



National Cooperative Highway Research Program

Synthesis of Highway Practice 281

Operational Impacts of Median Width on Larger Vehicles

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PREFACE

A vast storehouse of information exists on nearly every subject of concern to highway administrators and engineers. Much of this information has resulted from both research and the successful application of solutions to the problems faced by practitioners in their daily work. Because previously there has been no systematic means for compiling such useful information and making it available to the entire community, the American Association of State Highway and Transportation Officials has, through the mechanism of the National Cooperative Highway Research Program, authorized the Transportation Research Board to undertake a continuing project to search out and synthesize useful knowledge from all available sources and to prepare documented reports on current practices in the subject areas of concern.

This synthesis series reports on various practices, making specific recommendations where appropriate but without the detailed directions usually found in handbooks or design manuals. Nonetheless, these documents can serve similar purposes, for each is a compendium of the best knowledge available on those measures found to be the most successful in resolving specific problems. The extent to which these reports are useful will be tempered by the user's knowledge and experience in the particular problem area.

FOREWORD

*By Staff
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This synthesis report will be of interest to officials and staff of municipal, regional, and statewide transportation agencies who are responsible for roadway design and traffic control at intersections and driveways on divided highways where larger vehicles encounter narrow medians. It will also be of interest to other professionals who interact with these agencies to mitigate problems encountered. It presents state-of-the-practice information about current median design policies and practices, describes the traffic operational and safety problems encountered in designing for larger vehicles and narrow medians, and identifies alternative improvement techniques that can be used to minimize or eliminate problems encountered. It also identifies design techniques that can be used in new construction or reconstruction projects to avoid introducing traffic operational or safety problems in the future.

Administrators, engineers, and researchers are continually faced with highway problems on which much information exists, either in the form of reports or in terms of undocumented experience and practice. Unfortunately, this information often is scattered and unevaluated and, as a consequence, in seeking solutions, full information on what has been learned about a problem frequently is not assembled. Costly research findings may go unused, valuable experience may be overlooked, and full consideration may not be given to available practices for solving or alleviating the problem. In an effort to correct this situation, a continuing NCHRP project has the objective of reporting on common highway problems and synthesizing available information. The synthesis reports from this endeavor constitute an NCHRP publication series in which various forms of relevant information are assembled into single, concise documents pertaining to specific highway problems or sets of closely related problems.

This report of the Transportation Research Board focuses on 10 alternative cross sections that are widely used on arterial highways. Undivided roadways are also included for comparative purposes.

To develop this synthesis in a comprehensive manner and to ensure inclusion of significant knowledge, the available information was assembled from numerous sources, including a large number of state highway and transportation departments. A topic panel of experts in the subject area was established to guide the author's research in organizing and evaluating the collected data, and to review the final synthesis report.

This synthesis is an immediately useful document that records the practices that were acceptable within the limitations of the knowledge available at the time of its preparation. As the processes of advancement continue, new knowledge can be expected to be added to that now at hand.

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Information on current practice was provided by many highway and transportation agencies. Their cooperation and assistance are appreciated.

OPERATIONAL IMPACTS OF MEDIAN WIDTH ON LARGER VEHICLES

SUMMARY

Many arterial highways and streets are divided by raised, depressed, or flush medians. Where narrow raised or depressed medians are used, larger vehicles, such as trucks, buses, and recreational vehicles, may encounter traffic operational and safety problems in making left-turn and crossing maneuvers through the median at intersections or driveways with median openings. In addition, where left turns cannot be made because median openings are not provided, larger vehicles may be required to make U-turns at a downstream location and proceed to their destination, or may find it necessary to use an indirect route to reach their destination. Traffic operational and safety problems can also result from such U-turn maneuvers and indirect routings.

Median widths used by highway agencies on divided arterials in both rural and urban/suburban areas vary widely. The geometric design policies of the American Association of State Highway and Transportation Officials (AASHTO) specify a minimum median width of 1.2 m (4 ft) for divided arterials, but most divided highways have wider medians and such wider medians are desirable to accommodate larger vehicles.

The size of larger vehicles in the traffic stream has been growing steadily. The AASHTO design vehicles now used in the planning and design of roadways and intersections range up to 2.6 m (8.5 ft) in width and 35.9 m (118 ft) in length. Although the largest trucks are usually permitted only on freeways and toll roads, trucks of up to 23 m (75 ft) in length are now common on rural highways and urban arterials. Highway agencies face the challenge of providing access for these large trucks to reach their destinations. Narrow medians are one of the constraints that make it difficult for trucks to maneuver safely at intersections and avoid interfering with other traffic.

Divided highway median widths at rural unsignalized intersections should generally be as wide as possible. It is desirable to provide a median width sufficient to store any larger vehicles likely to use the intersection frequently. At urban/suburban unsignalized intersections on divided highways, accidents and undesirable driving behavior increase with increasing median width. Therefore, medians should generally be only as wide as necessary to accommodate current or planned left-turn treatments. However, at intersections used frequently by larger vehicles, it may be desirable to choose a median width sufficient to store a selected design vehicle with adequate clearance to the through lanes of the divided highway at both ends of the vehicle. This presents a difficult tradeoff for highway agencies in designing urban/suburban unsignalized intersections on divided highways. Wider medians provide more storage space in median openings and, therefore, reduce the likelihood that vehicles stopped in the median will encroach on the through traffic lanes. However, research has found wider medians at intersections and driveways in urban and suburban areas are also associated with an increased frequency of undesirable driving behavior and accidents. By contrast, at signalized intersections on divided highways, the

length of a specific design vehicle is not usually a consideration in selecting the median width because any larger vehicles that stop in the median should be able to clear the intersection at the end of any given signal phase.

This synthesis identifies a range of traffic operational and safety problems encountered by larger vehicles at divided highway intersections. These include problems related to: insufficient storage space in the median opening area, larger vehicles turning onto and off the divided highway, larger vehicles crossing the divided highway, and U-turn maneuvers by larger vehicles seeking to reach destinations at which a median opening is not provided or at which a median opening is provided but the median is too narrow for effective use. Only limited research was found that deals directly with problems encountered by larger vehicles at intersections with narrow medians. However, this synthesis includes findings of a broad range of published research on the topics of median type and width. Where passenger vehicles have encountered problems related to median width, such problems are likely to be even more critical when larger trucks use the same median. The synthesis identifies and discusses mitigation techniques that have been used by highway agencies to address such problems at existing intersections with narrow medians on divided highways. The synthesis also identifies design techniques that can be used by highway agencies in new construction and reconstruction projects to avoid introducing such problems in the future.

INTRODUCTION

BACKGROUND

Many arterial highways and streets are divided by raised, depressed, or flush medians. Guidelines for the design of highway and street medians are set by the American Association of State Highway and Transportation Officials (AASHTO) *Policy on Geometric Design of Highways and Streets (I)*. AASHTO policy encourages wider medians, but permits medians as narrow as 1.2 m (4 ft) to be used on arterial highways where a wider median cannot be provided. Many factors, such as limited or costly rights-of-way and the constraints of existing development and environmental concerns (e.g., encroachment on parks or wetlands), may lead highway agencies to choose a narrow median at locations where a wider median would be more desirable. Development activities, increased traffic demand, and increased vehicle size can cause divided highways that once served traffic demands effectively to operate poorly.

Most arterial highways are used frequently by larger vehicles, such as trucks, buses, and recreational vehicles (RVs). AASHTO policy makes consideration of larger vehicles and, in particular a specific design vehicle selected by the responsible highway agency, a key control on the design of intersections, driveways, turning roadways, and channelization details for any highway facility (*I*). In particular, larger vehicles are an important consideration in the design of intersections and driveways on a divided highway.

Where only a narrow median can be provided on a divided highway, larger vehicles, especially larger tractor-semitrailer combination trucks, may experience traffic operational delays or traffic safety problems in making turning and crossing maneuvers through the median opening area. Where such problems occur, highway agencies may be able to make geometric design or traffic control improvements to mitigate the problem.

PROBLEM STATEMENT AND SYNTHESIS OBJECTIVES

Divided roadways separated by narrow medians in urban, suburban, and rural areas can effect traffic operations and safety. Median width restrictions or limitations may result

from environmental considerations, limited or costly rights-of-way, development activities, increased traffic demand, and increased vehicle size among other factors. These limitations can adversely affect the operation of larger vehicles, such as commercial trucks, transit buses, school buses, and recreational vehicles.

To assist highway agencies in understanding and mitigating such problems this synthesis will:

- Document available literature, resources, and practical experience on the relationship of median width to the operation of larger vehicles;
- Identify and report on specific traffic operational and safety concerns (e.g., left turns, U-turns, sight distance, storage needs, and increased vehicle size); and
- Summarize the reported effectiveness of the various methods, techniques, and strategies (e.g., design criteria, routing, intersection control, access management, land-use planning, and local ordinances) used to address the identified concerns.

The preparation of this synthesis has included a literature search and review, a survey of highway agencies, and discussions with representatives of the trucking industry.

ORGANIZATION OF SYNTHESIS

Chapter 2 of this synthesis presents the current median design policies and practices of highway agencies. Chapter 3 describes the traffic operational and safety problems encountered by larger vehicles at intersections and driveways on divided highways with narrow medians. Chapter 4 describes alternative improvement techniques that can be used to mitigate the traffic operational and safety problems at intersections and driveways on divided highways with narrow medians. The conclusions of the synthesis are presented in chapter 5. Appendix A presents the survey questionnaire and summarizes the results of the highway agency survey conducted as part of the preparation of this synthesis.

CURRENT MEDIAN DESIGN PRACTICES

This chapter presents the current median design practices of highway agencies. The chapter begins with an overview of the alternative cross sections that can be used for urban, suburban, and rural arterial highways and their traffic operational and safety performance. Cross sections both with and without medians are reviewed for comparative purposes. The remainder of the chapter summarizes the median design policies and practices of highway agencies, the procedures that are used to design intersections and driveways on divided highways to accommodate larger vehicles, and research findings concerning the effect of median width on traffic operations and safety.

ALTERNATIVE CROSS SECTIONS FOR ARTERIAL HIGHWAYS

A broad variety of alternative cross sections are used on arterial highways in urban, suburban, and rural environments. These cross sections have been evaluated extensively in three recent reports: *NCHRP Report 282: Multilane Design Alternatives for Improving Suburban Highways* (2), *NCHRP Report 330: Effective Utilization of Street Width on Urban Arterials* (3), and *NCHRP Report 395: Capacity and Operational Effects of Midblock Left-Turn Lanes* (4). The following discussion identifies these cross sections and describes their typical uses.

This synthesis focuses on 10 alternative cross sections that are widely used on arterial highways. These alternatives range from one to four lanes for traffic in each direction of travel and include undivided roadways, roadways divided by a flush median that operates as a center two-way left-turn lane (TWLTL), and roadways divided by a raised or depressed median. These alternative cross sections are:

- Two-lane undivided (2U),
- Three-lane divided with a center TWLTL (3T),
- Four-lane undivided (4U),
- Four-lane divided with a raised or depressed median (4D),
- Five-lane divided with a center TWLTL (5T),
- Six-lane undivided (6U),
- Six-lane divided with a raised or depressed median (6D),
- Seven-lane divided with a center TWLTL (7T),
- Eight-lane undivided (8U), and
- Eight-lane divided with a raised or depressed median (8D).

The general geometric design characteristics of these alternative cross sections are illustrated in Figure 1. Many geometric variations of the basic cross sections considered here are possible. For example, each design alternative can be constructed with a range of lane and median widths. Shoulders are usually provided on rural and suburban highways, whereas urban arterials typically have a curb-and-gutter cross section. Curb parking lanes may be included on one side of the roadway, on both sides, or not at all.

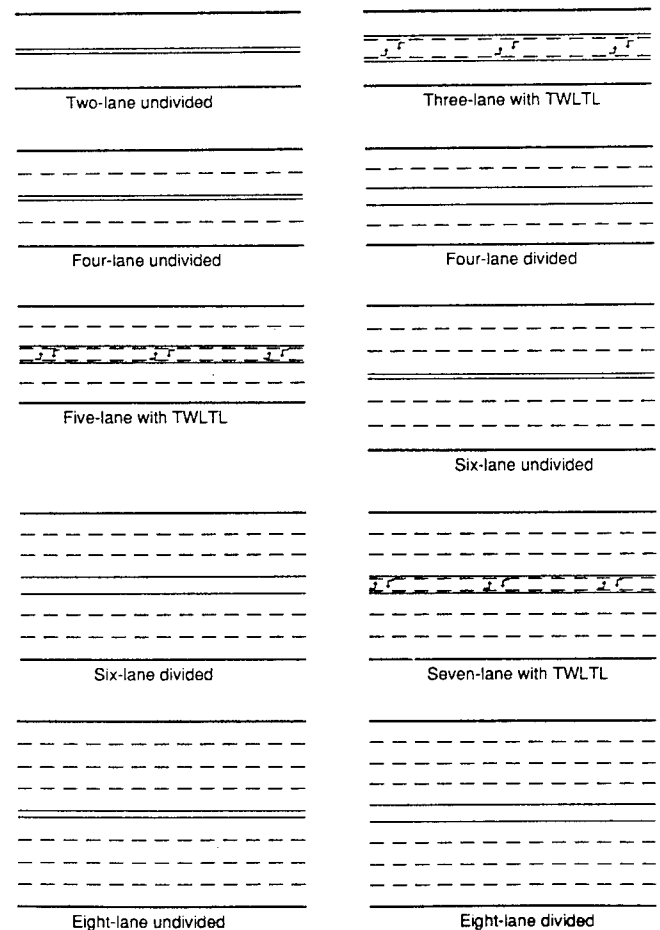


FIGURE 1 Design alternatives for arterial highways.

This synthesis focuses on the traffic operational and safety impacts of larger vehicles at intersections and driveways on divided highways with narrow medians. Undivided roadways are also included for comparative purposes.

Each basic cross section is briefly discussed below. The operational impacts of these cross sections on larger vehicles are more fully discussed later in this chapter.

Two-Lane Undivided

A two-lane undivided roadway is the basic design alternative for a low-volume rural highway or urban arterial. This design alternative consists of one lane of travel in each direction separated by a painted centerline.

Three-Lane with Two-Way Left-Turn Lane

A three-lane design including a center TWLTL is a simple improvement from the two-lane undivided alternative, in which a lane in the center of the roadway is reserved for use as a left-turn lane by vehicles traveling in either direction. The TWLTL in the median provides a deceleration and storage area for vehicles turning left at a driveway or at an unsignalized intersection so that through vehicles are not delayed by turning vehicles as they wait for a gap in opposing traffic to complete their turn. TWLTLs are also used as an acceleration and/or storage lane by vehicles turning onto an arterial from an intersection or driveway. As shown in Figure 1, the TWLTL is delineated by a broken and a solid yellow centerline adjacent to the through travel lane on each side of the TWLTL.

The three-lane TWLTL alternative has come into widespread use only within the past 20 years. It serves as a low-cost alternative to designs with multiple through lanes in each direction and is appropriate for highways with relatively low through traffic volumes, with frequent left-turn demands between intersections, and where available funds and/or right-of-way is limited. The three-lane TWLTL cross section has been used on rural and suburban highways and on urban arterials.

Four-Lane Undivided

The most simple design alternative with multiple lanes for through traffic in each direction of travel is the four-lane undivided cross section. This alternative has two through lanes in each direction of travel separated by a double yellow centerline.

Four-Lane Divided

Another four-lane alternative is the four-lane divided cross section with a raised or depressed median. Wider medians allow space for conventional (i.e., one-way) left-turn lanes

in the median at intersections and major driveways. Median openings, either with or without one-way left-turn lanes, are provided at signalized intersections and at selected intersections without signals and major driveways to facilitate crossing movements and left-turn movements onto and off of the roadway.

Five-Lane with Two-Way Left-Turn Lane

The five-lane design alternative including a center TWLTL in the median has, in the past 30 years, become a very common multilane design alternative for upgrading urban and suburban arterials. This design alternative has two through lanes of travel in each direction and a center TWLTL to provide for left-turn maneuvers at driveways and minor intersections.

Six-Lane Undivided

The six-lane undivided design is similar to the four-lane undivided design with two additional through lanes. The lanes in each direction of travel are separated by a double yellow centerline with no median to shelter or shadow left-turning vehicles.

Six-Lane Divided

Six-lane divided streets with a raised median and one-way left-turn lanes at intersections and major driveways are appropriate for use on higher volume urban streets. This alternative functions in a manner similar to the four-lane divided design with a raised or depressed median except that it provides three through lanes for travel in each direction.

Seven-Lane with Two-Way Left-Turn Lane

The seven-lane TWLTL design alternative operates in a manner similar to the five-lane TWLTL alternative, except that three through lanes are provided in each direction of travel.

Eight-Lane Undivided

Eight-lane undivided streets are rare because six-lane divided streets, six-lane undivided streets with parking lanes, or seven-lane streets with a center TWLTL are generally considered to more effectively use the available street width. However, the eight-lane undivided design alternative can be used for streets with very high through traffic volumes.

Eight-Lane Divided

The eight-lane divided cross section is entirely analogous to four-lane and six-lane divided cross sections with additional through traffic lanes. Conventional left-turn lanes in the median may be provided at intersections and major driveways. Some highway agencies have provided U-turn roadways through the median and other indirect left-turn roadways to avoid the need for direct left-turn movements at signalized intersections and, thus, reserve more time in the signal cycle for through movements.

TRAFFIC OPERATIONAL AND SAFETY COMPARISONS OF ALTERNATIVE CROSS SECTIONS

Traffic operational and safety comparisons of these alternative cross sections have been made in several recent NCHRP reports. *NCHRP Report 282: Multilane Design Alternatives for Improving Suburban Highways* (2) and *NCHRP Report 330: Effective Utilization of Street Width on Urban Arterials* (3) identified 11 operational and 13 safety factors that characterize the performance of the cross sections for arterial highways discussed previously.

Operational factors:

- Minimize or eliminate delay to through vehicles by left-turning vehicles.
- Minimize delay to through vehicles by right-turning vehicles.
- Allow provisions of turning lanes at intersections and high-volume driveways.
- Ease movement of emergency vehicles.
- Provide for storage of disabled vehicles.
- Ensure compatibility with use of frontage roads.
- Facilitate U-turns.
- Shadow vehicles making crossing maneuvers at unsignalized intersections (eliminate blocking of one direction while waiting for gap in the other direction).
- Facilitate pedestrian crossings.
- Encourage access development on side streets off of the arterial.
- Minimize high volume of left turn and U-turn movements at intersections.

Safety factors:

- Minimize rear-end conflicts between left-turning and through vehicles and allow left-turn drivers time to evaluate opposing gaps.
- Minimize high concentration of driveways and overlapping conflict patterns.
- Control conflicts between left turns into and out of driveways.

- Minimize or eliminate conflicts between opposing left turns off of the arterial.
- Minimize or eliminate conflicts between left turns and right turns from/to the same lane.
- Minimize or eliminate conflicts caused by encroachment on opposing lanes of vehicles turning right into and out of driveways.
- Minimize or eliminate conflicts caused by encroachment on adjacent lanes of vehicles turning right into and out of driveways.
- Minimize or eliminate conflicts in opposing lanes of vehicles turning left off of the arterial.
- Minimize time during which left-turn conflicts with opposing traffic can occur.
- Provide protected position in median for crossing vehicles.
- Provide protected position in median for crossing pedestrians.
- Minimize the conflicts between bicycles and motor vehicles.
- Increase width of roadside clear recovery area.

Figure 2 presents the relative ratings of these factors developed in NCHRP Report 282 for different cross sections for suburban arterial highways.

Many of these factors relate to the safety benefits of providing a median on an arterial roadway. Medians reduce conflicts by separating opposing traffic streams and allowing turning movements to occur only at locations where median openings are provided. Thus, medians can be expected to minimize the cross-centerline accidents, often quite severe, that might occur on an undivided roadway, as well as to limit accidents involving turning and crossing maneuvers to selected locations that can be designed to accommodate such maneuvers.

The following discussion summarizes key research findings on the safety performance of alternative roadway cross sections with and without medians. These findings should be interpreted carefully. For example, if a particular table shows that four-lane arterial highways with raised medians have lower accident rates than those with five-lane TWLTL cross sections, it would be inappropriate to presume that this finding will apply in all cases. The relative safety performance of different cross sections depends on the specific features of particular sites, and each cross section has sites for which it is best suited. Where research indicates that the overall safety performance of two or more alternatives is similar, it is likely that site-specific factors will be critical in determining which cross section will be most appropriate. For example, where there are many existing access points on an arterial roadway, installation of a median might unnecessarily limit the ability of drivers to reach their destinations. By contrast, where existing development is limited, installation of a

Design alternative	Description of geometrics	Total available width (ft)	Operational factors											Safety											
			1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11	12
Two-lane undivided (2U)	Narrow Lanes	20 — 22	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	--	--	--
	Wide Lanes	24 — 26	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	--	--	--
	Narrow Shoulder	28 — 36	-	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	--	--	--
Three-lane with TWLTL (3T)	Full Shoulder	38 — 40	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+
	Narrow Lanes	30 — 32	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Wide Lanes	34 — 40	++	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Four-lane undivided (4U)	Narrow Shoulder	42 — 48	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++
	Full Shoulder	50 — 56	++	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+
	Narrow Lanes	40 — 42	-	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Four-lane divided with raised median (4D)	Wide Lanes	44 — 52	-	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Narrow Shoulder	54 — 58	-	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Full Shoulder	60 — 64	-	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+
Five-lane with TWLTL (5T)	Narrow Lanes	48 — 54	+	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Wide Lanes	56 — 64	++	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Narrow Shoulder	66 — 70	++	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Five-lane with TWLTL (5T)	Full Shoulder	72 — 80	++	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+
	Wide median	72 — 94	++	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Narrow Lanes	50 — 54	+	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
Five-lane with TWLTL (5T)	Wide Lanes	56 — 64	++	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Narrow Shoulder	66 — 68	++	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--
	Full Shoulder	70 — 80	++	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+	++	+

Scale of operational and safety ratings

- ++ Most desirable
- + Desirable
- 0 Neutral
- Least desirable

FIGURE 2 Relative ratings of operational and safety factors for multilane design alternatives on suburban arterial highways (2).

median may assist local planners in encouraging development on large parcels of land and discouraging strip commercial development.

In summary, the following discussion should be considered as a whole and readers should resist the temptation to use any particular table as a universal guide to the selection of appropriate cross sections.

NCHRP Report 282 (2) developed a procedure for estimating the expected accident rates for suburban arterial highways with and without medians. Tables 1, 2, and 3, respectively, can be used for estimating the average accident rates for nonintersection accidents, unsignalized intersection accidents, and total accidents (including both nonintersection and unsignalized intersection accidents). Table 4 presents the percentage of accidents involving a fatality or injury for suburban arterials found in NCHRP Report 282 and Table 5 shows the percentage of accidents found to be susceptible to correction by multilane design

alternatives. The accident types that are generally found to be susceptible to correction by multilane design alternatives include head-on, rear-end, and angle collisions. Other accident types, including single-vehicle accidents, are not generally susceptible to correction by multilane design alternatives.

Although the safety results presented in NCHRP Report 282 are useful in estimating the expected accident rate of an arterial highway, the estimates shown for divided highways are not sensitive to median width, even for intersection locations. Furthermore, Tables 1, 2, and 3 show that the accident rate decreases with increasing truck percentage. The report notes that this effect is in a counterintuitive direction and could represent, in part, the effect of other factors correlated with truck percentage that were not available for modeling. Situations like this in which one variable may serve as a surrogate for other unknown variables are all too common in traffic accident research.

