above should be consulted for specific applications for each barrier type.

Street Furniture

General information. In many urban areas the use of street furniture is a common approach to improving the aesthetic and functional quality of a street. Street furniture includes items placed adjacent to the road that are there to improve the adjacent land use or to improve transportation operations. In some jurisdictions, street lights and signs are included in the category of street furniture; however, for the purposes of this review street furniture is considered to be supplemental items such as benches, public art, trash receptacles, phone booths, planters, bollards, fountains, kiosks, transit shelters, bicycle stands, etc. Often the placement of these devices can obscure sight distance, so their location should not occur in the sight triangles of intersections or driveways. Many street furniture items are placed along the right-of-way by the property-owners themselves, as in the case of the placement of a sidewalk cafe in front of a restaurant, and are thus largely outside the engineer's control.

Strategy summary. Little is known about the safe placement of street furniture. The following general recommendations should enhance roadside safety in these locations:

- While maintaining its functional purpose, locate street furniture as far from the street as possible.
- Restrict street furniture placement to avoid sight distance issues for road users. The Urban Control Zones previously identified should be applied to all street furniture.
- Where possible, deploy street furniture that meets basic crashworthy standards; however, concern for pedestrians has led to the use of fixed supports in some urban areas. Examples of sites where breakaway supports may be imprudent are sites adjacent to bus shelters or in areas of extensive pedestrian concentration.

APPENDIX D

Draft Chapter 10 for AASHTO *Roadside Design Guide*

APPENDIX D: Draft Chapter 10 for AASHTO *Roadside Design Guide* from the contractor's final report for NCHRP Project 16-04 is available on the TRB website at http://trb.org/news/blurb_detail.asp?id=9456.

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