TABLE 1
AVERAGE ACCIDENT RATES FOR NONINTERSECTION ACCIDENTS ON SUBURBAN ARTERIAL HIGHWAYS (2)

Basic Accident Rates (accidents per million vehicle-miles)					
Type of Development	Design Alternative				
	2U	3T	4U	4D	5T
Commercial	2.39	1.56	2.85	2.90	2.69
Residential	1.88	1.64	0.97	1.39	1.39
Adjustment Factors					
Driveways per mile			Under 30	30-60	Over 60
			-0.41	-0.03	+0.35
Truck percentage			Under 5%	5-10%	Over 10%
			+0.18	-0.07	-0.33

Note: Accident rates should be decreased by 5 percent for highway sections with full shoulders and increased by 5 percent for highway sections with no shoulders.

TABLE 2
AVERAGE ACCIDENT RATES FOR UNSIGNALIZED INTERSECTION ACCIDENTS ON SUBURBAN ARTERIAL HIGHWAYS (2)

Basic Accident Rates (accidents per million vehicle-miles)					
Type of Development	Design Alternative				
	2U	3T	4U	4D	5T
Commercial	2.11	2.43	4.77	4.71	3.11
Residential	2.88	1.91	3.03	2.71	1.85
Adjustment Factors					
Intersections per mile			Under 5	5-10	Over 10
			-0.99	+0.28	+1.55
Truck percentage			Under 5%	5-10%	Over 10%
			+0.22	-0.08	-0.38

TABLE 3
TOTAL ACCIDENT RATES FOR SUBURBAN ARTERIAL HIGHWAYS (INCLUDING
NONINTERSECTION AND UNSIGNALIZED INTERSECTION ACCIDENTS) (2)

Basic Accident Rates (accidents per million vehicle-miles)					
Type of Development	Design Alternative				
	2U	3T	4U	4D	5T
Commercial	4.50	3.99	7.62	7.61	5.80
Residential	4.76	3.55	4.00	4.10	3.24

Adjustment Factors					
	Under 30			30-60	
Driveways per mile			-0.41	-0.03	+0.35
Intersections per mile	Under 5			5-10	
			-0.99	+0.28	+1.55
Truck percentage	Under 5%			5-10%	
			+0.40	-0.15	-0.71

TABLE 4
ACCIDENT SEVERITY DISTRIBUTION FOR SUBURBAN ARTERIAL HIGHWAYS (2)

Design Alternative	Percentage of Accidents Involving Fatality or Injury			
	Nonintersection Accidents		Unsignalized Intersection Accidents	
	Commercial	Residential	Commercial	Residential
2U	38.4	43.6	39.0	32.9
3T	29.9	43.6	32.1	32.9
4U	38.4	38.8	32.1	32.9
4D	33.7	43.6	26.9	45.1
5T	33.7	38.8	32.1	26.6

TABLE 5
DISTRIBUTION OF ACCIDENT TYPES SUSCEPTIBLE TO CORRECTION BY MULTILANE
DESIGN ALTERNATIVES (2)

Design Alternative	Percentage of Accidents Susceptible to Correction ¹			
	Nonintersection Accidents		Unsignalized Intersection Accidents	
	Commercial	Residential	Commercial	Residential
2U	50.5	44.3	55.9	50.5
3T	45.0	49.4	65.2	56.7
4U	45.8	51.6	65.0	63.5
4D	58.6	43.2	55.3	42.4
5T	50.5	60.0	44.6	55.0

¹Head-on, rear-end, and angle accidents.

Traffic operational comparisons between the alternative cross sections can generally be made with the analysis procedures presented in the *Highway Capacity Manual* (5). This manual presents procedures that account for the effect of the number of lanes, lane width, shoulder widths, and many other factors of arterial highway cross sections. *Highway Capacity Manual* procedures also incorporate the effects of site-specific traffic volumes and characteristics including traffic flow rates, traffic peaking characteristics, and the percentage of trucks and other types of heavy vehicles in the traffic stream. The most applicable of these

procedures are those found in chapter 7 (*Rural and Suburban Highways*), chapter 8 (*Two-Lane Highways*), and chapter 11 (*Urban and Suburban Arterials*). The procedures applicable to at-grade intersections are discussed later in the synthesis.

The *Highway Capacity Manual* procedures do not address the traffic operational effects of TWLTLs between intersections. Table 6 presents estimates of the delay reduction resulting from installation of a TWLTL on a suburban arterial highway.

TABLE 6
 DELAY REDUCTION ESTIMATES FOR INSTALLATION OF TWLTL
 ON SUBURBAN ARTERIAL HIGHWAY (2)

Flow Rate (vph) ¹	Driveways per Mile	Delay Reduction ¹ (vehicles-sec per left-turn vehicle)	
		2U vs. 3T	4U vs. 5T
400	30	19.7	6.3
	60	13.1	5.4
	90	13.1	4.8
650	30	—	10.2
	60	—	8.7
	90	—	7.8
900	30	—	65.4
	60	—	56.3
	90	—	47.8
1,100	30	—	764.2
	60	—	673.5
	90	—	531.1

Note: vph = vehicles per hour.

¹Vehicle flow is cited in one direction of travel.

NCHRP Report 330 (3) examined the safety effects of implementing an alternative cross section on an urban street without changing the total curb-to-curb street width. Such projects are accomplished by adding, removing, or changing the widths of travel lanes, parking lanes, and medians. Table 7 summarizes the advantages and disadvantages of the alternative cross sections for urban arterial streets as found in this report. Figure 3 presents relative ratings of operational and safety factors for alternative cross sections as developed for NCHRP Report 330. The factors considered in Table 7 are a subset of those identified in the list of operational and safety factors cited earlier. Unlike the comparable chart in Figure 2, developed for NCHRP Report 282, the chart in Figure 3 takes into account not only total available street width, but also lane width and median width.

The main focus of NCHRP Report 330 was on safety issues. Table 8 summarizes the effects on safety of projects that change the allocations of street width to travel lanes, parking lanes, and medians without changing the total curb-to-curb width. This table addresses the percentage change in total and midblock accident rates and the change in the percentage of fatal and injury-related accidents. Table 9 presents comparable data on the percentage change in specific accident types including angle, sideswipe, and rear-end collisions.

NCHRP Report 330 drew no conclusions on the traffic operational performance of alternative cross sections for urban arterials beyond those presented in NCHRP Report 282 (2). NCHRP Report 395 (4) also considered the relative traffic operational and safety performance of cross sections for arterials, and highways that are undivided,

divided by a median, or divided by a center TWLTL. Table 10 presents a comparison of these three alternative cross sections indicating which cross section is preferred with respect to a set of factors related to operational safety, access, and other effects.

NCHRP Report 395 reviewed the relative safety performance of arterials with different cross sections. Table 11 summarizes the safety performance of these cross sections as reported by seven key sources in the literature, including Bowman and Vecellio (6), Chatterjee et al. (7), Parker (8), Squires and Parsonson (9), McCoy and Ballard (10), and Walton and Machemehl (11), as well as NCHRP Report 282 (2). Figure 4 illustrates the variation of arterial accident rates with average daily traffic (ADT) based on the composite data shown in Table 11.

The research in NCHRP Report 395 also gathered data on the safety history of arterials with alternative cross sections and established regression relationships for predicting their safety performance. Figures 5 and 6 illustrate the annual accident frequencies predicted by these relationships for alternative cross sections for business and office areas, and for residential and industrial areas, respectively. The predictions in Figures 5 and 6 apply to the specific conditions specified in the figures.

NCHRP Report 395 formulated nonlinear models for predicting through delay and left-turn delay for arterial segments with cross sections that are undivided, divided by a raised median, and divided by a center TWLTL. The research found that arterials with raised medians and TWLTLs have similar delays to through traffic on the arterial. It was found that either cross section could function

TABLE 7
ADVANTAGES AND DISADVANTAGES OF DESIGN ALTERNATIVES FOR URBAN ARTERIAL STREETS (3)

Design Alternative	Advantages	Disadvantages
Two-lane undivided	Least expensive alternative Minimal street width required	Minimal capacity for through traffic movement Delay to through vehicles by left-turning vehicles
Three-lane with TWLTL	Reduces frequency of rear-end and angle accidents associated with left-turn maneuvers Provides spatial separation between opposing lanes to reduce head-on accidents Reduces delay to through vehicles by left-turning vehicles Increases operational flexibility	No refuge area in median for pedestrians
Four-lane undivided	Provides additional lanes to increase capacity for through traffic movement	Required street width may not be available Delay to through vehicles by left-turning vehicles May generate safety problems associated with rear-end and lane changing conflicts
Four-lane divided	Provides additional lanes to increase capacity for through traffic movement Reduces rear-end and angle accidents associated with left-turn maneuvers Provides physical separation to reduce head-on accidents Provides a median refuge area for pedestrians	Required street width may not be available Increased delay to left-turning vehicles Indirect routing required for large trucks Lack of operational flexibility due to fixed median
Five-lane with TWLTL	Provides additional lanes to increase capacity for through traffic movement Reduces delay to through vehicles by left-turning vehicles Reduces frequency of rear-end and angle accidents associated with left-turn maneuvers Provides spatial separation between opposing lanes to reduce head-on accidents Increases operational flexibility	Required street width may not be available No refuge area in median for pedestrians May generate safety problems at closely spaced driveways and intersections
Six-lane undivided	Same as four-lane undivided alternative	Same as four-lane undivided alternative
Six-lane divided	Same as four-lane divided alternative Increases turning radius for U-turns	Same as four-lane divided alternative
Seven-lane with TWLTL	Same as five-lane TWLTL alternative	Same as five-lane TWLTL alternative
Eight-lane undivided	Same as four-lane undivided alternative	Same as four-lane undivided alternative
Eight-lane divided	Same as six-lane divided alternative	Same as four- and six-lane divided alternative

well at ADTs of 40,000 vehicles per day or less. Tables 12–14 summarize predicted delay (hours/year) with these models for three separate cross sections. For raised medians, Table 12 considers only left-turn delay within the limits of a midblock section of an arterial; it does not consider delay (i.e., additional travel time) attributable to vehicles that are denied left-turn access to a driveway or minor intersection and are, therefore, forced to use an indirect route to their destinations.

The usefulness of Table 11 in comparing the relative safety performance of arterials with different cross sections has been further recognized in *NCHRP Report 420: Impacts of Access Management Techniques* (12), published in 1999. NCHRP Report 420 recommends the values from Table 11 for use in assessing the median alternatives for urban and suburban arterials. However, the authors of NCHRP Report 420 recommend excluding the NCHRP Report 282 results from Table 11 because NCHRP Report 282 shows consistently lower accident rates for

roadways with TWLTLs than for roadways with raised medians, and the authors of NCHRP Report 420 do not believe this to be the case.

Parsonson et al. (13) provide an interesting case study of an improvement project in suburban Atlanta in which an existing TWLTL section was replaced with a raised median. Initial results indicated a substantial decrease in accident rate (37 percent for total accidents and 48 percent for injury accidents). A second review 8 years after project implementation found that these substantial reductions in accident rate had not held up over time, although there has yet to be a fatality at the project site. Retail business in this once prosperous area has declined and newspaper accounts have cited the access restrictions caused by the median as one of several factors in this decline. However, Parsonson et al. present evidence that the increase in accident rates over time since project implementation does not differ significantly from county-wide trends during the same period. Furthermore, they demonstrate that demographics

Design alternative	Street width (ft)	Lane width (ft)	Median width (ft)	Operational factors											Safety										
				1	2	3	4	5	6	7	8	9	10	11	1	2	3	4	5	6	7	8	9	10	11
Two-lane undivided	20-22	9-10	None	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	--	--	--	
	24-30	11-14	None	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0	--	--	--	--	--	
Three-lane with TWLTL	30-32	9-10	None	+	--	--	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
	34-46	11-14	None	++	--	--	+	--	--	--	--	--	--	--	--	--	--	--	+	--	--	--	--	--	
Four-lane undivided	38-44	9-10	None	-	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
	46-58	11-14	None	-	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Four-lane divided	42-52	9-10	4-12	+	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
	54-68	11-12	4-14	++	--	--	-	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
	70-80	11-14	16-22	++	--	--	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	++	
Five-lane with TWLTL	48-54	9-10	None	+	--	--	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
	54-74	11-14	None	++	--	--	+	--	--	--	--	--	--	--	--	--	--	--	+	--	--	--	--	--	

Scale of operational and safety ratings

- ++ Most desirable
- +
- 0
- Least desirable

FIGURE 3 Relative ratings of operational and safety factors for design alternatives for urban arterial highways (2).

TABLE 8

SUMMARY OF EFFECTS ON ACCIDENT RATE AND SEVERITY OF IMPROVEMENT PROJECTS ON URBAN ARTERIAL STREETS (3)

Project Type	Percent Change in Vehicle Accident Rate (per million vehicle-miles)		Change in Percentage of Fatal and Injury Accidents
	Total Accidents	Midblock Accidents	
Conversion from two-lane undivided to four-lane undivided	109.6	0.0 ¹	None
Conversion from four-lane undivided to five-lane with TWLTL	-44.1 ²	-45.0	None
Conversion from four-lane divided with narrow median to five-lane with TWLTL	-52.6 ²	-56.6 ²	None
Conversion from five-lane with TWLTL to seven-lane with TWLTL	23.7 ²	31.3	None
Conversion from six-lane divided with narrow median to seven-lane with TWLTL	-24.0	-32.1 ²	None
Conversion from six-lane divided to eight-lane divided	23.0	0.0 ¹	None

¹Change in accident rate was not statistically significant.

²May vary substantially from site to site.

TABLE 9

SUMMARY OF EFFECTS ON SPECIFIC COLLISION TYPES OF IMPROVEMENT PROJECTS ON URBAN ARTERIAL STREETS (3)

Project Type	Percent Change in Frequency of Specific Accident Types					
	Midblock Accidents			Intersection Accidents		
	Angle	Sideswipe ¹	Rear-end	Angle	Sideswipe ¹	Rear-end
Conversion from two-lane undivided to four-lane undivided	185	-35	-100	-5	281	350
Conversion from four-lane undivided to five-lane with TWLTL	-33	-38	-60	0	-53	-68
Conversion from four-lane divided with narrow median to five-lane with TWLTL	20	120	-40	-23	-52	-80
Conversion from five-lane with TWLTL to seven-lane with TWLTL	15	180	11	65	77	-65
Conversion from six-lane divided with narrow median to seven-lane with TWLTL	37	-28	-51	-5	-17	-37
Conversion from six-lane divided to eight-lane divided	46	104	-37	41	88	70

¹Same direction sideswipe collisions only.

in the corridor were weakening years before the median was built, so it may be unfair to attribute the decline of retail business to the median. This case study illustrates the importance of site-specific factors in understanding the effects on safety or land use of a change in design alternative at any particular site.

In summary, there has been a broad variety of research on the traffic operational and safety performance of alternative cross sections for arterial highways. Each of the cross sections evaluated is suited to particular types of sites and the choice among them, therefore, requires careful consideration of site-specific factors. None of the studies reviewed dealt explicitly with the role of median widths or the consideration of larger vehicles, such as trucks, in the selection of an appropriate arterial cross section.

MEDIAN DESIGN POLICIES AND PRACTICES OF HIGHWAY AGENCIES

This section presents the current median design policies and practices of highway agencies related to highway medians, median width, and median intersection design. Design policies at the national level are based on the AASHTO *Policy on Geometric Design of Highways and Streets (1)* (the AASHTO "Green Book"). The presentation of state and local agency design policies is based on responses to the survey of highway agencies that is presented in *NCHRP Report 375: Median Intersection Design (14)*. Most highway agency design policies are based on the AASHTO *Green Book*, although many agencies have their own design manuals and have adapted the AASHTO policies to their own needs.

TABLE 10
COMPARISON OF EFFECTS OF THREE ALTERNATIVE CROSS SECTIONS WITH DIFFERING MIDBLOCK LEFT-TURN TREATMENT TYPES (4)

Comparison Factor	"Preferred" Midblock Left-Turn Treatment ¹		
	Raised Median vs. TWLTL	Raised Median vs. Undivided	TWLTL vs. Undivided
Operation effects			
Major street through movement delay	ND	Raised median	TWLTL
Major street left-turn movement delay	ND	Raised median	TWLTL
Minor street left and through delay (two-stage entry)	ND	Raised median	TWLTL
Pedestrian refuge area	Raised median	Raised median	ND
Operational flexibility	TWLTL	Undivided	ND
Safety effects			
Vehicle accident frequency	Raised median	Raised median	TWLTL
Pedestrian accident frequency	Raised median	Raised median	ND
Turning driver misuse/misunderstanding of markings	Raised median	Raised median	Undivided
Design variations can minimize conflicts (e.g., islands)	Raised median	Raised median	TWLTL
Positive guidance (communication to motorist)	Raised median	Raised median	ND
Access effects			
Control of access (access management tool)	Raised median	Raised median	ND
Direct access to all properties along the arterial	TWLTL	Undivided	ND
Other effects			
Cost of maintaining delineation	ND	Undivided	Undivided
Median reconstruction cost	TWLTL	Undivided	Undivided
Facilitate snow removal (i.e., impediment to plowing)	TWLTL	Undivided	ND
Visibility of delineation	Raised median	Raised median	ND
Aesthetic potential	Raised median	Raised median	ND
Location for signs and signal poles	Raised median	Raised median	ND

Note: ND = negligible difference or lack of a consensus of opinion on this factor.

¹The "Preferred" left-turn treatment is based on the findings of the research and more commonly found opinion during a review of the literature.

The following discussion makes extensive use of material from the AASHTO *Green Book*. The AASHTO design policies concerning medians and related issues are spread throughout the *Green Book* in chapters dealing with elements of design, cross-section elements, and specific functional classes of highways. In the following discussion, the various material from the *Green Book* that deals with medians on divided highways has been combined and is presented, together with a description of state and local highway agency policies, as a comprehensive overview of current median design policies.

Functions and Types of Medians

A median is defined by the AASHTO *Green Book* as the portion of the highway separating the traveled ways for traffic in opposing directions. The *Green Book* states that a median is highly desirable on arterials carrying four or more lanes.

According to Chapter IV of the *Green Book (Cross-Section Elements)*, the functions of a median include:

- Minimizing interference of opposing traffic,
- Providing a recovery area for out-of-control vehicles,
- Providing a stopping area in case of emergencies,

- Providing open green space,
- Minimizing headlight glare from opposing vehicles,
- Providing space for speed-change lanes and storage areas for left- and U-turn vehicles, and
- Restricting left-turns except at those locations where median openings are provided.

There are three major types of medians: raised, depressed, and flush. Flush medians include both painted medians and continuous TWLTLs. Divided highways with a nontraversable median between the lanes in opposite directions of travel typically have either raised or depressed medians. However, flush medians have some of the same intersection design considerations as raised or depressed medians.

Median Width

The following discussion addresses current highway agency design policies for median width. Median width considerations between intersections and at intersections are addressed separately.

Median Width Between Intersections

AASHTO Policy—The median width between intersections is defined as the distance between the edges of the

TABLE 11
COMPARISON OF SAFETY PERFORMANCE OF ALTERNATIVE MIDBLOCK CROSS SECTIONS AS REPORTED BY STUDIES IN THE LITERATURE (4)

(Left-Turn Treatment; Reference Source)	Expected Accidents (miles/year)											
	10,000			20,000			30,000			40,000		
	TWLT/L	Undivided	Raised Median	TWLT/L	Undivided	Raised Median	TWLT/L	Undivided	Raised Median	TWLT/L	Undivided	Raised Median
NCHRP Report 282- 1995 (2)	27	36	72	54	72	81	108	109	108	144	145	
Bowman and Vecellio-1994 (6)	43	63	50	85	126	128	75	190	170	101	253	
Chatterjee et al.-1991 (7)	55	NA	81	90	NA	125	116	NA	OOR	OOR	NA	
Parker-1991 (8)	27	NA	32	43	NA	58	45	NA	73	59	NA	
Squires and Parsonson-1989 (9)	-8	NA	56	31	NA	69	75	NA	108	94	NA	
McCoy and Ballard- 1986 (10)	31	33	NA	52	OOR	OOR	NA	OOR	OOR	NA	OOR	
Walton and Machemehl-1979 (11)	37	NA	NA	58	NA	78	NA	NA	98	NA	NA	
Average frequency	30	44	58	59	99	90	84	149	112	100	199	
Standard deviation	7	10	9	8	27	12	13	41	16	18	54	

Notes: ADT = average daily traffic; NA = model not available or developed for this midblock left-turn treatment type; and OOR = traffic demand exceeds range of data used to calibrate the model.

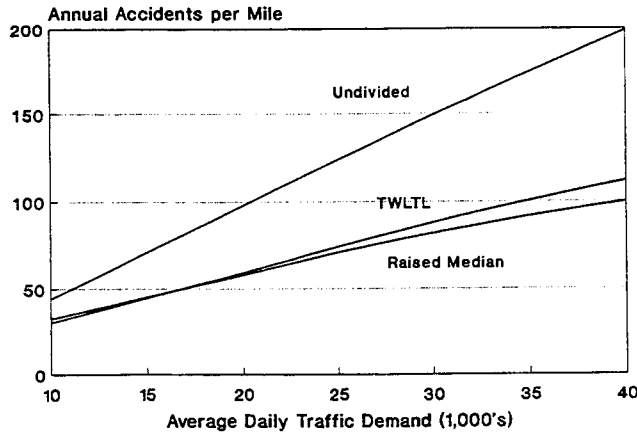


FIGURE 4 Comparison of predicted average frequencies for alternative midblock cross sections (4).

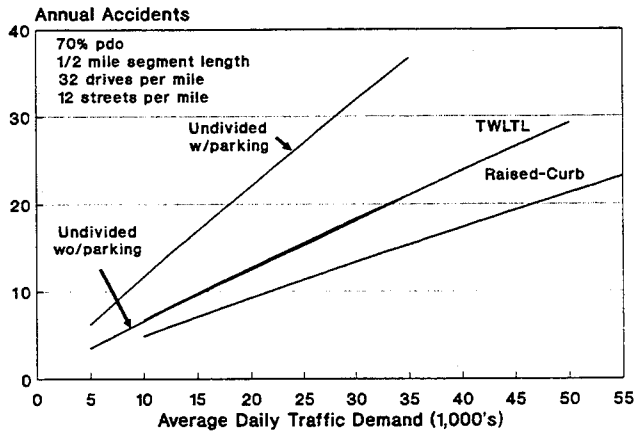


FIGURE 5 Effect of traffic demand on accident frequency for alternative midblock cross sections in business and office areas (4).

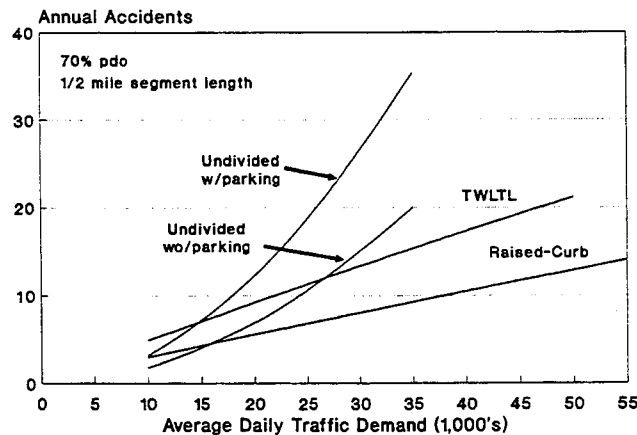


FIGURE 6 Effect of traffic demand on accident frequency for alternative midblock cross sections in residential and industrial areas (4).

through lanes in opposing directions, and includes the width of the left shoulders, if any. The *Green Book* generally does not prescribe particular median widths as appropriate for particular types of highway facilities. Instead, it summarizes the advantages and disadvantages of particular

median widths and permits designers to make appropriate choices on a case-by-case basis.

The minimum median width permitted by the *Green Book* for most highways is 1.2 m (4 ft). Raised or depressed medians less than 1.2 m (4 ft) in width are not practical, and a flush divider less than 1.2 m (4 ft) wide would not be considered a median. Although wider medians are desirable, the *Green Book* makes clear that there is demonstrated benefit in any separation, raised or flush, even if the separation is as little as 1.2 m (4 ft). The only exception in the *Green Book* to the minimum 1.2-m (4-ft) median width is for multilane urban collector streets, where median widths as narrow as 0.6 m (2 ft) are permitted.

Most divided highways have median widths that range from 1.2 to 24 m (4 to 80 ft). However, median widths wider than 24 m (80 ft) have been used. AASHTO policies impose no maximum limit on median width.

The *Green Book* states that medians should be as wide as feasible, but of a dimension in balance with other components of the cross section. As far as the safety and convenience of motor vehicle operation between intersections are concerned, the farther apart the pavements are, the better. However, economic factors often limit the median width that can be provided. Construction and maintenance costs increase in proportion to increases in median width, but the additional cost may not be appreciable compared with the cost of the highway as a whole and may be justified in view of the benefits derived.

Insofar as through traffic is concerned, the *Green Book* states that the desired ease and freedom of operation, in the sense of physical and psychological separation from opposing traffic, is obtained when median widths are about 12 m (40 ft) or wider. With such widths, the facility is truly divided. The noise and air pressure of opposing traffic is not noticeable, and the glare of headlights is greatly reduced. With widths of 18 m (60 ft) or more the median can be pleasingly landscaped in a park-like manner. Landscaping to achieve this park-like appearance need not compromise the roadside recovery area.

The *Green Book* discussion of rural arterials states that on highways without at-grade intersections, the median may be as narrow as 1.2 to 1.8 m (4 to 6 ft) under very restricted conditions, but that a width of 20 m (60 ft) or more should be provided whenever feasible. One advantage of a wide median on a rural arterial without intersections is that it allows the use of independent profiles.

Roadside design is an important issue in selecting an appropriate median width. Wider medians are generally preferable because they allow the use of flatter roadside slopes while still providing adequate drainage.

TABLE 12

ANNUAL DELAY TO MAJOR STREET LEFT-TURN AND THROUGH VEHICLES FOR UNDIVIDED CROSS SECTION (hours/year) (4)

Through Lanes	ADT	Access Point Density ¹ (ap/mi)	Left-Turn Percentage per 1,320-ft Segment Length ²					
			0	5	10	15	20	30
4	17,500	30	300	500	1,000	1,400	1,600	2,300
		60	300	500	1,000	1,400	1,700	2,400
		90	300	500	1,000	1,400	1,700	2,400
	22,500	30	500	1,200	2,200	2,900	3,300	4,700
		60	500	1,200	2,200	3,000	3,500	4,800
		90	500	1,200	2,200	3,000	3,700	5,100
	27,500	30	800	2,300	4,100	5,300	6,100	8,200
		60	800	2,400	4,300	5,700	6,700	8,900
		90	800	2,400	4,400	5,900	7,200	9,700
	32,500	30	1,200	4,200	7,100	9,100	10,600	13,300
		60	1,200	4,400	7,800	10,200	12,000	15,400
		90	1,200	4,500	8,000	10,800	13,100	17,100
	37,500	30	1,600	7,300	11,600	14,800	17,500	20,900
		60	1,700	7,700	13,100	17,100	20,200	25,200
		90	1,800	7,800	13,700	18,500	22,200	28,400
	42,500	30	2,200	11,700	18,100	23,000	27,800	—
		60	2,400	12,700	21,000	27,100	32,200	39,800
		90	2,500	12,900	22,100	30,000	35,900	45,200
6	26,250	30	300	1,000	2,200	2,800	3,500	3,900
		60	400	1,100	2,300	3,400	4,400	5,500
		90	400	1,100	2,300	3,400	4,700	6,600
	33,750	30	500	2,300	4,000	5,000	6,000	7,700
		60	700	2,500	4,400	6,000	7,400	9,200
		90	700	2,500	4,600	6,200	8,100	10,800
	41,250	30	900	4,500	6,500	8,400	9,800	14,600
		60	1,200	4,800	7,700	9,600	11,700	14,900
		90	1,200	5,100	8,500	10,600	13,000	16,900
	48,750	30	1,400	7,600	10,100	13,600	—	—
		60	1,800	8,800	12,500	14,700	17,800	—
		90	1,800	9,400	14,500	17,000	19,700	25,800
	56,250	30	2,100	12,100	15,000	—	—	—
		60	2,500	15,000	19,300	21,700	26,500	—
		90	2,600	16,400	23,400	25,800	28,700	38,800
	63,750	30	2,900	18,300	—	—	—	—
		60	3,400	24,300	28,600	31,300	—	—
		90	3,500	27,000	36,000	37,800	41,100	—

Note: ADT = average daily traffic; —, delays to one or more major street left-turn movements are in excess of 40 sec/veh/approach leading to congested flow conditions, queue spillback, and possible gridlock.

¹Access point (ap) density represents the total number of access points of both sides of the street segment (i.e., a two-way total) divided by the length of the segment (in miles).

²Total number of left-turns per hour exiting the major street into an access point in one direction of travel per 1,320-ft length of roadway divided by the total flow rate in that direction (expressed as a percentage).

The *Green Book* also makes clear that there is a tradeoff between median width and the border width between the traveled way and adjacent development. If right-of-way is restricted, a wide median may not be justified if provided at the expense of narrowed border areas. A reasonable border width is required to adequately serve as a buffer between the private development along the road and the traveled way, particularly where zoning is limited or nonexistent. Space must be provided on the borders for sidewalks, highway signs, utility lines, parking, drainage channels and structures, proper slopes, a roadside clear zone, and any retained natural growth. Narrowing the border areas may tend to develop obstacles and hindrances adjacent to the roadway similar to those the median is intended to avoid.

Whenever possible, medians should be designed with sufficient width to avoid the need for a median barrier.

Figure 7 shows the median barrier warrants applicable to high-speed freeways and divided highways with partial control of access (expressways) that are presented in the *AASHTO Roadside Design Guide* (15). As shown in the figure, most medians less than 10 m (33 ft) wide on divided highways with ADT over 20,000 vehicles per day warrant an evaluation of the need for a median barrier. The figure shows that median barriers are optional for medians on roadways with ADT of fewer than 20,000 vehicles per day and for medians of 10 to 15 m (33 to 50 ft) in width on higher volume roadways. Where median barriers are optional, they are generally warranted only if there is a history of cross-median accidents. The figure indicates that median barriers are not normally considered for flat medians over 15 m (50 ft) in width. However, if there are steep slopes in the median or objects that cannot be removed, roadside barriers may be warranted for medians of

TABLE 13

ANNUAL DELAY TO MAJOR STREET LEFT-TURN AND THROUGH VEHICLES FOR THE RAISED MEDIAN TREATMENT
(hours/year) (4)

Through Lanes	ADT	Access Point Density ¹ (ap/mi)	Left-Turn Percentage per 1,320-ft Segment Length ²					
			0	5	10	15	20	30
4	17,500	30	300	400	800	1,000	1,200	1,600
		60	300	400	800	1,000	1,300	1,700
		90	300	400	800	1,000	1,300	1,700
	22,500	30	500	800	1,300	1,700	2,000	2,700
		60	500	800	1,400	1,800	2,200	2,900
		90	500	900	1,400	1,800	2,200	2,900
	27,500	30	800	1,300	2,100	2,700	3,200	4,400
		60	800	1,300	2,300	3,000	3,600	5,000
		90	800	1,500	2,300	3,000	3,600	5,000
	32,500	30	1,200	2,000	3,100	4,000	4,900	6,900
		60	1,200	2,100	3,500	4,800	5,900	8,500
		90	1,200	2,200	3,400	4,700	5,900	8,400
	37,500	30	1,600	2,900	4,400	5,900	7,300	10,600
		60	1,700	3,100	5,300	7,300	9,300	13,800
		90	1,800	3,200	5,100	7,200	9,300	13,500
	42,500	30	2,200	4,100	6,100	8,400	10,700	16,100
		60	2,400	4,600	7,600	10,900	14,200	21,800
		90	2,500	4,500	7,300	10,600	14,100	21,200
6	26,250	30	300	800	1,300	1,800	2,100	3,200
		60	400	900	1,400	2,000	2,400	3,200
		90	400	900	1,400	2,100	2,500	3,500
	33,750	30	500	1,400	2,300	3,200	3,900	5,800
		60	700	1,500	2,600	3,500	4,400	6,200
		90	700	1,500	2,600	3,700	4,500	6,500
	41,250	30	900	2,200	3,700	5,300	6,700	9,800
		60	1,200	2,500	4,300	5,900	7,700	11,500
		90	1,200	2,500	4,300	6,100	7,500	11,300
	48,750	30	1,400	3,400	5,600	8,500	11,200	16,200
		60	1,800	4,000	6,800	9,400	12,700	20,700
		90	1,800	4,000	6,900	9,700	12,200	19,400
	56,250	30	2,100	5,000	8,400	13,300	—	—
		60	2,500	6,100	10,400	14,500	20,400	—
		90	2,600	6,100	10,500	14,800	19,100	32,000
	63,750	30	2,900	7,100	12,200	—	—	—
		60	3,400	9,000	15,500	21,800	—	—
		90	3,500	8,900	15,600	22,000	29,200	—

Note: ADT = average daily traffic; —, delays to one or more major street left-turn movements are in excess of 40 sec/veh/approach leading to congested flow conditions, queue spillback, and possible gridlock.

¹Access point (ap) density represents the total number of access points of both sides of the street segment (i.e., a two-way total) divided by the length of the segment (in miles).

²Total number of left-turns per hour exiting the major street into an access point in one direction of travel per 1,320-ft length of roadway divided by the total flow rate in that direction (expressed as a percentage).

any width; the *Roadside Design Guide* provides cost-effectiveness procedures to address barrier needs in such situations. Median barriers are less desirable on divided highways without full control of access than on freeways, because the barrier may restrict intersection sight distance.

A recent accident investigation by the National Transportation Safety Board has recommended that the median barrier warrants in Figure 7 be updated because they are based on older research and do not consider current barrier design, heavy trucks, and the high proportion of vans, sport/utility vehicles, and light trucks in the current vehicle fleet (16). This could lead to the use of barriers in medians wider than 15 m (50 ft) and to redesigned barriers that would be more appropriate for larger vehicles.

An alternative to the median barrier warrants shown in Figure 7 was developed by the California Department of Transportation (DOT) (17) in 1997. These California warrants, presented in Figure 8, indicate that barriers may be considered in medians up to 23 m (75 ft) wide. Concrete median barriers would be considered for median widths from 0 to 11 m (0 to 36 ft) and three-beam guardrails for median widths from 6 to 23 m (20 to 75 ft). These warrants are used in California for freeways, in contrast to those shown in Figure 7, which apply to both freeways and expressways.

Highway Agency Policies—The highway agency survey presented in NCHRP Report 375 (14) found a range of highway agency views on the appropriate median width for divided highways. State highway agencies were asked

TABLE 14
ANNUAL DELAY TO MAJOR STREET LEFT-TURN AND THROUGH VEHICLES FOR THE TWLTL TREATMENT (hours/year) (4)

Through Lanes	ADT	Access Point Density ¹ (ap/mi)	Left-Turn Percentage per 1,320-ft Segment Length ²					
			0	5	10	15	20	30
4	17,500	30	300	400	800	1,000	1,200	1,600
		60	300	400	800	1,000	1,300	1,700
		90	300	400	800	1,000	1,300	1,700
	22,500	30	500	800	1,300	1,700	2,000	2,700
		60	500	800	1,400	1,800	2,200	2,900
		90	500	900	1,400	1,800	2,200	2,900
	27,500	30	800	1,300	2,100	2,700	3,200	4,400
		60	800	1,300	2,200	2,800	3,400	4,600
		90	800	1,500	2,200	2,800	3,400	4,700
	32,500	30	1,200	2,000	3,000	4,000	4,900	6,800
		60	1,200	2,100	3,200	4,200	5,100	7,100
		90	1,200	2,200	3,200	4,200	5,200	7,400
	37,500	30	1,600	2,900	4,300	5,800	7,200	10,400
		60	1,700	3,000	4,600	6,000	7,500	10,700
		90	1,800	3,200	4,600	6,000	7,800	11,200
42,500	30	2,200	4,000	6,000	8,200	10,500	15,500	
	60	2,400	4,300	6,400	8,600	10,700	16,000	
	90	2,500	4,400	6,400	8,600	11,200	16,600	
6	26,250	30	300	800	1,300	1,800	2,100	3,200
		60	400	900	1,400	2,000	2,400	3,200
		90	400	900	1,400	2,100	2,500	3,400
	33,750	30	500	1,400	2,300	3,100	3,800	5,700
		60	700	1,500	2,500	3,400	4,300	6,000
		90	700	1,500	2,500	3,500	4,300	6,100
	41,250	30	900	2,200	3,600	5,100	6,600	9,600
		60	1,200	2,500	3,900	5,400	7,100	10,500
		90	1,200	2,500	3,900	5,600	7,000	10,400
	48,750	30	1,400	3,400	5,500	8,200	11,000	15,600
		60	1,800	3,700	5,800	8,200	11,100	18,000
		90	1,800	3,800	5,900	8,500	10,900	17,400
	56,250	30	2,100	4,900	8,000	12,700	—	—
		60	2,500	5,300	8,400	12,100	16,900	—
		90	2,600	5,400	8,600	12,500	16,700	28,400
63,750	30	2,900	6,900	11,600	—	—	—	
	60	3,400	7,400	11,900	7,600	—	—	
	90	3,500	7,500	12,200	18,000	24,900	—	

Note: ADT = average daily traffic; —, delays to one or more major street left-turn movements are in excess of 40 sec/veh/approach leading to congested flow conditions, queue spillback, and possible gridlock.

¹Access point (ap) density represents the total number of access points of both sides of the street segment (i.e., a two-way total) divided by the length of the segment (in miles).

²Total number of left-turns per hour exiting the major street into an access point in one direction of travel per 1,320-ft length of roadway divided by the total flow rate in that direction (expressed as a percentage).

to assess the minimum, desirable, and maximum median widths for rural and urban nonfreeways. These assessments may reflect both median width requirements between intersections and effects on intersection operations. Although the survey did not inquire specifically about the median width requirements necessary to accommodate large trucks, the selected design vehicle is one of the major considerations in choosing an appropriate median width. The survey included responses from 44 of the 50 state highway agencies (88 percent). Table 15 summarizes the survey results concerning median width requirements.

The minimum median widths for rural nonfreeways reported by state highway agencies varied greatly, from as little as 0.9 m (3 ft) to as much as 20 m (64 ft). Approximately 42 percent of the responses recommended minimum

median widths greater than 9 m (30 ft). Desirable median widths for rural divided highways ranged from 5 to 26 m (18 to 84 ft). Approximately 62 percent of the responses indicated a desirable median width greater than 15 m (50 ft). Many state highway agencies did not indicate a maximum median width, implying that the median should be as wide as possible. Those agencies that did respond indicated maximum median widths ranging from 8 to 92 m (25 to 300 ft).

Another recent survey of state highway agencies concerning median widths on rural divided highways without full control of access conducted for a 1993 report by Bonneson et al. (18) found results similar to those for the survey conducted in NCHRP Report 375. Like the previous survey, the survey by the Bonneson et al. did not focus specifically on large trucks, but the selected design vehicle

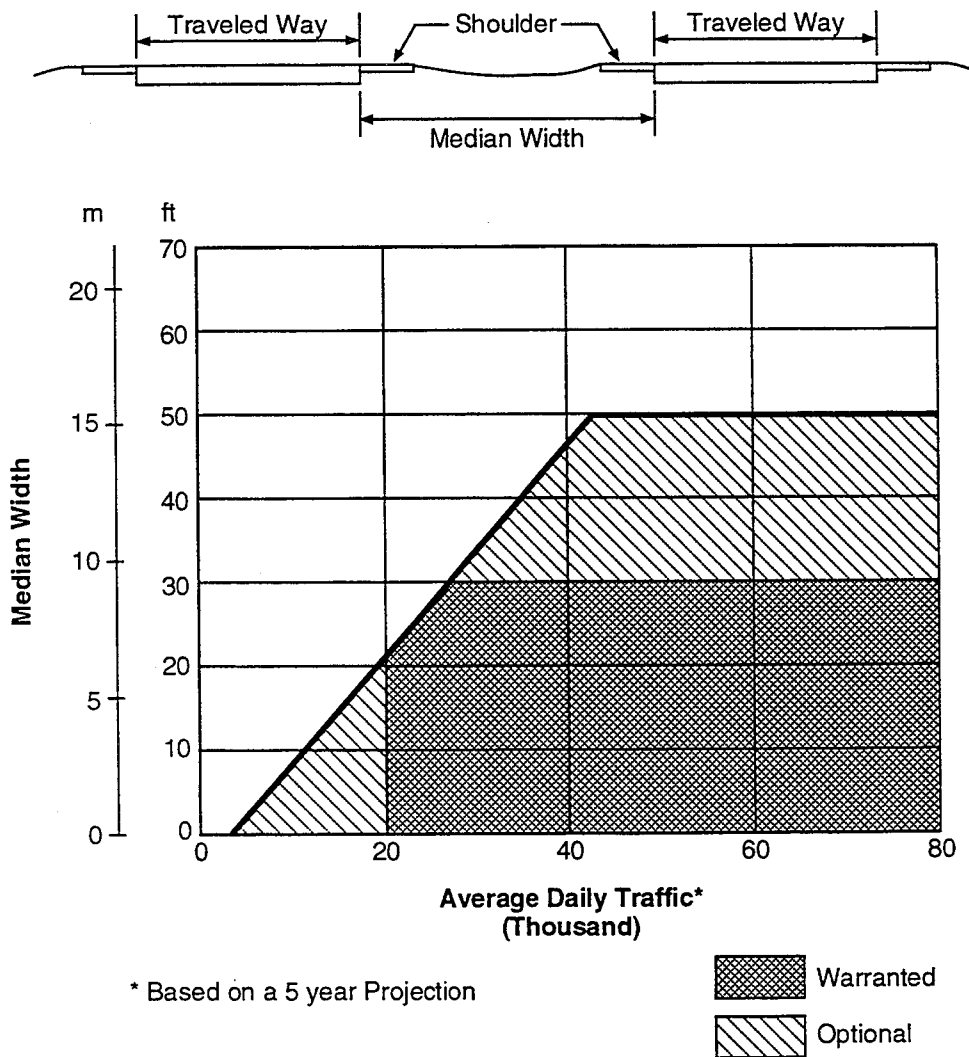


FIGURE 7 Median barrier warrants for freeways and expressways (13).

is one of the major considerations in selecting an appropriate median width. Table 16 summarizes the range of minimum, desirable, and maximum median widths found by Bonneson et al. The range of desirable and maximum median widths found in the Bonneson et al. study was not as broad as the range found in NCHRP Report 375.

For urban and suburban nonfreeways, the minimum median widths indicated by state highway agencies ranged from 1.2 to 9 m (4 to 30 ft). Approximately 56 percent of respondents indicated a minimum median width for urban facilities of 3 m (10 ft) or less. The desirable median widths indicated by highway agencies for urban/suburban conditions ranged from 2.7 to 20 m (9 to 64 ft). Approximately 39 percent of state highway agencies indicated a desirable median width greater than or equal to 9 m (30 ft). The maximum median widths indicated by state highway agencies ranged from 5 to 31 m (16 to 101 ft).

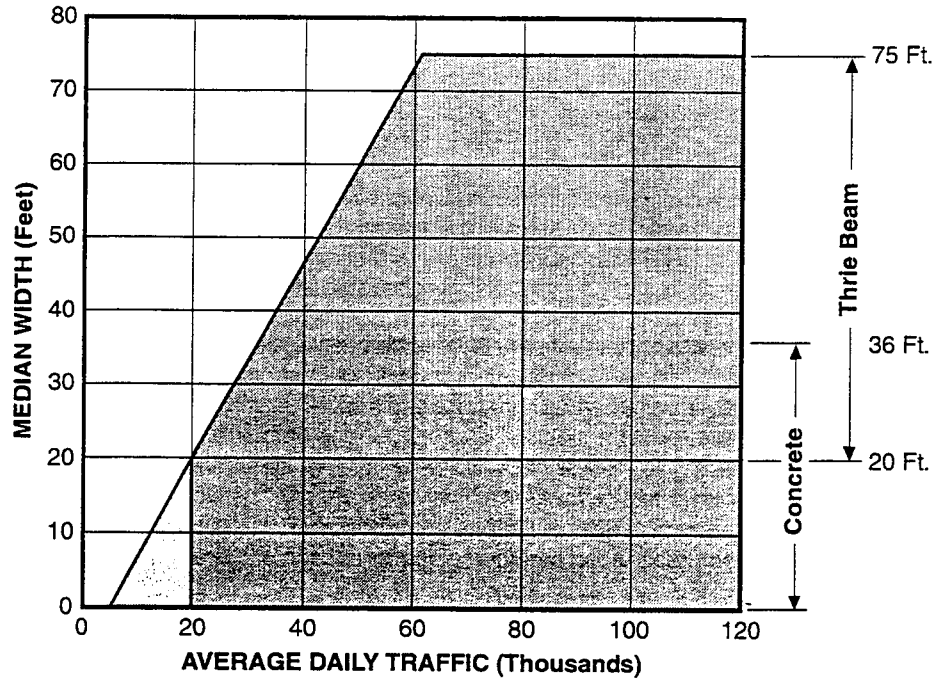
The results of both the NCHRP Report 375 and Bonneson et al. surveys show that there is a broad range of opinions

among state highway agencies concerning the appropriate median widths for both rural and urban divided highways. Those highway agencies that use the narrowest medians [e.g., less than 1.2 m (4 ft)] probably provide indirect routings for left-turning vehicles (e.g., see the discussion of loops and jughandles in chapter 4), so that such vehicles do not need to be stored in the median area.

Median Width at Intersections

As is the case between intersections, the median width at an intersection is defined to include the entire distance between the edges of the through lanes in the opposing directions of travel. Thus, at an intersection, both the left shoulders and any left-turn lanes are considered to be part of the median width. This is consistent with the definitions of median width presented in the AASHTO *Green Book* (1).

AASHTO Policy—The AASHTO *Green Book* policies on median width at intersections are presented throughout the



 **Study Warranted**


 **Studies for barriers in these cases is optional, based on accident history or other special considerations.**

FIGURE 8 Recommended freeway median barrier volume/width study warrants used in California (17).

TABLE 15

SUMMARY OF 1995 HIGHWAY AGENCY SURVEY RESULTS ON MINIMUM, MAXIMUM, AND DESIRABLE WIDTHS FOR DIVIDED HIGHWAY MEDIANS (14)

Median Width	Rural		Urban	
	Range [m (ft)]	Median Value [m (ft)]	Range [m (ft)]	Median Value [m (ft)]
Minimum	1-20 (3-64)	8 (27)	0.3-9 (1-30)	3 (10)
Desirable	5-26 (18-84)	16 (54)	3-20 (9-64)	9 (30)
Maximum	8-92 (25-300)	29 (94)	5-31 (16-101)	13 (43)

TABLE 16

SUMMARY OF RESULTS FROM 1993 SURVEY ON RURAL DIVIDED HIGHWAY MEDIAN WIDTHS (18)

Median Width	Range [m (ft)]	Median Value [m (ft)]
Minimum	1-26 (4-84)	14 (46)
Desirable	12-20 (40-66)	15 (48)
Maximum	12-32 (40-104)	15 (48)

various chapters that deal with specific functional classes of highways: local roads and streets, urban collector roads and streets, and rural and urban arterials.

The most extensive discussion of the attributes of different widths is found in the section on rural arterials in Chapter VII of the 1994 *Green Book*. The following material from that discussion summarizes what is known about the advantages and disadvantages of different median widths on divided highways:

When intersections are to be provided, special concern must be given to the width of the median. While medians as narrow as 1.2 to 1.8 m may be required under very restricted conditions, medians 3.6 to 9 m wide provide protection for left-turning vehicles at intersections.

Median widths from 9 to 15 m should be carefully considered from an operational standpoint at intersections. These widths do not provide median storage space for larger vehicles crossing the median. Also, these widths may encourage the driver to attempt the crossings independently leaving a portion of the vehicle unprotected from through traffic. These widths, even with these problems, normally operate quite well and apparently are within the realm of normal operational expectations of the driver. Widths in the range of 15 to 24 m have developed accident problems in some areas as the drivers apparently tend to become confused about the intended operational characteristics of the multiple intersections encountered. Medians wide enough to assure the driver that the intersection with the two sets of lanes operate separately have worked quite well. Research may prove that wider medians are not desirable for some facilities with at-grade intersections (1).

Although the preceding discussion identifies the potential advantages and the possible operational problems of different median widths, it is not very specific. The designer is left without much guidance in the use of median widths in the ranges from 9 to 15 m (30 to 50 ft) and 15 to 24 m (50 to 80 ft), because the *Green Book* implies that medians in these width ranges operate well in most cases, but may develop operational problems in some cases.

The *Green Book* provides the following guidance on the choice of median widths on urban arterials:

Medians are a desirable feature of arterial streets and should be provided where space permits. . . . Where right-of-way is limited, it is frequently necessary to decide how best to allocate the available space between border areas, traffic lanes, and medians. On the less important arterials the decision is often resolved in favor of no median at all. A median only 1.2 m wide is better than no median at all; however, each additional foot provides an added increment of safety and improved operation. At intersections where left-turns are made, a left-turn lane is always desirable from a capacity and safety standpoint. The median width to accommodate left-turning movements should desirably be at least 3.6 m. Desirably, the median should be at least 5.4 m wide for a 3.6-m median lane and a 1.8-ft medial separator. At restricted locations, a 3.0-m lane with a 0.6-m medial separator may be used (1).

The urban arterials to which the guidelines given above apply include higher-speed suburban arterials. Medians of

less than 7.2 m (24 ft) in width on urban arterials are generally raised medians. The *Green Book* states that in suburban areas and elsewhere, where a median width of 7.2 m (24 ft) or more can be provided, a flush or depressed median offers most of the advantages of a raised median with few of the unfavorable attributes. The *Green Book* goes on to repeat much of the discussion from the section on rural arterials concerning the advantages and disadvantages of median widths in the 9 to 15 m (30 to 50 ft) and 15 to 24 m (50 to 80 ft) ranges.

The *Green Book* notes that, for urban arterials, experience indicates that drivers prefer medians that are either obviously narrow or that provide an adequate refuge area to allow independent roadway crossing operations. This statement is made from the point of view of the driver on a minor-road approach to a divided intersection that intends to cross or turn left onto the divided highway.

Highway Agency Policies—In the highway agency survey conducted for NCHRP Report 375 (14), approximately 76 percent of state highway agencies indicated that they consider intersection operations in selecting the median width for a divided highway. Approximately 50 percent of the responding highway agencies indicated that storage needs in the median area have influenced either their median width policy or their choice of median width for particular projects.

Several highway agencies reported that they have selected a large school bus as the design vehicle for median width on rural divided highways. Typically, such agencies use medians with a minimum width of 15 m (50 ft) to safely store the largest school bus, which is 12.0 m (39.5 ft) in length and carries 84 passengers. Other highway agencies stated that they consider the expected queue lengths of left-turning vehicles in selecting the median width.

One highway agency indicated that they had widened the 14 m (46 ft) median of one particular rural divided highway to 21 m (70 ft) at intersections to facilitate truck movements onto and off the divided highway. Another highway agency has adopted a policy of widening divided highway medians to 46 m (150 ft) at major intersections while maintaining their standard 18 m (60 ft) median at minor intersections.

A total of 10 state highway agencies, representing 24 percent of the agencies that responded to the question, stated that they intentionally design narrow medians so that vehicles entering from the crossroad will not attempt to stop in the median. If the median is not wide enough to store a vehicle, then a vehicle must wait for a simultaneous gap in traffic in both directions of travel. However, several of these agencies indicated that they use narrow medians primarily to enhance the operational efficiency of signalized intersections.

On the other hand, 19 state highway agencies, or 45 percent of the agencies that responded to the question, indicated that they have encountered traffic operational or safety problems related to turning and crossing maneuvers by trucks and buses.

A total of 20 state highway agencies, or 47 percent of the respondents, reported operational problems at intersections related to medians that were considered to be too wide. These problems included:

- Side-by-side queuing in the median area, with resulting confusion about which vehicle is to proceed first;
- Conflicting movements on the median roadway;
- Inefficient signal timing because of long clearance interval requirements at the end of particular signal phases;
- Lack of sufficient sight distance if drivers do not stop in the median; and
- Increased potential for wrong-way movements at night.

Only six state highway agencies, or 15 percent of the respondents, indicated that they have median width policies that differentiate between the median widths used at signalized and unsignalized intersections. The highway agencies that limit median width at signalized intersections have found that intersections with wider medians are difficult to signalize effectively. This suggests that highway agencies should carefully consider the median widths selected for unsignalized intersections that are likely to require signalization at some future date.

Nine state highway agencies (23 percent) indicated that they consider bicycle operations and 18 agencies (46 percent) indicated that they consider pedestrian needs in selecting median widths for divided highways.

In the highway agency survey conducted for this synthesis, respondents were asked what minimum median width they consider too narrow to accommodate larger vehicles. Table 17 shows a broad range of responses to this question. Some agencies indicated that medians as narrow as 0.6 to 1.2 m (2 to 4 ft) can adequately accommodate larger vehicles; such agencies must use indirect routings for handling crossing and turning maneuvers by larger vehicles (e.g., see the discussion of loops and jughandles in chapter 4). Other agencies stated that median width as great as 31 to 38 m (100 to 125 ft) are needed to accommodate larger vehicles. The median (or 50th percentile) value of minimum median width identified by the respondents was 18 m (60 ft) in rural areas and 7.6 m (25 ft) in urban areas. Median widths of 18 m (60 ft) in rural areas and 7.6 m (25 ft) in urban areas are representative of the range of current design practice in most states.

TABLE 17
HIGHWAY AGENCY ASSESSMENTS OF MINIMUM MEDIAN WIDTHS TO ACCOMMODATE LARGER VEHICLES

Descriptive Statistics	Minimum Median Width (ft)	
	Rural Divided Highways	Urban/Suburban Divided Arterials
Minimum	4	2
Maximum	125	100
Mean	58	33
15 th percentile	25	12
25 th percentile	30	16
Median (50 th percentile)	60	25
75 th percentile	70	60
85 th percentile	80	60
Number of responses	15	20

Note: Based on results of the highway agency survey conducted for this synthesis

Research Findings—Prior to NCHRP Report 375, there was relatively little information on the effect on traffic operations and safety of median widths at intersections on divided highways. An Ohio study by Priest (19) in 1964 found that intersection accident rates generally decrease with increasing median width. By contrast, a 1977 Purdue University study by Van Maren (20) found no statistically significant relationship between median width and intersection accident rate. Radwan et al. (21–23) applied an early version of NETSIM (a computer simulation model of traffic operations on arterial highways) to unsignalized intersections and generally found no statistically significant effect of median width on traffic delays and traffic conflicts over the range of median widths from 9 to 18 m (30 to 60 ft).

The research for NCHRP Report 375 found that at intersections on rural divided arterials, the frequency of both accidents and undesirable driving behavior (e.g., side-by-side queuing, angle stopping, and encroaching on the through lanes) decreases as the median width increases. No upper limit on median width at which safety problems occur was found at rural divided highway intersections as long as both roadways are visible to any vehicle stopped at the intersection. Rural divided highway intersections with medians as wide as 44 m (144 ft) were evaluated in reaching this conclusion. Therefore, it was recommended that, at rural unsignalized intersections on divided highways, medians should generally be as wide as possible to accommodate turning and crossing maneuvers by a selected design vehicle, as well as any needed left-turn treatments (14).

The research for NCHRP Report 375 found that at intersections on divided suburban arterials, the frequency of both accidents and undesirable driving behavior increases as the median width increases. Therefore, it was recommended that at suburban unsignalized intersections on

divided highways, medians generally should not be wider than necessary to provide whatever left-turn treatment is selected. It was further recommended that, at specific unsignalized intersections where substantial turning and crossing volumes of larger vehicles (such as school buses or trucks) are present, highway agencies may find it appropriate to select an appropriate median width to store a design vehicle of that type safely in the median. This may result in medians at suburban unsignalized intersections that are wider than the minimum necessary to accommodate the selected left-turn treatment. At signalized intersections there would be no need to provide a median wider than necessary to accommodate the selected left-turn treatment because it should not be necessary to store larger vehicles in the median at signalized intersections past the end of any given signal phase (14).

The relationships between total multiple-vehicle accident frequency and median width at divided highway intersections developed in NCHRP Report 375 were based on Poisson regression models. Figures 9, 10, and 11 illustrate the relationships for particular assumed intersection characteristics for rural unsignalized intersections, urban/suburban unsignalized intersections, and urban/suburban signalized intersections, respectively. Similar relationships were found between median width and the frequency of

fatal and injury-producing multiple-vehicle accidents, except that no statistically significant effect of median width on fatal-and-injury accident frequency was found for urban/suburban, three-leg, unsignalized intersections.

ROADWAY AND INTERSECTION DESIGN FOR LARGER VEHICLES

Under AASHTO policy, the design of each roadway or intersection is based on a selected design vehicle. The selection of an appropriate design vehicle is critical to assuring that a roadway or intersection will operate in accordance with the designer's intentions. The size of trucks on the U.S. highway system has increased steadily in recent years and the sizes of the AASHTO design vehicles have been increased accordingly. Table 18 presents the dimensions of the design vehicles that are currently specified in AASHTO policy. Table 18 shows that the vehicles now used in the planning and design of roadways and intersections range up to 2.6 m (8.5 ft) in width and 35.9 m (118 ft) in length. Although the largest trucks are usually permitted only on freeways and toll roads, trucks up to 23 m (75 ft) in length are now common on rural highways and urban arterials. Highway agencies face the challenge of providing destination access for these large trucks.

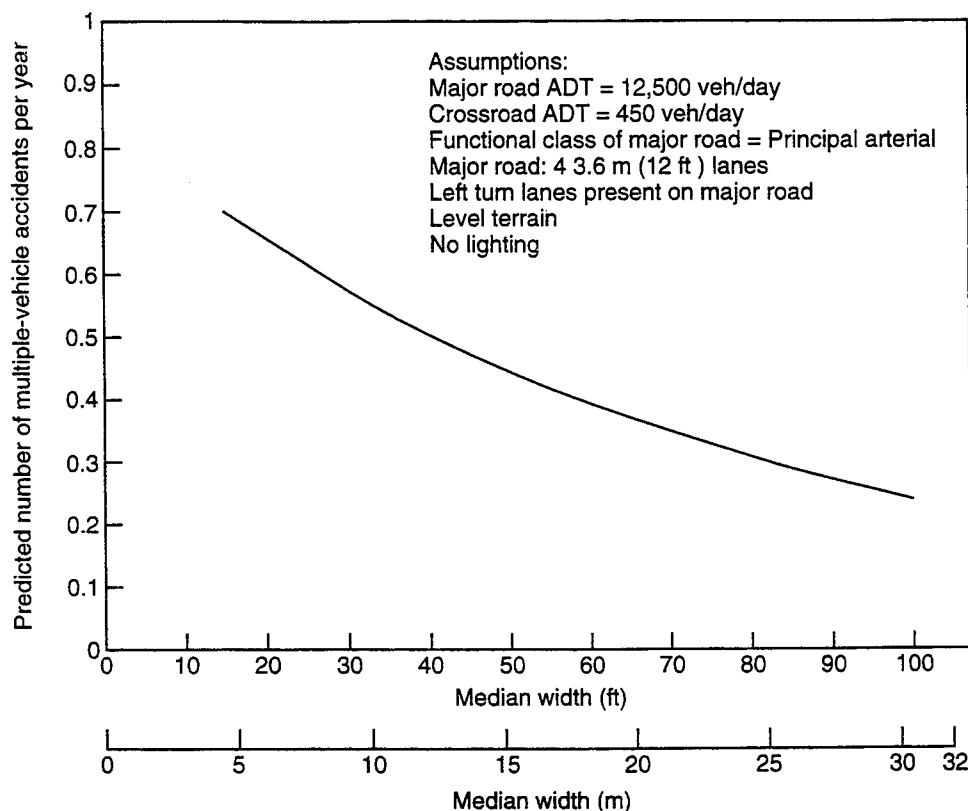


FIGURE 9 Predicted number of multiple-vehicle accidents per year as a function of median width for typical rural four-leg unsignalized intersection (14).

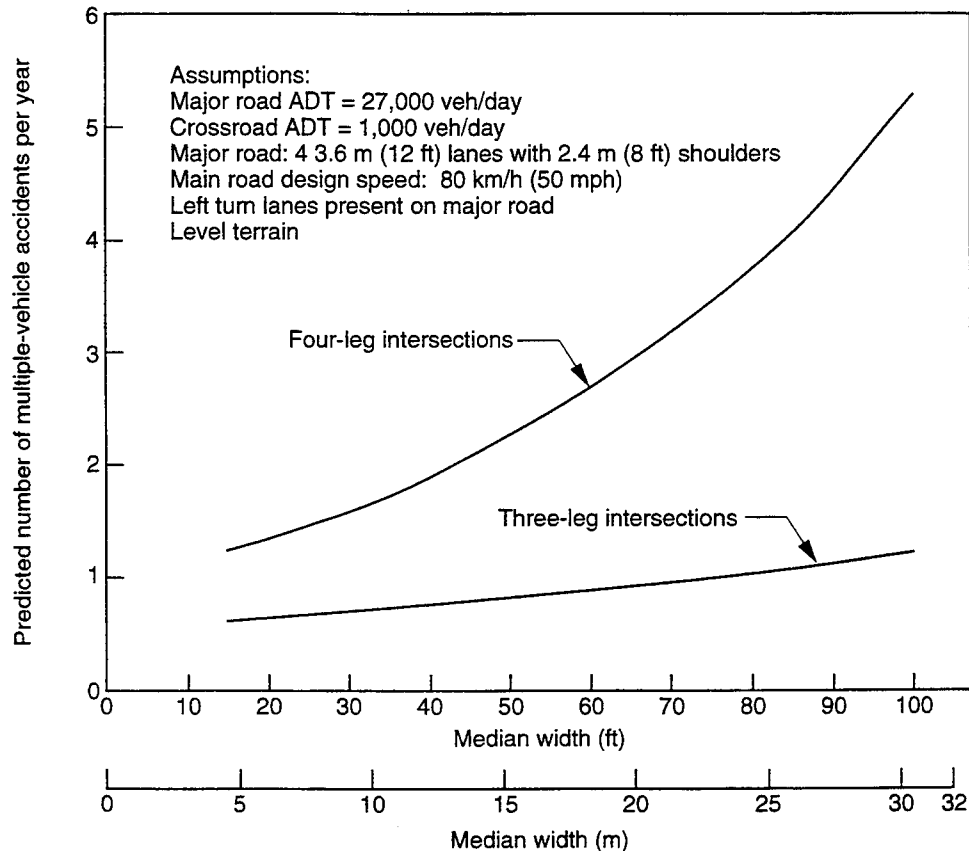


FIGURE 10 Predicted number of multiple-vehicle accidents per year as a function of median width for typical urban/suburban unsignalized intersection (14).

Median widths are one of the constraints that make it difficult for trucks to maneuver safely at intersections and to avoid interfering with other traffic. Table 19 presents the minimum turning radii for the AASHTO design vehicles that are used in assessing the ability of trucks to maneuver through specific roadway or intersection geometrics.

Consideration of larger vehicles is extremely important in the design of intersections because of the phenomenon called *offtracking*. When a vehicle makes a turn, its rear wheels do not follow the same path as its front wheels. The magnitude of this difference in path is called offtracking; it generally increases with increased spacings between the axles of the vehicle and decreases for larger radius turns.

The amount of offtracking is often measured by the differences in the paths of the centerlines of the front and subsequent axles. A more appropriate descriptor of offtracking for many roadway geometric design applications is the *swept path width*, which is the difference between the paths of the outside front tire and the inside rear tire(s) of the vehicle. It is normally determined by computing the amount of offtracking of the center of the rear axle(s) with respect to the center of the front axle, and

adding half of the width of the front axle plus half of the width of the rear axle. A more precise determination adds in an amount to take account of the front overhang of the vehicle relative to its front axle. The results are called the turning paths and are illustrated in Figure 12 for a WB-15 (large semitrailer) design vehicle. The paths shown in the figure are for the left front overhang and the outside rear wheel. The left front wheel follows a circular curve with a radius of 13.7 m (49.9 ft); however, its path is not shown.

The design vehicle for any project is selected by the responsible highway agency based on consideration of the actual or anticipated vehicle mix in the traffic using the facility. Most at-grade intersections on divided highways are conceived to accommodate a design vehicle at least as large as a bus (B design vehicle) or a single-unit truck (SU design vehicle). Where larger trucks make frequent turning or crossing maneuvers at a divided highway intersection, a larger design vehicle (such as the WB-15 combination truck) may be appropriate.

Increases in truck sizes have made it more difficult for trucks to maneuver at intersections on highways with narrow medians. AASHTO policy takes particular care in

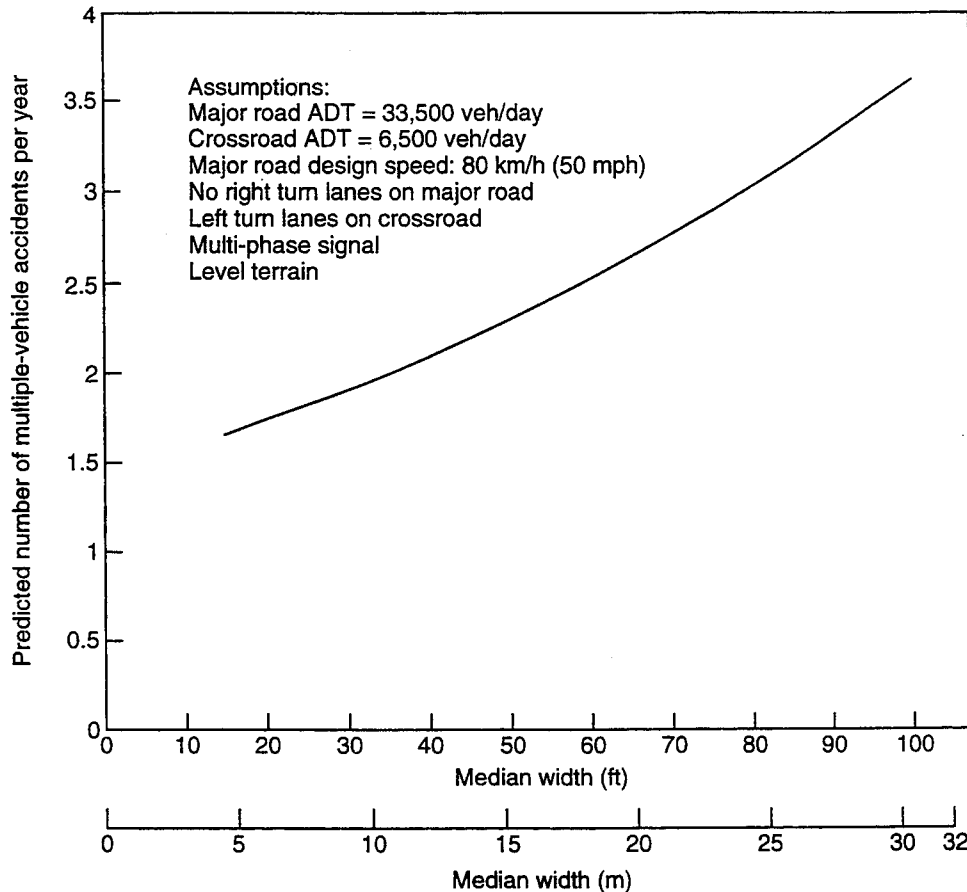


FIGURE 11 Predicted number of multiple-vehicle accidents per year as a function of median width for typical urban/suburban signalized intersection (14).

the consideration of larger vehicles in the design of openings at intersections and driveways on divided highways (1). AASHTO policies for minimum length of median openings, median nose treatments, and spacing between median openings are presented below.

Minimum Length of Median Opening

The *Green Book* states that the minimum length of the median opening should be the width of the crossroad roadway pavement plus shoulders. In no case should the width of the median opening be less than 12 m (40 ft). Design of the median opening length is based on the path of a particular design vehicle turning left at a speed of 15 to 25 km/hr (10 to 15 mph). The *Green Book* provides tables of minimum median opening lengths based on control radii of 12, 15, and 23 m (40, 50, and 75 ft). The control radius represents the minimum left-turn path for a particular design vehicle.

Figure 13 and Table 20 illustrate the AASHTO criteria for minimum design of median openings based on a 15-m (50-ft) control radius; this figure and table are analogous

to the figures and tables presented in the *Green Book* for the other control radii.

The control radius is selected as follows:

- A 12-m (40-ft) control radius will accommodate passenger cars and an occasional single-unit truck.
- A 15-m (50-ft) control radius will accommodate single-unit trucks and an occasional WB-12 (intermediate semitrailer) vehicle with some encroachment on an adjacent lane.
- A 23-m (75-ft) control radius will accommodate the WB-12 and WB-15 design vehicles with only minor encroachment on an adjacent lane at the end of the turn.

The *Green Book* also presents above-minimum median opening design appropriate for control radii of 30, 50, and 70 m (90, 150, and 230 ft) (see Figure 14) based on *Green Book* Figure IX-64. Such designs can provide for design vehicles larger than the WB-15 truck (which is a relatively small combination truck in today's fleet), and will permit

TABLE 18
DIMENSIONS OF AASHTO DESIGN VEHICLES (1)

Design Vehicle Type	Overall		Overhang		WB ₁	WB ₂	S	T	WB ₃	WB ₄
	Height	Width	Length	Front						
Passenger car (P)	1.3	2.1	5.8	0.9	1.5	3.4				
Single-unit truck (SU)	4.1	2.6	9.1	1.2	1.8	6.1				
Single-unit bus (BUS)	4.1	2.6	12.1	2.1	2.4	7.6				
Articulated bus (A-BUS)	3.2	2.6	18.3	2.6	2.9	5.5	1.2 ¹	6.1 ¹		
Combination trucks										
Intermediate semitrailer (WB-12)	4.1	2.6	15.2	1.2	1.8	4.0			8.2	
Large semitrailer (WB-15)	4.1	2.6	16.7	0.9	0.6	6.1			9.1	
Double bottom semitrailer-full trailer (WB-18)	4.1	2.6	19.9	0.6	0.9	3.0			6.1	
Interstate semitrailer (WB-19) ³	4.1	2.6	21.0	1.2	0.9	6.1	1.2 ²	1.6 ²	6.4	
Interstate semitrailer (WB-20) ⁴	4.1	2.6	22.5	1.2	0.9	6.1			12.8	
Triple semitrailer (WB-29)	4.1	2.6	31.0	0.8	1.0	4.1	1.0 ⁵	1.8 ⁵	6.6	6.6
Turnpike double semitrailer (WB-35)	4.1	2.6	35.9	0.6	0.6	6.7	0.6 ⁶	1.8 ⁶	13.4	
Recreational vehicle										
Motor home (MH)		2.4	9.1	1.2	1.8	6.1				
Car and camper trailer (P/T)		2.4	14.9	0.9	3.0	3.4	1.5		6.1	
Car and boat trailer (P/B)		2.4	12.8	0.9	2.4	3.4	1.5		4.6	
Motor home and boat trailer (MH/B)		2.4	16.1	1.2	2.4	6.1	1.8		4.6	

Note: All dimensions in the table are specified in meters. WB₁, WB₂, WB₃, WB₄, are effective vehicle wheelbases. S = distance from the rear effective axle to the hitch point; T = distance from the hitch point to the lead effective axle of the following unit.

¹Combined dimension 7.3 m, split is estimated. ²Combined dimension 2.9 m, split is estimated. ³Design vehicle with 14.6-m trailer as adopted in 1982 STAA (Surface Transportation Assistance Act).

⁴Design vehicle with 16.2-m trailer as grandfathered in 1982 STAA (Surface Transportation Assistance Act). ⁵Combined dimension 2.8 m, split is estimated. ⁶Combined dimension 2.4 m, split is estimated.

TABLE 19
MINIMUM TURNING RADII OF AASHTO DESIGN VEHICLES (1)

Radius (m)	Design Vehicle Type													
	Passenger Car (P)	Single-Unit Truck (SU)	Single-Unit Bus (BUS)	Articulated Bus (A-BUS)	Semitrailer (Inter-mediate) (WB-12)	Semitrailer Combination (Large) (WB-15)	Semitrailer Full Combination (WB-18)	Interstate Semitrailer (WB-19) ¹	Interstate Semitrailer (WB-20) ²	Triple Semitrailer (WB-29)	Turnpike Double Semitrailer (WB-35)	Motor Home and Boat Trailer (MH/B)	Passenger Car with Boat and Trailer (P/B)	Motor Home and Boat Trailer (MH/B)
Minimum design turning	7.3	12.8	12.8	11.6	12.2	13.7	13.7	13.7	13.7	15.2	18.3	12.2	7.3	15.2
Minimum inside	4.2	8.5	7.4	4.3	5.7	5.8	6.8	2.8	0	6.3	5.2	7.9	0.6	2.0

¹Design vehicle with 14.6-m trailer as adopted in 1982 STAA (Surface Transportation Assistance Act).

²Design vehicle with 16.2-m trailer as grandfathered in 1982 STAA (Surface Transportation Assistance Act).

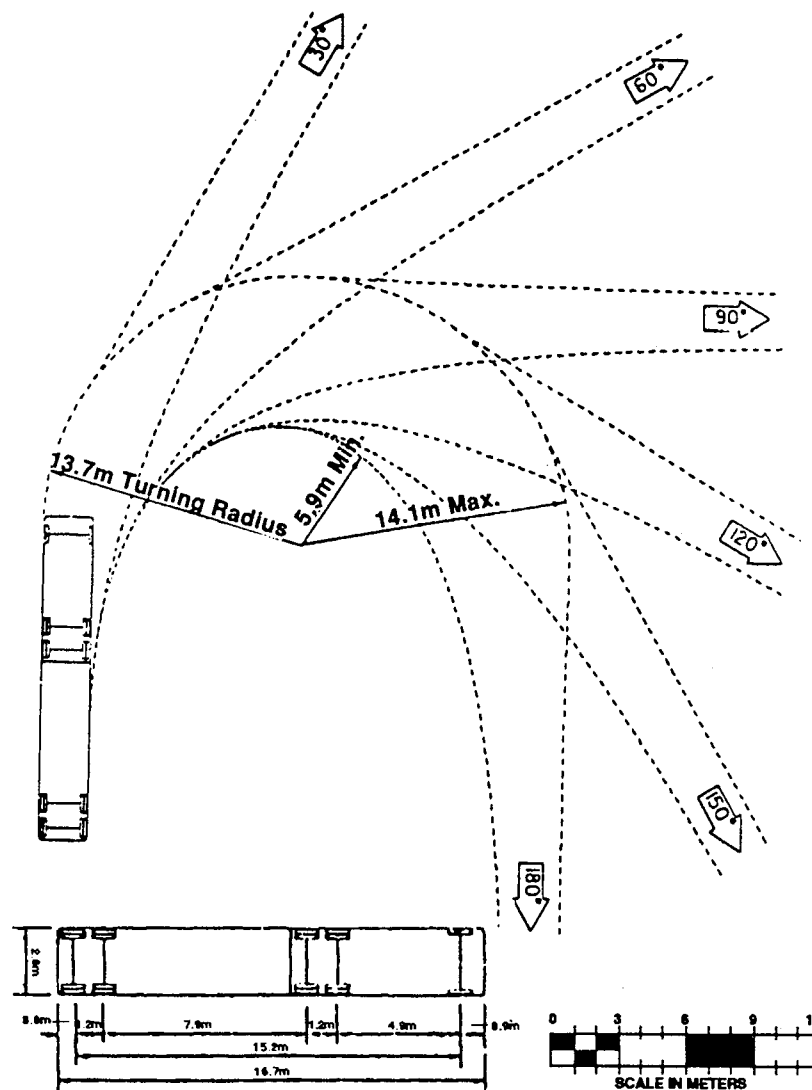


FIGURE 12 Minimum turning path for AASHTO WB-15 design vehicle (1).

WB-15 and smaller trucks to turn at speeds higher than 15 to 25 km/hr (10 to 15 mph) without encroaching on an adjacent lane.

Median Nose Treatments

There are three distinct types of nose treatments for medians. The two most common types are a semicircular nose and a bullet nose. A third type of end treatment, a squared-end nose, is not generally used.

According to the *Green Book*, medians of less than 3 m (10 ft) in width experience no difference in operations as a result of the median nose type. With median widths greater than 3 m (10 ft), the bullet nose is superior because it more closely approximates the path of the inner rear wheel. This results in less intersection pavement and a shorter length of opening.

One state highway agency (the Arizona DOT) reported that they had evaluated a squared median nose in comparison with a bullet nose. The results of the study indicated that the bullet nose had several advantages over the squared end, including lower accident experience, higher intersection capacity, and the ability to provide for a full range of signal phasing (24). The bullet nose median is better suited to accommodating trucks and other large vehicles because its tapered shape should accommodate vehicle-turning paths with larger radii.

Spacing Between Median Openings

Very few state highway agency design policies have formal provisions for the minimum spacing between median openings. One state highway agency recommended that

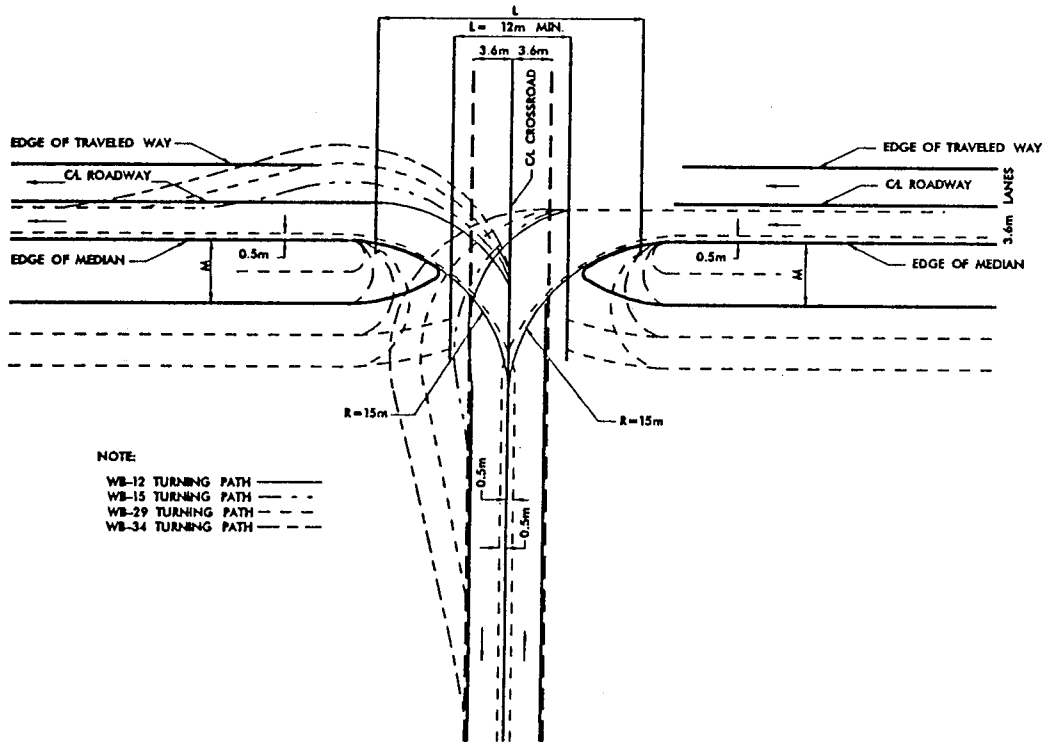


FIGURE 13 Minimum design of median openings (SU design vehicle, control radius of 15 m) (1).

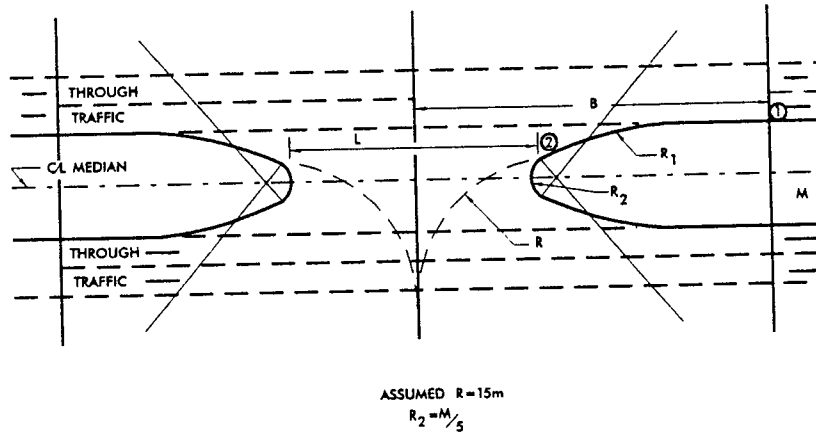
TABLE 20
 MINIMUM DESIGN OF MEDIAN OPENINGS (SU DESIGN
 VEHICLE, CONTROL RADIUS OF 15 m) (1)

Median Width (m)	Minimum Length of Median Opening (m)	
	Semicircular	Bullet Nose
1.2	28.8	28.8
1.8	28.2	22.8
2.4	27.6	20.4
3.0	27.0	18.6
3.6	26.4	17.4
4.2	25.8	15.9
4.8	25.2	15.0
6.0	24.0	13.2
7.2	22.8	12.0*
8.4	21.6	12.0*
9.6	20.4	12.0*
10.8	19.2	12.0*
12.0	18.0	12.0*
15.0	15.0	12.0*
18.0	12.0*	12.0*
21.0	12.0*	12.0*

Note: SU = single-unit truck.
 *, minimum.

median openings in urban/suburban areas be spaced no closer than 488 m (1,600 ft) apart if the intersections are to be signalized. For intersections without signals, the spacing requirement is such that exclusive left-turn lanes with the proper taper and storage lengths can be provided. Another highway agency provides median openings no closer than 270 m (880 ft) in urban areas.

In rural areas, one state highway agency recommends a minimum spacing of 0.4 km (0.25 mi) between median openings and a maximum spacing of 0.8 km (0.5 mi). A second state uses a minimum spacing between median openings of 0.5 km (0.3 mi) in rural areas. Another state uses a minimum spacing of 0.8 to 1.6 km (0.5 to 1.0 mi) between median openings on divided highways unless existing intersections



M WIDTH OF MEDIAN, METERS	DIMENSIONS IN METERS WHEN					
	$R_1 = 30\text{m}$		$R_1 = 50\text{m}$		$R_1 = 70\text{m}$	
	L	b	L	b	L	b
6.0	17.4	19.5	19.8	23.4	21.3	27.0
9.0	14.4	20.4	17.1	25.5	18.9	30.3
12.0	12.0	21.3	15.0	27.0	17.1	32.7
15.0	—	—	13.2	28.5	15.3	39.5
18.0	—	—	—	—	13.8	36.4
21.0	—	—	—	—	12.3	34.4

FIGURE 14 Above-minimum design of median openings (typical bullet nose ends) (1).

require a closer spacing. Still another state tries to maintain an average 1.6-km (1-mi) spacing between median openings on rural divided highways with partial control of access on new alignments, and an average spacing of 0.8 km (0.5 mi) between median openings along existing roadways.

In rural areas, median openings are normally provided at all intersections with public roads. Most states do not provide median openings for all driveways, although openings may be warranted for higher volume commercial or industrial driveways.

TRAFFIC OPERATIONAL AND SAFETY PROBLEMS ENCOUNTERED BY LARGER VEHICLES AT NARROW MEDIANS

This chapter discusses the traffic operational and safety problems encountered by larger vehicles at intersections or driveways with narrow medians on divided highways. The chapter draws extensively on the results of a survey of highway agencies conducted as part of the preparation of this synthesis. The results of that survey, together with the survey questionnaire, are presented in detail in Appendix A and are summarized in this chapter.

TRAFFIC OPERATIONAL AND SAFETY FREQUENCY OF PROBLEMS REPORTED BY HIGHWAY AGENCIES

A total of 32 state highway agencies and 23 local highway agencies responded to the survey conducted for the synthesis (see Appendix A). Of the 32 state highway agencies, 20 (63 percent) indicated that they had encountered traffic operational or safety problems related to truck operations on highways or streets with narrow medians. Thirteen of these 20 agencies (65 percent) indicated that they had encountered such problems on rural divided highways and 17 of the 20 agencies (85 percent) indicated that they had encountered such problems on urban/suburban arterials. In general, larger and more urbanized states were more likely to indicate that they had encountered truck-related operational or safety problems on roads with narrow medians, whereas smaller, less urbanized states generally had not encountered such problems.

Only 6 of the 23 local highway agencies (26 percent) responding to the survey indicated that they had encountered traffic operational or safety problems. These problems all occurred on urban/suburban highways, because the local agencies surveyed were all located in urban areas. The six local agencies that had experienced such problems are located in several different regions of the United States (Southeast, Midwest, and West) and so there does not appear to be any particular regional character to these perceived problems.

Another question in the survey asked highway agencies whether they had encountered concerns or complaints from the trucking industry or from businesses that they serve about access difficulties associated with narrow medians. This question was posed because even if highway agencies have not encountered traffic operational or safety problems associated with larger vehicles and narrow medians it is possible that truckers are encountering difficulties entering particular business establishments.

Concerns or complaints from the trucking industry were reported by 11 of the 32 state highway agencies that responded to the survey (34 percent) and 4 of the 23 local highway agencies that responded to the survey (17 percent). The respondents in three additional state highway agencies indicated that they thought there had been industry complaints about isolated locations, but that they had no specific knowledge of such complaints.

TRUCKING INDUSTRY PERSPECTIVE

A modest survey of trucking organizations and firms was undertaken to determine the extent to which they perceived narrow medians to be an operational or safety issue for large trucks. Nine interviews were conducted, most with trucking associations and organizations rather than individual trucking firms. The consensus was that narrow medians were not high on the list of trucker's concerns. Individuals interviewed all noted some particular potential problems with access for trucks to specific locations, such as difficulties in crossing through a narrow median and trying to make a left turn without the benefit of a left-turn lane. However, an attitude was expressed that most drivers take these things in stride—it is part of the job of a truck driver to deal with such challenges.

Some state trucking associations indicated that they had very few complaints because they had developed a close working relationship with their state highway agency. These trucking associations stated that they were regularly consulted about plans for new routes or changes in existing routes.

In general, it appears that the concerns of truckers about narrow medians are site-specific in nature. They do see narrow medians as a problem at some specific locations, but they do not consider narrow medians to be a high-priority concern of the industry.

TYPES OF TRAFFIC OPERATIONAL AND SAFETY PROBLEMS ENCOUNTERED BY LARGER VEHICLES

This section discusses the types of traffic operational and safety problems encountered by larger vehicles at intersections and driveways on divided highways with narrow medians. The discussion addresses traffic operational and

TABLE 21
 TYPES OF PROBLEMS RELATED TO LARGER VEHICLES AND NARROW MEDIANS EXPERIENCED BY HIGHWAY AGENCIES

Type of Problem	Agencies Reporting Problem
Encroachment on through lanes by larger vehicles stopped in the median	21 (80.8%)
Left-turn maneuvers by larger vehicles entering the highway	19 (73.1%)
Inadequate storage space in the median opening area	19 (73.1%)
Maneuvers by larger vehicles crossing the highway	17 (65.3%)
Left-turn maneuvers by larger vehicles leaving the highway	16 (61.5%)
U-turn maneuvers by larger vehicles	15 (57.7%)
Inadequate storage length in left-turn lanes	15 (57.7%)
Restricted sight distance due to opposing left-turn vehicles	15 (57.7%)
Use of indirect routes to reach destinations with no median opening	7 (26.9%)
Use of indirect routes to reach destinations with a median opening, but restricted median width	5 (19.2%)

Note: Based on the results of the highway agency survey conducted for this synthesis.

safety problems reported by both highway agencies and truckers and describes the nature of each problem. Potential solutions to these problems are presented in chapter 4.

Table 21 summarizes the types of problems related to larger vehicles and narrow medians reported by highway agencies. The table is arranged in descending order of the frequency with which each problem was reported among the highway agencies that responded to the survey conducted as part of the preparation of this synthesis. The percentages shown in the table are based on the total of 26 state and local highway agencies that reported traffic operational and safety problems related to larger vehicles and narrow medians.

Table 21 shows that the most common problem, as reported by 81 percent of highway agencies that had experienced problems, was encroachment on through lanes by larger vehicles stopped in the median. Five highway agencies also noted that the trucking industry had complained about narrow medians with inadequate storage space that forced their trucks to encroach on through travel lanes. The second and third most common problems were inadequate storage space in the median opening area and left-turn maneuvers by larger vehicles entering the highway, both reported by 73 percent of highway agencies. Each of these problems is related to narrow median widths that do not provide sufficient space in the median opening area to store a larger vehicle or a larger vehicle, as well as other vehicles, making turning or crossing maneuvers. Three highway agencies noted trucking industry concerns or complaints about the difficulty in finding breaks in traffic for trucks to make turning or crossing maneuvers.

Other specific traffic operational and safety problems noted by 50 percent or more of highway agencies that had experienced traffic operational or safety problems included maneuvers by larger vehicles crossing the highway, left-turn maneuvers by large vehicles leaving the highway, U-turn maneuvers by larger vehicles, inadequate storage

length in left-turn lanes, and restricted sight distance due to opposing left-turn vehicles.

Two other problems that were reported less frequently by highway agencies were the use of indirect routes to reach destinations with no median opening and the use of indirect routes to reach destinations with a median opening but with restricted median width. These problems were reported by 27 and 19 percent of highway agencies, respectively. It is likely that these problems are encountered often by truckers on highways with raised medians, although such concerns may not always come to the attention of highway agencies. Four highway agencies noted trucking industry concerns about the difficulty in accessing businesses on the opposite side of the road because of the difficulty in making U-turns or the limited number of locations where U-turns are possible.

Clearly, the traffic operational and safety problems reported by highway agencies in Table 21 are not unique to larger vehicles. Most of these problems are also encountered by passenger cars, as well. However, larger vehicles are more likely than passenger cars to encounter such problems. Furthermore, passenger cars may encounter problems only at very narrow medians. Larger vehicles are likely to encounter problems at wider medians than passenger cars.

Table 22 summarizes the types of larger vehicles reported by highway agencies that encounter traffic operational and safety problems related to narrow medians. The table shows that nearly all of the agencies (96 percent) that had problems reported that these problems had been encountered by combination trucks (e.g., tractor-semi-trailers). The second most frequently cited vehicle type was school buses (42 percent). Other vehicle types noted by highway agencies were single-unit trucks (35 percent), recreational vehicles (27 percent), local transit buses (19 percent), and intercity buses (8 percent). It is clear from these results that the overwhelming majority of traffic operational and safety problems are related to combination

TABLE 22
TYPES OF LARGER VEHICLES THAT ENCOUNTER PROBLEMS RELATED TO
NARROW MEDIANS

Types of Larger Vehicles	Agencies Reporting Problems Encountered by This Vehicle Type
Single-unit trucks	9 (34.6%)
Combination trucks (e.g., tractor-semitrailers)	25 (96.2%)
Intercity buses	2 (7.7%)
Local transit buses	5 (19.2%)
School buses	11 (42.3%)
Recreational vehicles (e.g., motor homes)	7 (26.9%)

Note: Based on the results of the highway agency survey conducted for this synthesis. Percentages are based on the total of 26 highway agencies that reported traffic operational and safety problems related to larger vehicles and narrow medians.

trucks, although school buses and smaller trucks are also a concern.

Table 23 summarizes the types of locations where traffic operational and safety problems have been encountered, as reported by highway agencies. The table indicates that larger vehicles encounter problems most frequently at unsignalized intersections. However, problems appear to be common at all types of locations where turning and/or crossing maneuvers occur, including signalized intersections, driveways with median openings, and driveways without median openings. Traffic operational and safety problems at driveways with no median opening must necessarily relate only indirectly to the median width. It is likely that such problems relate to indirect routes required to reach driveways with no median opening (i.e., routes served only by right turns into and right turns out of the driveway).

TABLE 23
TYPES OF LOCATIONS WHERE PROBLEMS INVOLVING
LARGER VEHICLES AND NARROW MEDIANS HAVE
BEEN ENCOUNTERED

Types of Locations	Agencies Reporting Problems at This Location Type
Signalized intersections	15 (57.7%)
Unsignalized locations	21 (80.8%)
Driveways with median openings	17 (65.3%)
Driveways without median openings	13 (50.0%)

Note: Based on the results of the highway agency survey conducted for this synthesis. Percentages are based on the total of 26 highway agencies that reported traffic operational and safety problems related to larger vehicles and narrow medians.

Highway agencies were asked to identify specific traffic accident patterns they had observed at intersections with narrow medians. The traffic accident patterns described were:

- Higher than average concentration of accidents at intersections and median openings,

- Collisions between through vehicles and vehicles in the median encroaching on through lanes,
- Collisions between left-turning and opposing through vehicles,
- Collisions between U-turn and opposing through vehicles because of the inability of trucks to complete the U-turn maneuver in one swing,
- Rear-end collisions in through lanes, and
- Damage to KEEP RIGHT signs on ends of medians.

The following sections more thoroughly discuss each type of identified traffic and safety problem related to larger vehicles and narrow medians.

Encroachment on Through Lanes by Larger Vehicles

The most common traffic operational and safety problem cited by highway agencies at intersections and driveways with narrow medians was encroachment on through lanes by larger vehicles stopped in the median. Drivers making left-turn or crossing maneuvers at an unsignalized intersection on a divided arterial often prefer to cross the near lanes of the arterial and stop in the median because they can consider available gaps in traffic on the roadways in each direction of travel separately. This is referred to in the chapter on unsignalized intersections (chapter 10) of the *Highway Capacity Manual* as two-stage gap acceptance (5). However, if a particular larger vehicle is longer than the median width, the driver of that vehicle cannot stop in the median without encroaching on the through travel lanes at either the front of the vehicle, the back of the vehicle, or both. Figure 15 illustrates this problem.

Drivers of vehicles that are longer than the median width are expected to realize that the median is not wide enough to accommodate their vehicle and, therefore, they should not begin their turning maneuver until a suitable gap is available in both directions of travel on the major road at the same time. Drivers of longer vehicles often fail to do this, however, because it may be difficult to judge the width of the median relative to the length of their vehicle,

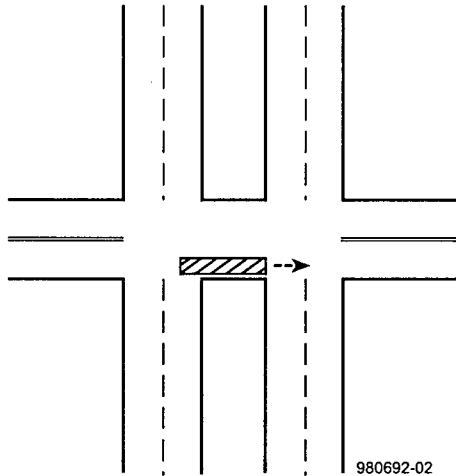


FIGURE 15 Encroachment on through lanes of a divided highway by a larger vehicle stopped in a narrow median.

because they become impatient waiting for simultaneous gaps in traffic in both directions of travel, or because they misjudge the gap available in the far lanes of traffic.

Encroachment on the through lanes by larger vehicles can lead to angle collisions between the encroaching vehicle and through vehicles on the major road and can also

lead to accidents on the major road between through vehicles and vehicles changing lanes to avoid the encroaching vehicle. Even when no accident occurs, major-road vehicles can be delayed by the encroaching vehicle.

Inadequate Storage Space in the Median Opening Area

A related problem that also occurs at intersections and driveways on divided highways with narrow medians involves inadequate storage space in the median opening area. Even if the median width is sufficient to store a specific larger vehicle, the median opening at an intersection or driveway may be occupied by one or more additional vehicles at the time when a larger vehicle wishes to use it. Drivers of larger vehicles may misjudge the remaining storage space in the median opening area or may misjudge the intentions of drivers already stopped in the median.

Figure 16 illustrates the types of undesirable driving behavior that can result when multiple vehicles, especially multiple vehicles traveling in the same direction, attempt to simultaneously use a single median. These problems include encroachment on the through lanes (see preceding discussion), angle stopping, and side-by-side queuing.

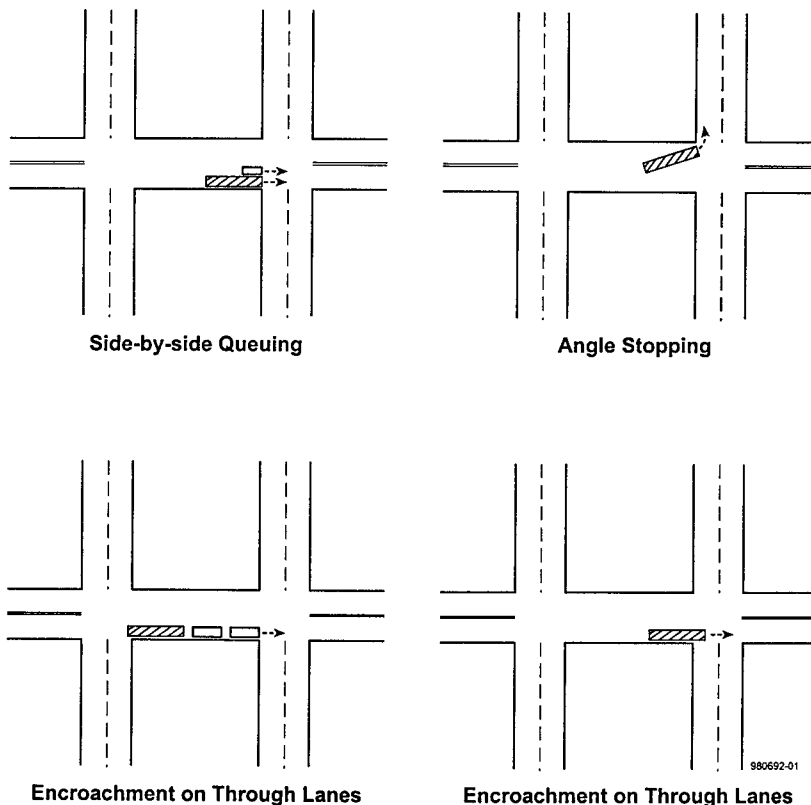


FIGURE 16 Types of undesirable driving behavior related to larger vehicles and narrow medians.

When several vehicles are present in the median opening area at the same time, various combinations of encroachment on the through lanes, angle stopping, and side-by-side queuing may occur.

Field studies of divided highway intersections conducted with video cameras for NCHRP Report 375 (14) found that the rate of undesirable driving behavior was 123.3 undesirable maneuvers per 1,000 vehicles passing through the median opening for rural unsignalized intersections and 99.2 undesirable maneuvers per 1,000 vehicles passing through the median opening for suburban unsignalized intersections. By contrast, suburban signalized intersections experienced a rate of undesirable driving behavior of only 4.8 undesirable maneuvers per 1,000 vehicles passing through the median opening. Signalized intersections appear to be much less susceptible to problems related to inadequate storage space in the median opening than unsignalized intersections because, at signalized intersections, gaps in the major-road traffic for crossing or entering the major road are provided by the signal and drivers are not required to wait for such gaps to occur.

Furthermore, the clearance interval at the end of the minor-road green light phase provides an opportunity for most vehicles that have been waiting for gaps in traffic from the opposing minor-road approach to clear the median area. Problems related to inadequate storage in the median opening area appear to occur at signalized intersections on divided arterials only when the median is so wide that separate signals are required for the two directions of travel on the major road.

Further analyses of the data on undesirable driving behavior in NCHRP Report 375 found that the rate of undesirable driving behavior tends to decrease with increasing median width at rural unsignalized intersections and to increase with increasing median width at suburban unsignalized intersections. These findings led to the recommendations, reported in chapter 2, that the median width at rural unsignalized intersections should be as wide as possible (as long as both of the divided roadways are visible to the minor-road driver) and that the median width at urban or suburban unsignalized intersections should be only as wide as necessary to accommodate the selected left-turn treatments for the major road or the length of a selected design vehicle, plus appropriate clearance at either end of the vehicle (14).

In summary, inadequate storage space in the median opening area was found to be a problem at both rural and urban unsignalized intersections, but is not usually a problem at signalized intersections. At rural unsignalized intersections, problems created by inadequate storage space in the median opening area can be remedied by providing a wider median. A more difficult tradeoff is

faced at unsignalized intersections in urban and suburban areas. Provision of a larger median opening area can provide storage space for more vehicles in the median, but can also increase the frequency of undesirable driving behavior and related accidents. This trade-off is addressed further in chapter 4.

Left-Turn Maneuvers by Larger Vehicles Entering the Highway

Traffic operational and safety problems encountered in left-turn maneuvers by larger vehicles entering the highway are often attributable to the lack of sufficient storage space in the median opening area as discussed previously. This is treated as a separate traffic operational and safety problem here because, as shown in chapter 4, there are unique solutions to problems related to left-turn maneuvers onto the highway that do not apply to other types of maneuvers.

Drivers of larger vehicles making left turns must use two-stage gap acceptance, as discussed previously, if the length of their vehicle is greater than the median width or if the median opening area is already occupied and the length of their vehicle is greater than the remaining space in the median opening area. Figures 15 and 16 illustrate the types of undesirable driving behavior that can result when either a larger vehicle whose length exceeds the median width or a larger vehicle together with one or more smaller vehicles use the median opening area at the same time.

Crossing Maneuvers by Larger Vehicles

Crossing maneuvers through the median opening area were also identified by more than 50 percent of highway departments as a source of traffic operational and safety problems for larger vehicles at intersections and driveways with narrow medians. Crossing maneuvers involve a movement by a larger vehicle approaching the intersection (or driveway) on one minor-road leg across one direction of travel on the major road, through the median opening area, across the other direction of travel on the major road, and departing the intersection on the opposite minor-road leg. Like the left-turn maneuvers discussed previously, larger vehicles may not be able to stop in the median and take advantage of two-stage gap acceptance if the vehicle length is greater than the median width or if there are other vehicles in the median opening area. These maneuvers and conflicts between vehicles in the median opening area can lead to undesirable driving behavior, including encroachment by stopped vehicles on the through travel lanes, angle stopping, and side-by-side queuing.

Left-Turn Maneuvers by Larger Vehicles Leaving the Highway

Larger vehicles leaving a divided arterial by turning left also pass through the median opening area and compete for space in the median opening area with vehicles making left turns to enter the highway and vehicles making crossing maneuvers from a minor-road approach or driveway. As in the case of these other maneuvers, left turns from the divided arterial through the median opening area can lead to undesirable driving behavior, including encroachment by stopped vehicles on the through travel lanes, angle stopping, and side-by-side queuing. Still another problem that is unique to left turns from undivided highways or divided highways with narrow medians is restricted sight distance due to opposing left-turn vehicles. This issue is discussed later in this chapter.

U-Turn Maneuvers by Larger Vehicles

One effect of using a raised or depressed median on a divided highway, in contrast to undivided highways or highways with flush medians, is that direct left-turn access may be denied at minor intersections and driveways where median openings are not provided. The elimination of direct left-turn access may have definite traffic operational and safety benefits in allowing portions of the highway between major intersections to operate with fewer traffic conflicts, fewer accidents, and reduced delay to through vehicles. However, the price of eliminating left turns between major intersections may be to increase U-turn maneuvers at or near those major intersections. Where direct left-turn access to (and from) a minor intersection or driveway is denied, drivers attempting to reach (or leave) that location must either (1) make a U-turn at the next location further downstream on the arterial where a median opening is provided or (2) use an indirect route to reach their destination (or leave their origin).

Tables 24, 25, and 26 show a traffic operational comparison of the four-lane undivided and four-lane divided cross sections for 30, 60, and 90 driveways per mile prepared for NCHRP Report 282 (2). The tables present the delay reduction for both through vehicles and left-turn vehicles (in vehicle-seconds per hour and vehicle-seconds per left-turn vehicle). The delay reduction estimates in the tables are computed as the sum of the following five delay components:

- Reduction in delay to through vehicles because they are not delayed by vehicles waiting to turn left at midblock driveways (C_1),
- Reduction in delay to left-turning vehicles by not having to wait for gaps in opposing traffic at a midblock driveway (C_2),
- Increase in travel time for left-turning vehicles as they proceed to the next intersection and return to their destination after making a U-turn (C_3),

- Increased delay to U-turning vehicles as they wait to make a left turn at a signalized intersection (C_4), and
- Increased delay to all other vehicles at the signalized intersection due to increased left-turn volumes resulting from the U-turn demand (C_5).

The delay measures in Tables 24–26 are shown as delay reductions. Thus, negative values of delay reduction, such as those shown for components C_3 , C_4 , and C_5 , represent increases in delay. In other words, when the net delay reduction is negative, this indicates an overall increase in delay with installation of a four-lane divided cross section.

The delay estimates shown in Tables 24–26 indicate that the installation of a median divider on a four-lane undivided highway generally increases delay up to a flow rate of approximately 1,000 veh/hr in each direction of travel. Above that flow rate, drivers making midblock left turns are better served by the indirect U-turn routing than by waiting for a gap in opposing traffic to complete a left turn. Because of the variability inherent in the simulation model results, the 1,000 veh/hr flow rate should not be regarded as a precise boundary between conditions appropriate for a four-lane undivided highway and for installation of a raised median. However, the results strongly suggest that as flow rates approach or exceed 1,000 veh/hr, the installation of a raised median becomes more desirable. Raised medians may also be appropriate at flow rates of less than 1,000 veh/hr, when there are other benefits to offset the operational disadvantage of increased delay.

The comparable delay reduction estimates in NCHRP Report 395 (4) include only the delay terms analogous to components C_1 and C_2 , but do not include delay terms analogous to components C_3 , C_4 , and C_5 . However, it should be recognized that the estimates of components C_3 , C_4 , and C_5 from NCHRP Report 282 (2) required assumptions about the length of the analysis section (typical distance from a driveway to the next major intersection) and about the turning demands at that next major intersection.

Inadequate Storage Length in Left-Turn Lanes

The survey results indicate that inadequate storage length in left-turn lanes is also a common problem at intersections with narrow medians. AASHTO policy specifies required deceleration and storage lengths for left-turn lanes on divided highways (1). Provision of inadequate storage length in a left-turn lane does not necessarily result directly from the presence of a narrow median, but the narrow median may be one of the constraints that led to provision of inadequate storage length. Growth of left-turn volumes (particularly trucks turning left) and growth of opposing traffic volumes (requiring larger left-turn waiting times) are factors that may result in a left-turn lane that had adequate

TABLE 24

OPERATIONAL EFFECTIVENESS OF FOUR-LANE DIVIDED ALTERNATIVE COMPARED WITH FOUR-LANE UNDIVIDED ALTERNATIVE FOR 30 DRIVEWAYS PER MILE (2)

Flow Rate ¹ (vph)	Left-Turn Demand in 1000-ft Section ¹		Components of Delay Reduction ¹ (veh-sec per hr)					Net Delay Reduction (veh-sec)	
	Percent	vph	C ₁	C ₂	C ₃	C ₄	C ₅	Per Hour ¹	Per Left-Turn Vehicle
650	7.5	49	499.3	342.4	-835.5	-1,137.5	-3,221.9	-4,353.2	-88.8
650	10.0	65	622.4	461.4	-1,108.3	-1,770.2	-3,408.9	-5,163.6	-79.4
650	12.5	81	825.4	475.3	-1,381.1	-2,293.4	-5,557.8	-7,931.6	-97.9
900	5.0	45	2,944.4	613.2	-876.6	-1,670.4	527.6	483.0	10.7
900	7.5	68	4,449.2	970.3	-1,324.4	-3,174.4	-3,539.8	-2,619.3	-38.5
900	10.0	90	5,888.7	1,183.1	-1,753.2	-3,506.0	-10,906.6	-9,094.0	-101.0
1,100	2.5	28	21,397.6	1,056.8	-545.4	-1,160.7	-4,931.6	15,816.7	564.9
1,100	5.0	55	42,031.0	1,675.9	-1,071.4	-2,987.8	-7,145.6	32,502.1	590.9
1,100	7.5	83	63,428.6	2,614.3	-1,616.8	-4,336.7	13,568.7	46,520.7	560.4

Note: vph = vehicles per hour.

¹In each direction of travel.

TABLE 25

OPERATIONAL EFFECTIVENESS OF FOUR-LANE DIVIDED ALTERNATIVE COMPARED WITH FOUR-LANE UNDIVIDED ALTERNATIVE FOR 60 DRIVEWAYS PER MILE (2)

Flow Rate ¹ (vph)	Left-Turn Demand in 1000-ft Section ¹		Components of Delay Reduction ¹ (veh-sec per hr)					Net Delay Reduction (veh-sec)	
	Percent	vph	C ₁	C ₂	C ₃	C ₄	C ₅	Per Hour ¹	Per Left-Turn Vehicle
650	7.5	49	424.3	284.2	-835.5	-1,137.5	-3,221.9	-4,385.9	-91.5
650	10.0	65	563.6	311.9	-1,108.3	-1,770.2	-3,408.9	-5,411.9	-83.3
650	12.5	81	702.3	338.0	-1,381.1	-2,293.4	-5,557.8	-8,192.0	-101.1
900	5.0	45	2,535.3	529.1	-876.6	-1,670.4	527.6	10.2	0.2
900	7.5	68	3,831.1	918.3	-1,324.4	-3,174.4	-3,539.8	-3,289.4	-48.4
900	10.0	90	5,070.6	1,190.0	-1,753.2	-3,506.0	-10,906.6	-10,005.2	-111.2
1,100	2.5	28	18,858.6	1,345.0	-545.4	-1,160.7	-4,931.6	13,565.9	484.5
1,100	5.0	55	37,043.6	1,505.1	-1,071.4	-2,987.8	-7,145.6	27,343.9	497.2
1,100	7.5	83	55,902.2	2,261.3	-1,616.8	-4,336.7	13,568.7	38,641.3	465.6

Note: vph = vehicles per hour.

¹In each direction of travel.

TABLE 26

OPERATIONAL EFFECTIVENESS OF FOUR-LANE DIVIDED ALTERNATIVE COMPARED WITH FOUR-LANE UNDIVIDED ALTERNATIVE FOR 90 DRIVEWAYS PER MILE (2)

Flow Rate ¹ (vph)	Left-Turn Demand in 1000-ft Section ¹		Components of Delay Reduction ¹ (veh-sec per hr)					Net Delay Reduction (veh-sec)	
	Percent	vph	C ₁	C ₂	C ₃	C ₄	C ₅	Per Hour ¹	Per Left-Turn Vehicle
650	7.5	49	381.2	199.1	-835.5	-1,137.5	-3,221.9	-4,614.6	-94.2
650	10.0	65	505.7	301.4	-1,108.3	-1,770.2	-3,408.9	-5,480.3	-84.3
650	12.5	81	630.2	311.5	-1,381.1	-2,293.4	-5,557.8	-8,290.6	-102.4
900	5.0	45	2,149.8	325.5	-876.6	-1,670.4	527.6	599.3	13.3
900	7.5	68	3,247.0	536.1	-1,324.4	-3,174.4	-3,539.8	-4,255.7	-62.6
900	10.0	90	4,297.5	959.8	-1,753.2	-3,506.0	-10,906.6	-10,908.5	-121.2
1,100	2.5	28	14,871.1	680.1	-545.4	-1,160.7	-4,931.6	8,913.5	318.3
1,100	5.0	55	29,211.1	1,175.9	-1,071.4	-2,987.8	-7,145.6	19,182.2	348.8
1,100	7.5	83	44,082.1	2,131.0	-1,616.8	-4,336.7	13,568.7	26,690.9	321.6

Note: vph = vehicles per hour.

¹In each direction of travel.

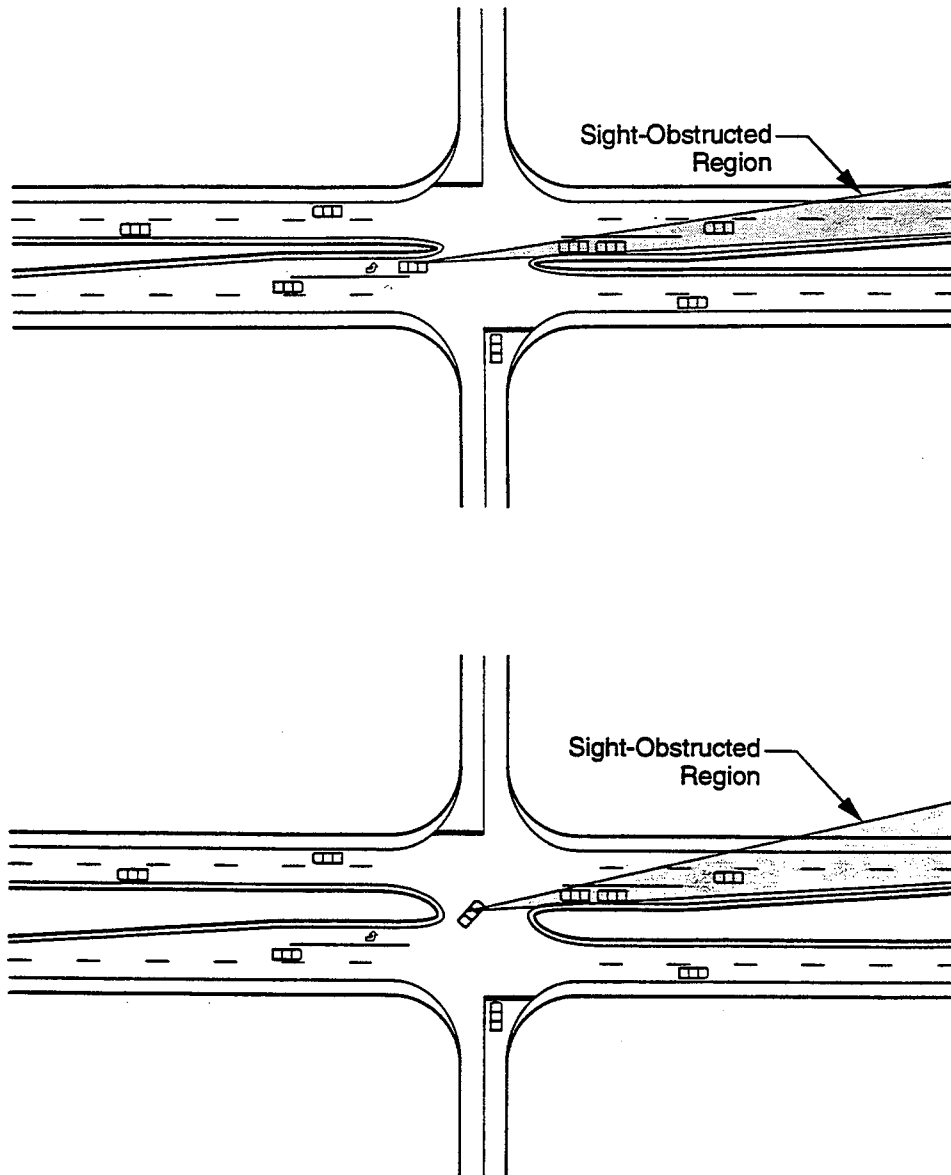


FIGURE 17 Examples of sight obstructions caused by opposing left-turn vehicles (18).

storage length when it was constructed becoming inadequate for current conditions.

Restricted Sight Distance Due to Opposing Left-Turn Vehicles

A common safety problem at divided highway intersections is restricted sight distance resulting from the view of the driver of a left-turning vehicle being obstructed by the presence of another vehicle in the left-turn lane for the opposing direction of travel. Figure 17 illustrates how opposing left-turn vehicles can block the driver's view of oncoming traffic. This problem is inherent in the design of most intersections on divided highways with narrow medians and can even occur at intersections with wider medians

if the left-turn lanes are not offset (see chapter 4). The problem is also exacerbated when the opposing left-turn vehicle blocking the driver's view is a truck or bus.

Use of Indirect Routes to Reach Destinations with No Median Opening

The discussion of U-turn maneuvers by larger vehicles provided quantitative estimates of delay if vehicles denied left-turn access by a raised median proceed to the next major intersection and make a U-turn. Although denial of left-turn access is likely to increase U-turn demand at nearby median openings, it is also likely that some larger vehicles will use indirect routes that do not involve a U-turn maneuver on the divided highway to reach their

destination. Such routes may involve going around the block or may incorporate an entirely different route from origin to destination, so that the larger vehicle can make a right turn into the driveway at its destination. There are no generally applicable estimates concerning how much delay to larger vehicles may result from such indirect routings.

Use of Indirect Routes to Reach Destinations with a Median Opening, But with a Restricted Median Width

Where the median width of a divided highway at a median opening is narrow, and particularly where no left-turn lane

is provided and the opposing traffic flow is high, drivers of trucks and other larger vehicles that desire to make a left turn may recognize that the median opening does not have sufficient size to accommodate their vehicle and that stopping in a through traffic lane to wait for a gap in opposing traffic leaves them potentially exposed to rear-end collisions. In this situation, provision of a median opening that is too small due to the narrow median width may be no better than providing no median opening at all. In this situation, drivers of larger vehicles may proceed to the next major intersection to complete a U-turn maneuver or may use an indirect routing to their destination, just as they would if no median opening were provided.

ALTERNATIVE IMPROVEMENT TECHNIQUES

This chapter discusses alternative improvement techniques that can be implemented to mitigate the problems encountered by larger vehicles at divided highway intersections with narrow medians. The chapter focuses on mitigation techniques for intersections with existing traffic operational or safety problems; however, a section on effective design techniques to avoid introducing such problems in new designs is also presented.

MITIGATION TECHNIQUES

This section describes the techniques that have been used by highway agencies to mitigate the traffic operational and safety problems found by highway agencies at intersections with narrow medians. Table 27 presents a summary of the mitigation techniques found to be in use by state and local highway agencies. The table is based on the responses to the highway agency survey reported in Appendix A and the practices of highway agencies reported in the literature and observed in the field. Tables A-7 and A-8 in Appendix A illustrate the frequency with which specific problems have been encountered and the frequency with which particular mitigation techniques have been used by highway agencies. The mitigation techniques presented in the table are all intended to address traffic operational and safety problems encountered by larger vehicles on divided highways. However, many of the same techniques should also be effective in mitigating traffic operational and safety problems encountered by passenger cars on divided highways, as well.

Table 27 is organized into three columns: symptoms, diagnosis, and mitigation techniques. The symptoms identified are traffic operational or safety problems that can occur at divided highway intersections. The diagnosis column identifies one or more possible causes of those symptoms. The mitigation techniques column identifies measures that can be taken by the responsible highway agency to mitigate the traffic operational or safety problems.

All of the traffic operational and safety problems addressed in the table are related directly or indirectly to the operation of large vehicles at divided highway intersections or driveways with narrow medians. Some of the problems directly address conditions at the intersection or driveway in question. Others address problems that can arise as a result of one of the mitigation techniques; for example, closure of a median opening at an intersection or

driveway can lead to problems at nearby median openings where larger vehicles make U-turn maneuvers.

Each set of symptoms for traffic operational and safety problems, together with the related diagnosis and mitigation techniques, are discussed below.

Undesirable Driving Behavior and Collisions Involving Vehicles in the Median Opening Area

The following three types of undesirable driving behavior are commonly observed in the median opening area at intersections or driveways on divided highways with narrow medians:

- Encroachment on through lanes by vehicles in the median opening area,
- Side-by-side queuing of vehicles in the median opening area, and
- Angle stopping by vehicles in the median opening area.

These are all problems that can be observed at median openings where only passenger cars are present, but such problems are even more likely to lead to traffic safety problems when larger vehicles are present in the median opening area. Encroachment on the through lanes is a particular problem for larger vehicles that stop in the median opening area. Side-by-side queuing and angle stopping are more commonly observed for passenger cars, but the presence of a larger vehicle in the median may make side-by-side queuing and angle stopping by other vehicles more common.

Collisions between left-turning vehicles and vehicles stopped in the median opening area have causes similar to the undesirable driving behavior discussed above and the same mitigation techniques apply. Both the three types of undesirable driving behavior discussed above and the traffic operational and safety problems that result, including collisions involving left-turning vehicles in the median opening area, are caused by insufficient or inappropriate storage space in the median opening area. Fifteen mitigation techniques applicable to such intersections are:

- Reconstruct rural highways with wider median
- Reconstruct rural highways with wider median at selected intersections only

TABLE 27

SYMPTOMS, DIAGNOSIS, AND MITIGATION TECHNIQUES FOR TRAFFIC OPERATIONAL AND SAFETY PROBLEMS RELATED TO LARGER VEHICLES ON DIVIDED HIGHWAYS WITH NARROW MEDIANS

Symptoms	Diagnosis	Mitigation Techniques
Undesirable driving behavior including: Encroachment on through lanes by vehicles in the median opening Side-by-side queuing in the median opening Angle stopping in the median opening	Insufficient/inappropriate storage space in the median opening area	Reconstruct highways with wider median Reconstruct highways with wider median at selected intersections Reconstruct urban/suburban highway with narrower median Remove raised or depressed median and replace with flush median
Collisions between left-turning vehicles and vehicles stopped in the median opening area		Prohibit left-turn maneuvers Close median opening Reconfigure median to prohibit crossing maneuvers while still permitting left turns Require indirect left-turn movements Provide median acceleration lanes Extend edgelines to better define median opening area Mark double yellow centerline on roadway in the median opening area Remove STOP signs in median Install traffic signals Provide protected left-turn signal phasing
Collisions between vehicles turning left from the divided highway and other same-direction vehicles	Turning conflicts unexpected by through drivers Large speed differences between through and turning vehicles	Install advance signing Install bigger signs Install better delineation Implement lower speed limits Implement advisory speeds on the major road Provide left-turn lanes on the major road Increase the deceleration and storage length of existing left-turn lanes Prohibit left-turns from the major road Close the median opening Require indirect left-turn movements
Collisions between vehicles turning left from the divided highway and opposing through vehicles	Sight distance for left-turn vehicles limited by opposing through vehicles	Offset opposing left-turn lanes by moving them laterally within the median Provide protected left-turn phases at signals Prohibit left turns from the major road Close the median opening Require indirect left-turn movements
Collisions between vehicles making U-turns and opposing through vehicles	Slow turning speed of larger vehicles making U-turns Inability of larger vehicles to complete U-turn maneuvers in one swing	Add additional lanes to the divided highway Add paved/stabilized shoulder to allow trucks to swing wider Reconstruct highway with wider median Reconstruct highway with wider median at selected intersection Provide median crossover roadways or indirect routes for U-turns Prohibit U-turn maneuvers Prohibit U-turn maneuvers by larger vehicles Close median opening

Note: Based on results of the highway agency survey and the literature review conducted for this synthesis.

- Reconstruct urban/suburban highways with narrower median
 - Remove median
 - Remove raised or depressed median and replace with flush median
 - Prohibit left-turn maneuvers
 - Close median opening
 - Reconfigure median to prohibit crossing maneuvers while still permitting left turns
 - Require indirect left-turn movements
 - Provide median acceleration lanes
 - Extend edgelines to better define median opening area
 - Mark double yellow centerline on roadway in the median opening area
 - Remove STOP signs in median
 - Install traffic signals
 - Provide protected left-turn signal phasing.
- Each of these mitigation techniques is discussed here.

Reconstruct Rural Highways with Wider Median

The first mitigation technique discussed here is to reconstruct the highway with a wider median to provide more storage area in the median openings at intersections and driveways along the corridor. NCHRP Report 375 (14) has shown that undesirable driving behavior at intersections on rural divided highways generally becomes less frequent as the median becomes wider, whereas the opposite is true on urban and suburban divided highways. Therefore, this mitigation technique is most appropriate for application on rural divided highways. In such cases, the median should be as wide as possible as long as both roadways of the divided highway remain visible to drivers on the minor-road approaches. At a minimum, a particular larger vehicle that frequently makes turning or crossing maneuvers at intersections in the corridor can be selected from among the AASHTO design vehicles in Table 18, and the intersection can be made wide enough to store that particular design vehicle. Where volumes are higher, the median might be made sufficiently wide to store the selected design vehicle plus several other vehicles. However, as a practical matter, right-of-way costs, existing development, and environmental considerations will set practical limits on how wide the median can be made and, at many locations, this mitigation technique may not be feasible or cost effective. This mitigation technique is used sparingly because of its high cost. Only 15 percent of the highway agencies that responded to the survey conducted for this synthesis indicated that they have used this technique.

Highway agencies face a difficult tradeoff in deciding whether to widen medians on divided highways in urban and suburban areas. A wider median will provide more storage space in median openings and, therefore, reduce the likelihood that vehicles stopped in the median will encroach on the through lanes. However, research has found wider medians in urban and suburban areas to be associated with increased frequency of undesirable driving behavior and accidents. Because of these concerns, plans to widen existing medians on divided highways in urban and suburban areas should receive a thorough engineering study.

Reconstruct Rural Highways with Wider Median at Selected Intersections Only

Another mitigation technique is to reconstruct a divided highway with a wider median only at those intersections where the crossing and turning volumes, and especially the volumes of crossing and turning maneuvers involving larger vehicles, are such that substantial problems related to undesirable driving behavior are expected. This approach costs substantially less and has fewer adverse effects than widening the median continuously along an entire divided highway corridor. For example, the Kansas DOT has

adopted a policy of widening the median of rural divided highways to 46 m (150 ft) at major intersections. Like the previous technique, this mitigation technique is most appropriate in rural areas, and could be counterproductive in urban and suburban areas.

Reconstruct Urban/Suburban Highways with Narrower Median

Research in NCHRP Report 375 (14) has shown that divided highway medians should not be unnecessarily wide at intersections in urban and suburban areas because the frequency of undesirable driving behavior increases as the median becomes wider. NCHRP Report 375 recommends that medians on divided highways in urban and suburban areas be no wider than necessary to accommodate existing and planned left-turn treatments. Thus, at an urban or suburban intersection where undesirable driving behavior is observed, an appropriate mitigation technique could be to decrease the frequency of such behavior by reconstructing the highway with a narrower median. A narrower median would discourage vehicles from stopping in the median opening area, but might increase traffic operational delays, because vehicles would need to use one-stage gap acceptance to cross or turn left onto the divided highway. Narrowing of an existing median may be undesirable at locations where there are substantial volumes of large trucks turning left onto or crossing the divided highway. The authors are not aware of any sites where a highway agency has reconstructed an urban or suburban arterial with a narrower median primarily to mitigate an existing traffic safety problem at intersections or driveways. Traffic safety problems would probably need to be quite serious to serve as the sole justification for such a project. However, a change in median width might be considered if the highway were reconstructed for other reasons. This technique should be considered carefully because it would not be desirable to create a situation in which larger vehicles continue to stop in the narrow median and thereby increased the likelihood of encroachment by larger vehicles on the through lanes.

Remove Median

This mitigation technique involves removing the divided highway median and operating the facility as an undivided highway. Such an approach might be appropriate where there was a need to reconstruct the highway with additional travel lanes for through traffic. In urban and suburban areas, removing the median could mitigate problems related to undesirable driving behavior in the existing median. Such a decision should be made carefully, weighing the possible adverse effects of not providing midblock or intersection left-turn treatments and the traffic operational

delays inherent in forcing crossing and turning vehicles to use one-stage gap acceptance. This technique is less appropriate in rural areas where wider, rather than narrower, medians are desirable.

Remove Raised or Depressed Median and Replace with Flush Median

Another approach is to remove an existing raised or depressed median and replace it with a flush median, such as a center TWLTL. If this approach narrows the median, this may help to mitigate problems related to undesirable driving behavior at urban and suburban intersections while still providing space for left-turn treatments. The provision of a center TWLTL also reduces delay for vehicles making left turns between intersections except at very high flow rates for through traffic (see Tables 6 and 14). Flush medians are generally 3 to 6 m (10 to 18 ft) in width and, therefore, may require larger vehicles to use one-stage gap acceptance when crossing or turning onto the major road. TWLTLs are appropriate for streets with existing strip commercial development. However, TWLTLs may not be appropriate on streets where the local planning agency wants to discourage strip commercial development. At such locations, provision of a raised or depressed median, together with local land use ordinances that require large lot sizes, may discourage strip commercial development (2).

Prohibit Left-Turn Maneuvers

A major source of undesirable driving behavior may be eliminated by prohibiting left-turn maneuvers at a divided highway intersection with a narrow median. Signing may be provided to prohibit left turns off the divided highway, left turns onto the divided highway, or both. Prohibition of

left turns will reserve the median opening area for vehicles making crossing maneuvers, and the reduction in the frequency of traffic movements through the median opening area should reduce the likelihood of encroachment by stopped vehicles on the through lanes, side-by-side queuing, and angle stopping. However, where such turn prohibitions are made, consideration must be given to the alternative routes available to drivers to reach their destinations, lest the problem merely be transferred to another location. The following discussions of indirect left-turn maneuvers and median U-turn roadways provide examples of techniques that can be used to provide alternate paths for left-turn movements.

Close Median Opening

Traffic operational and safety problems at a median opening with a narrow median may be mitigated simply by closing the median opening to prohibit all left-turn and crossing maneuvers at a particular location. Although this technique is obviously 100 percent effective at eliminating problems at the location in question, a careful analysis of the routes that will be used by the diverted traffic is required to assure that traffic operational delays are not substantially increased and that safety problems are not merely transferred to another location.

Reconfigure Median to Prohibit Crossing Maneuvers While Still Permitting Left Turns

A divided highway intersection with a narrow median can be channelized to prohibit crossing maneuvers while still permitting left turns from the divided highway. This mitigation technique is illustrated in Figure 18. The reduction in traffic volumes in the median opening area due to prohibition

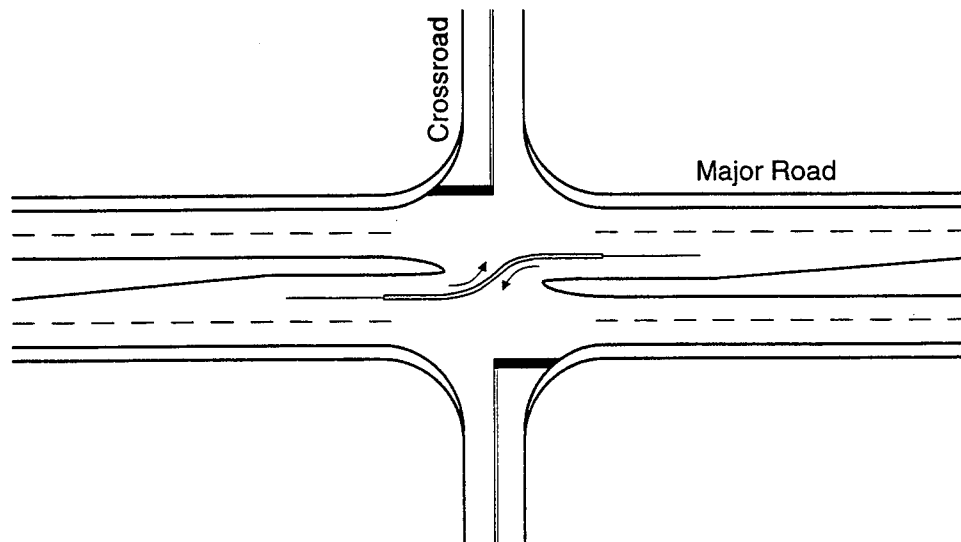
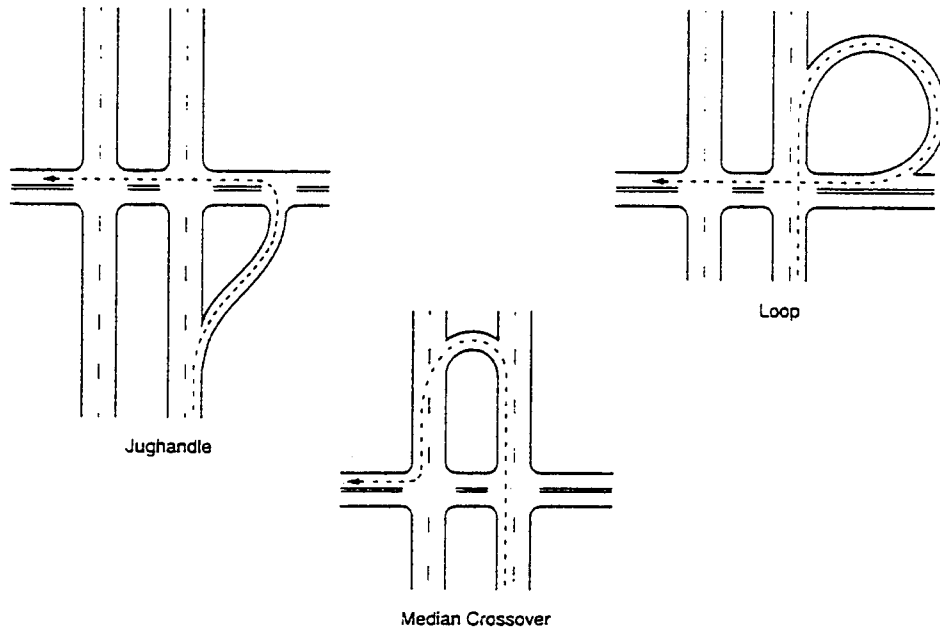


FIGURE 18 Median channelization to prevent movements through median except left turns off divided highway (14).

Indirect Left Turns from a Divided Highway



Indirect Left Turns onto a Divided Highway

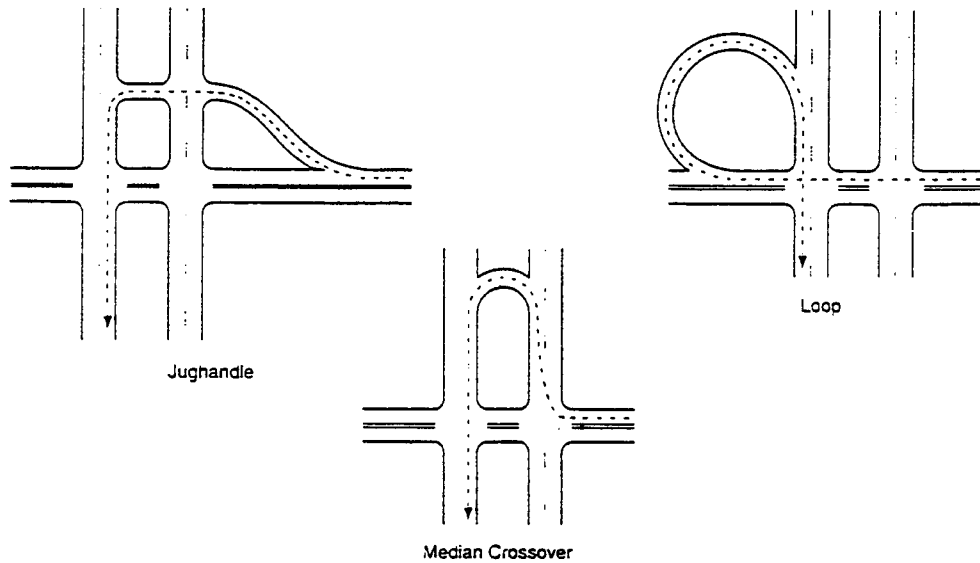


FIGURE 19 Examples of indirect left-turn and U-turn treatments for divided highway intersections (14).

of particular traffic movements and the separation by channelization of the traffic movements that are permitted can reduce traffic operational and safety problems related to undesirable driving behavior. The same concept can be used in other ways; for example, channelization can be used to allow only left turns onto the major roads as four-leg intersections or to prohibit certain movements at offset three-leg intersections. As with any mitigation technique that prohibits a particular traffic movement, consideration must be given to the alternate routes that will be used by the diverted traffic and the traffic operational and safety impacts on other locations. Design guidance for mitigation

techniques involving channelization can be found in NCHRP Report 279 (25).

Require Indirect Left-Turn Movements

An approach to implement left-turn maneuvers efficiently and effectively at divided highway intersections with narrow medians is to provide turning roadways for indirect left-turn movements. Three general types of indirect left-turn movements are illustrated in Figure 19: jughandles, loops, and median crossovers. Jughandles and loops are

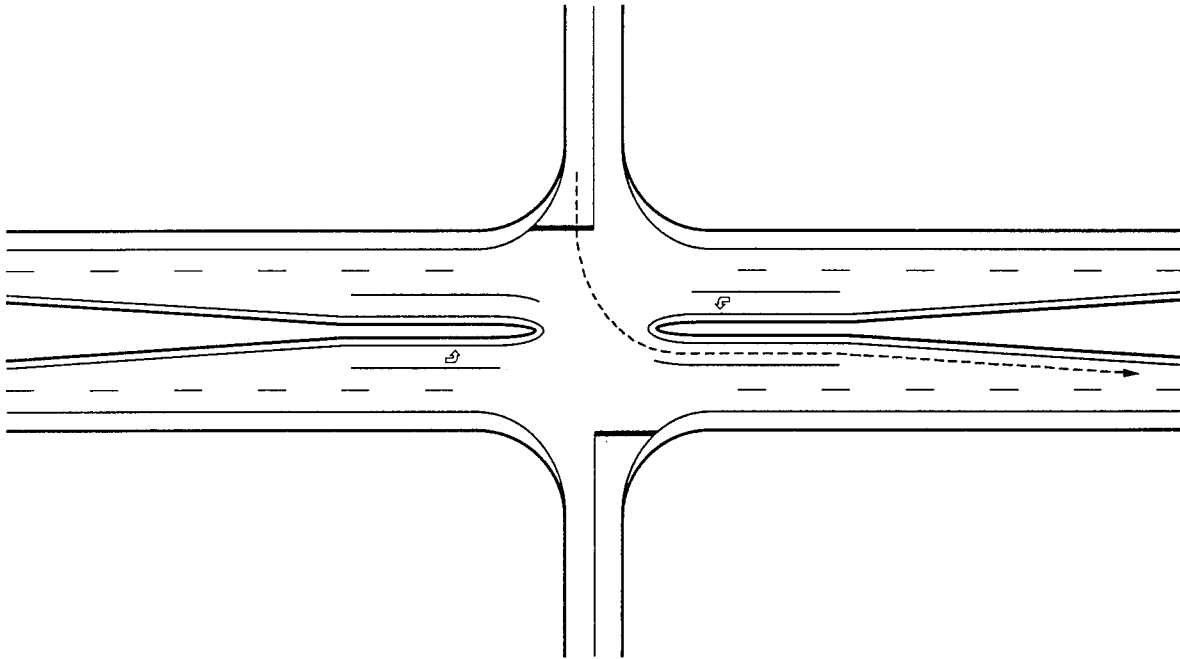


FIGURE 20 Typical four-leg divided highway intersection with median acceleration lanes (14).

used extensively by the New Jersey DOT so that all turns from a divided highway are made from the right lane of the major roadway. Median crossovers beyond the intersection are used extensively by the Michigan DOT to facilitate left turns onto and off a divided highway. These techniques are particularly appropriate at signalized intersections on a divided highway because they can reduce delay by allowing the main intersection to operate with simple two-phase signalization. Where the indirect left-turn volumes are high, signalization of the intersections of jughandles and median crossovers with the divided highway or crossroad may require signalization as well. The operation of such signalization for secondary movements can be coordinated with the primary signal.

Provide Median Acceleration Lanes

Encroachment on the through lanes of a divided highway with a narrow median is a particular problem when larger vehicles are forced to stop in the median opening area. One method of minimizing the likelihood that larger vehicles will be required to stop in the median opening area is to provide median acceleration lanes for left turns onto the divided highway, as shown in Figure 20. Median acceleration lanes normally allow vehicles turning left onto the divided highway to proceed without stopping except when other conflicting traffic is present in the median opening area at the same time. Furthermore, the acceleration lane permits larger vehicles, which accelerate slowly, to enter the through lanes of the divided highway at a higher speed. This should minimize the potential for collisions between through and turning vehicles. Figure 21 shows how a me-

diagonal acceleration lane can be used at a three-leg signalized intersection to avoid the need to signalize the through lanes in one direction of travel.

Extend Edgelines to Better Define Median Opening Area

Motorists may be more likely to stop their vehicles within the median opening area and avoid encroaching on the through lanes if the boundaries of the median opening area are visually well defined. This can be accomplished by extending the median edge lines of the divided highway as dashed lines across the median opening area, as illustrated in Figure 22.

Mark Double Yellow Centerline on Roadway in the Median Opening Area

Angle stopping can be discouraged by marking a double yellow centerline on the roadway in the median opening area to separate traffic in opposing directions of travel. Such a marking is equivalent to extending the centerline marking on the crossroad into the median opening area as illustrated in Figure 23. Marking of a double yellow centerline is generally recommended only for unsignalized intersections with median widths of 31 m (100 ft) or more (14).

Remove STOP Signs in Median

Another method of reducing the likelihood that larger vehicles will need to stop in the median opening area is to remove STOP signs in the median. The Federal Highway

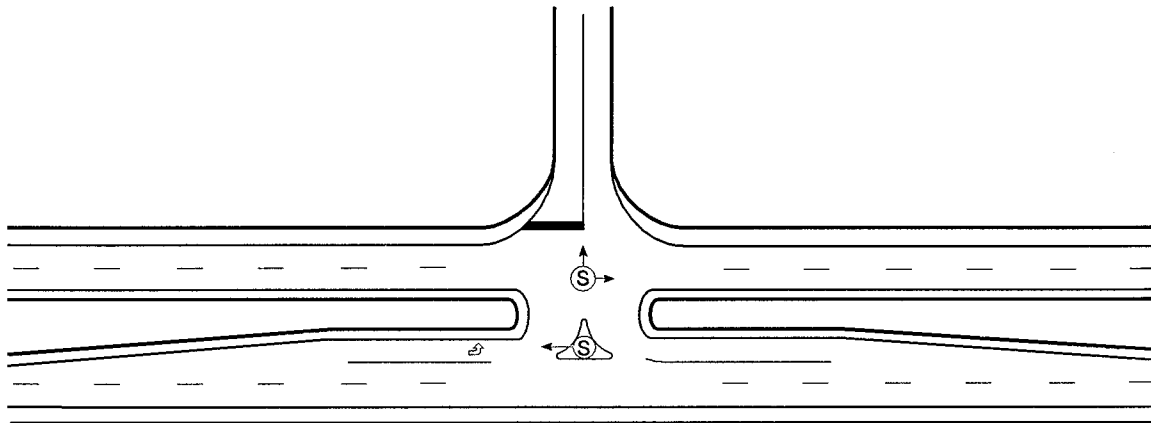


FIGURE 21 Three-leg divided highway intersection with median acceleration lane provided to eliminate the need for signalization of one direction of travel.

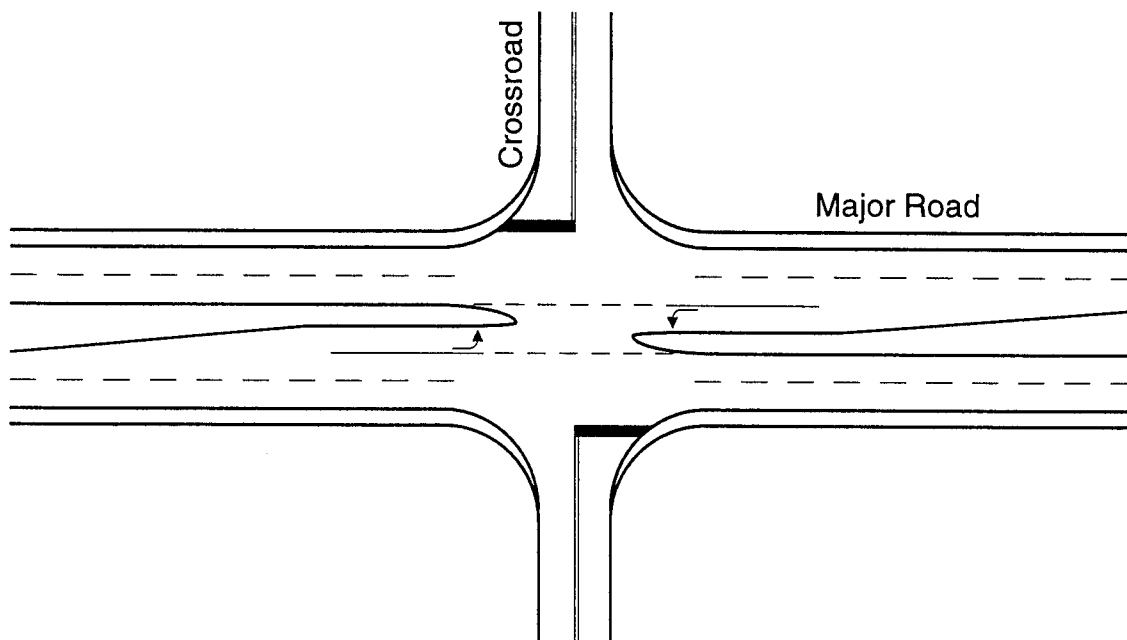


FIGURE 22 Extending edgelines across median to better define boundaries of median opening (14).

Administration Manual on Uniform Traffic Control Devices for Streets and Highways (26) presents alternative plans for signing of divided highway intersections using either STOP or YIELD signs in the median opening area for median widths of 9 m (30 ft) or more. NCHRP Report 375 (14) found that the actual practice of most highway agencies was to use no control in the median opening area for median widths up to 9 m (30 ft), to use YIELD control for median widths from 9 to 25 m (30 to 82 ft), and to use STOP control for median widths of 25 m (82 ft) or more. The use of STOP signs in the median opening area requires vehicles making crossing maneuvers or left-turn maneuvers onto a divided highway to stop in the median opening area even when no conflicting traffic is present in the far lanes of the divided highway. However, when the crossing or turning

vehicle is a truck, bus, or recreational vehicle, an unnecessary stop in the median opening area can leave the rear end of the vehicle encroaching on the near lanes of the divided highway and exposed to potential collisions with through traffic in those lanes. Highway agencies can eliminate the potential for such collisions by using no control or YIELD control at median openings with median widths of less than 25 m (82 ft) to eliminate unnecessary stops in the median opening area.

Install Traffic Signals

Installation of traffic signals at an existing unsignalized intersection can substantially reduce the potential for undesirable

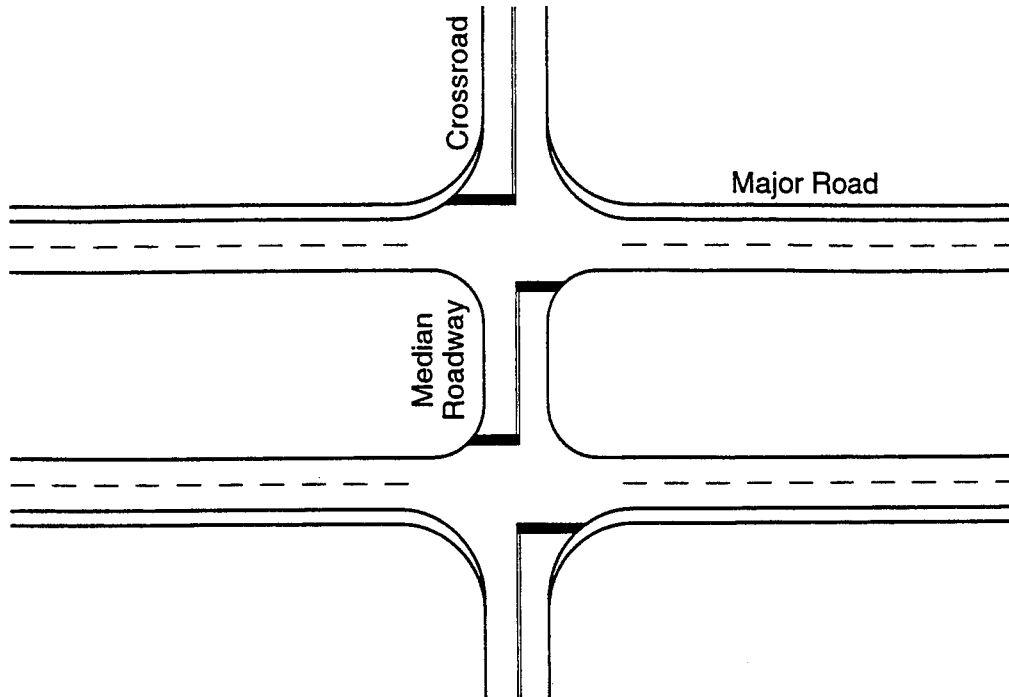


FIGURE 23 Recommended marking of the median roadway at a wide-median intersection with a two-lane crossroad (14).

driving behavior in the median opening area. Traffic signals separate conflicting movements in time and, therefore, reduce the number of vehicles in the median opening area at any one time and provide an opportunity for those vehicles to clear the median opening area either during or at the end of the signal phase. Larger vehicles may encroach on the through roadway of a divided highway when making a left turn onto a divided highway at a signalized intersection, but this occurs only during a signal phase when the through traffic on the divided highway is stopped. Traffic signals are most appropriate at urban and suburban locations; traffic signals are used at some locations in rural areas, but are less desirable because of high approach speeds. Installation of traffic signals at median openings should be considered only at locations where the *Manual on Uniform Traffic Control Devices* signal warrants are met (26).

Provide Protected Left-Turn Signal Phasing

The provision of a protected left-turn phase, either fully protected or with protected-permissive phasing, at a signalized intersection provides an opportunity for vehicles to complete left-turn maneuvers onto or off the divided highway without the need to stop in the median opening area. Fully protected left-turn phases allow all left-turn maneuvers to proceed with no conflicting traffic and with no need to stop in the median opening area. Protected-permissive operation provides full protection during a portion of the signal phase, but permits left turns to proceed (with

a potential that opposing traffic will require a vehicle to stop in the median opening area) during other portions of the phase.

Collisions Between Vehicles Turning Left from a Divided Highway and Other Same-Direction Vehicles

A common traffic safety problem at divided highway intersections involves collisions between vehicles turning left from the divided highway and other same-direction vehicles. Such collisions can occur between passenger cars and for any median width, but problems of this type are more likely when the turning vehicle is a larger vehicle and when the median is narrow.

The two most prevalent causes of such collisions are that turning conflicts may be unexpected by through motorists on the divided highway, because they do not realize that the intersection is present, and that large speed differences may be present between the turning and through vehicles.

The mitigation techniques that can be used to relieve the problem of collisions between vehicles turning from a divided highway and other same-direction through vehicles are as follows:

- Install advance intersection signing
- Install bigger signs
- Install better delineation

- Implement lower speed limits
- Implement advisory speeds on the major road
- Provide left-turn lanes on the major road
- Increase the deceleration and storage length of existing left-turn lanes
- Prohibit left turns from the major road
- Close the median opening
- Require indirect left-turn movements.

Each of these mitigation techniques is discussed here.

Install Advance Intersection Signing

One method of making drivers on the divided highway more aware of the presence of an intersection is to install advance signing. Either the intersection advance warning sign (*Manual of Uniform Traffic Control Devices* Codes W2-1), or advance guide signing with the name of the intersection street or road, or both, can be used for this purpose (26). This mitigation technique is intended to make motorists on the divided highway more aware of the presence of the intersection so that left turns by all types of vehicles, including larger vehicles, will be more expected.

Install Bigger Signs

Some divided highway intersections have advance signing in place, but the signs may not be large enough to be noticed by approaching motorists or may be located too close to the intersection. Approaching motorists may be more aware of the presence of the intersection if both the signs and their legends are made larger. Advance signing should also be placed sufficiently far in advance of the intersection, as indicated in the sign placement guidelines in *Manual of Uniform Traffic Control Devices* Section 2C-3 (26).

Install Better Delineation

Improved delineation may provide drivers with visual cues to help them better recognize the presence of an intersection on a divided highway. Methods of making intersections more evident to approaching motorists include marking curbs and channelizing islands with reflective paint, creating obvious breaks in delineator spacing at the intersection, creating obvious breaks in pavement markings at the intersection, and marking of stop bars on the pavement at signalized intersections.

Implement Lower Speed Limits

Another cause of collisions between left-turning and same-direction through vehicles at intersections on divided

highways is large speed differentials between through and turning vehicles. One technique that may have some effect on the speed differential is to lower the speed limit on the major-road approach to the intersection. However, such a changed speed limit should only be considered on the basis of an engineering study that finds that the existing speed limit is higher than the 85th percentile speed of traffic (26).

Implement Advisory Speeds on the Major Road

Another technique to limit speeds on the approach to an intersection is to post an advisory speed. The advisory speed for an intersection approach is typically signed on a supplementary plate displayed in conjunction with the advance intersection warning sign (W2-1) discussed previously. However, the effectiveness of advisory speeds for intersection approaches has not been clearly established.

Provide Left-Turn Lanes on the Major Road

Installation of separate left-turn lanes on the major road can help to reduce conflicts between through and turning vehicles by minimizing the need for vehicles to change speeds in the through lanes of the divided highway. Left-turn lanes include a deceleration length, so that drivers can leave the through lanes at a higher speed and decelerate to their turning speed (or, if necessary, to a stop) in a portion of the roadway protected from through traffic. Left-turn lanes also provide a storage area to allow left-turning vehicles to stop, when necessary, in a sheltered position not exposed to the risk of rear-end collisions with through vehicles. However, left-turn lanes can only be used when the median is wide enough to accommodate them. Typically, a median width of 4.3 to 4.9 m (14 to 16 ft) is considered necessary to accommodate a left-turn lane. Wider medians may allow left-turn lanes to be offset so that vehicles in the left-turn lanes in opposing directions of travel do not block their drivers' views of opposing traffic. The use of offset left-turn lanes is discussed in a later section.

Increase the Deceleration and Storage Length of Existing Left-Turn Lanes

Where left-turn lanes have been provided at an intersection on a divided highway, conflicts between left-turning and through vehicles may still occur if the deceleration and storage lengths within the left-turn lane are not adequate for current conditions. Inadequate deceleration length may cause left-turning vehicles to slow more than necessary before leaving the through lanes of traffic. Inadequate storage length may result in left-turning traffic

backing into the through lanes during some periods of the day and, therefore, being exposed to the risk of collisions with through vehicles approaching from the rear. These problems can be corrected by extending the left-turn lane to include increased deceleration and/or storage length. Extending the length of a left-turn lane may only be feasible where the highway median is sufficiently wide to accommodate the extended median. AASHTO policy provides guidance on the appropriate deceleration and storage lengths for left-turn lanes (1).

Prohibit Left Turns from the Major Road

The occurrence of collisions between vehicles turning left from a divided highway and same-direction through vehicles may be eliminated at a particular intersection by prohibiting left turns from the divided highway. However, consideration must be given to the alternate routes that will be used by drivers of left-turning vehicles to reach their destination or the problem may simply be transferred to another location.

Close the Median Opening

Left turns from the divided highway, and thus the potential for collisions between left-turn and same-direction vehicles, may be eliminated by closing the median opening. This effectively prohibits all left-turn and crossing maneuvers at the intersection or driveway. However, as noted previously, consideration must be given to the alternate routes that drivers who desire to turn left will use instead to reach their destination or the problem may simply be transferred to another location.

Require Indirect Left-Turn Movements

Where left turns are prohibited at an intersection, turning roadways may be used to provide a path for indirect left-turn movements. Figure 18 illustrates the provision for indirect left-turn movements by jughandles, loops, and median crossovers. Such indirect left-turn movements may reduce both the potential for collisions between through and turning vehicles and the delays to traffic at the intersection.

Collisions Between Left-Turning and Opposing Through Vehicles

Collisions between left-turning and opposing through vehicles are a common problem at divided highway intersections. This problem typically occurs at locations where a vehicle in the opposing left-turn lane blocks the

left-turning driver's view of opposing through vehicles. Without sufficient sight distance to opposing through traffic, left-turning drivers cannot decide when it is safe to proceed. This problem has been illustrated in Figure 17.

The mitigation techniques for this problem involve either offsetting the left-turn lanes to avoid the sight distance lockage, separating the left turn and opposing through movements in time, or prohibiting left turns. The following specific mitigation techniques are discussed here:

- Offset opposing left-turn lanes by moving them laterally within the median
- Provide protected left-turn signal phasing
- Prohibit left turns from the major road
- Close the median opening
- Require indirect left-turn movements.

Offset Opposing Left-Turn Lanes by Moving Them Laterally Within the Median

The problem of vehicles in opposing left-turn lanes at a divided highway intersection blocking their respective driver's view is common and can be particularly serious when one or both of the left-turning vehicles are larger, because larger vehicles block more of a driver's view than passenger cars. This problem can be solved by moving the left-turn lanes laterally within the median to increase their offset relative to one another and relative to the adjacent through lanes in the same direction of travel. Figure 24 illustrates two methods of accomplishing this: parallel offset left-turn lanes and tapered offset left-turn lanes. Offset left-turn lanes work because the vehicles in opposing left-turn lanes are moved to positions from which they no longer block the views of their respective drivers. NCHRP Report 375 (14) found that these techniques worked effectively and found no evidence of safety problems related to driver confusion about how to use offset left-turn lanes. Offset left-turn lanes can generally be provided only when the median of the divided highway is at least 12 m (40 ft) wide. Thus, where the existing median is less than 12 m (40 ft) in width, it may only be possible to provide offset left-turn lanes as part of a project that also widens the median.

Provide Protected Left-Turn Signal Phasing

The provision of a protected left-turn phase at a signalized intersection allows vehicles to complete left-turn maneuvers off the divided highway with minimal conflict with opposing through vehicles. Fully protected left-turn phases allow all left-turn maneuvers to proceed with no conflicts with opposing through vehicles. Protected-permissive

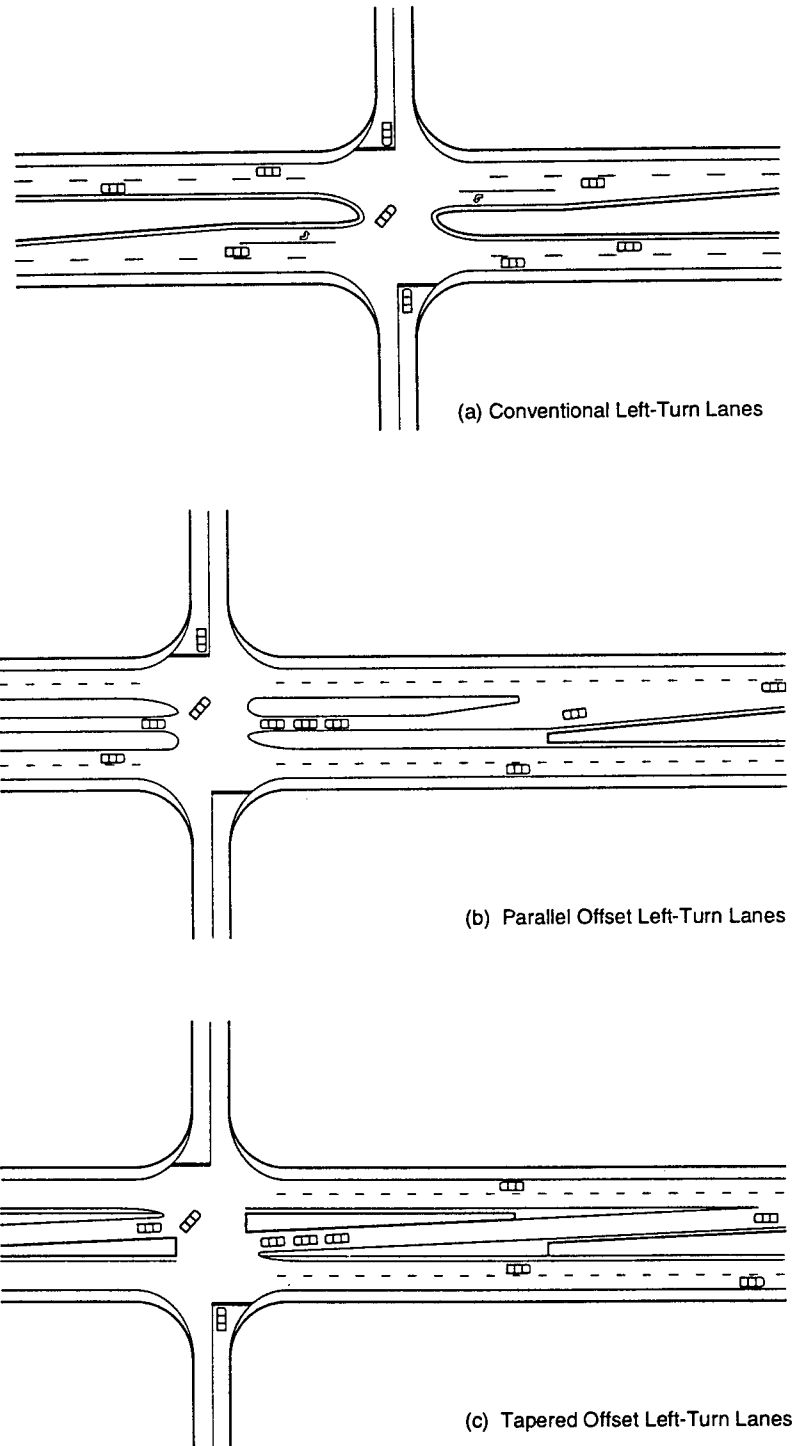


FIGURE 24 Layout of parallel and tapered offset left-turn lanes in comparison to conventional left-turn lanes (14).

operation provides full protection during a portion of the signal phase, but permits left turns to proceed (with a potential for conflicts with opposing left-turn vehicles) during the remainder of the signal phase. At intersections where offsetting the left-turn lanes is not feasible, installation of signals (if not already present) and provision of a

fully protected left-turn phase may accomplish the same goal. Signalization of an intersection that is currently unsignalized should be considered only where the *Manual of Uniform Traffic Control Devices* signalization warrants are met (26). Installation of unwarranted signals may unnecessarily increase delay to motorists.

Prohibit Left Turns from the Major Road

The problem of collisions between left-turning and opposing through vehicles can be mitigated by prohibiting left turns, either by signing or by closing the median opening at a particular intersection or driveway. As mentioned in preceding discussions of left-turn prohibitions, consideration must be given to the alternate routes that drivers desiring to turn left will use instead to reach their destination or the problem may simply be transferred to another location.

Close the Median Opening

Collisions between left-turning and opposing through vehicles at a specific location can be mitigated by closing the median opening. This effectively prohibits all left-turn and crossing maneuvers at the intersection or driveway. However, as noted previously, consideration must be given to the alternate routes that drivers who desire to turn left will use instead to reach their destination or the problem may simply be transferred to another location.

Require Indirect Left-Turn Movements

Where left turns are prohibited at an intersection, turning roadways may be used to provide a path for indirect left-turn movements. Figure 19 illustrates the provision for indirect left-turn movements by jughandles, loops, and median crossovers. As mentioned above, such indirect left-turn movements may reduce the potential for collisions between through and turning vehicles and the delays to traffic at intersections.

Collisions Between Vehicles Making U-Turns and Opposing Through Vehicles

Many of the preceding mitigation techniques that discourage or prohibit left-turn maneuvers by larger vehicles at particular intersections either encourage or require those larger vehicles to make U-turn maneuvers at another location. Denial of direct left-turn access by provision of raised or depressed medians (rather than flush medians or an undivided cross section), by prohibition of left turns at particular median openings, or by closing particular median openings, will usually lead to an increase in demand for U-turn maneuvers at other locations. Highway agencies should anticipate this U-turn demand either by providing median crossover roadways for U-turns or by assuring that other median openings with conventional left-turn lanes have appropriate geometrics for U-turn maneuvers by larger vehicles.

Mitigation techniques that encourage U-turn maneuvers at other locations should be considered carefully by

highway agencies. Collisions between vehicles making U-turns and opposing through vehicles may become a problem at locations where U-turn demand is increased by mitigation measures implemented elsewhere along the divided highway, because U-turn maneuvers have potentially higher safety risks than comparable left-turn maneuvers. Collisions involving U-turn maneuvers can result from the slow turning speed of larger vehicles making U-turns or the inability of larger vehicles to complete a U-turn maneuver in one swing.

Where mitigation techniques that encourage U-turn maneuvers at other locations are considered, care should be taken to assure that the sight distance is adequate to safely accommodate the U-turn maneuvers at the locations where they will be made.

Mitigation techniques where an accident pattern involving U-turn collisions develops are as follows:

- Reconstruct the highway with a wider median
- Add additional lanes to the divided highway
- Add paved/stabilized shoulder to allow larger vehicles to swing wider
- Provide median crossover roadways or indirect routes for U-turns
- Prohibit U-turn maneuvers
- Prohibit U-turn maneuvers by larger vehicles
- Close the median opening.

The mitigation techniques for safety problems related to U-turn maneuvers are supplementary techniques that can be considered to mitigate any problems created by the primary mitigation techniques discussed previously. Highway agencies were not actually surveyed about these supplementary techniques as part of this synthesis. Each of the mitigation techniques identified, however, is analogous to one of the primary techniques about which highway agencies were surveyed. Each of these mitigation techniques is discussed here.

Reconstruct the Highway with a Wider Median

Slow turning speeds in U-turn maneuvers or the inability to complete a U-turn maneuver in one swing can result because roadway geometrics require the vehicle making the U-turn to use too tight a turning radius. Figure 25 summarizes the roadway median requirements for larger vehicles to make U-turns. The turning radius can be increased by widening the median of the divided highway. The median width requirements in Figure 25 are based on U-turns from the through lanes of the divided highway. Where U-turns are made from a left-turn lane, the appropriate median width is the value shown in Figure 25 plus the left-turn lane width. As in the previous discussion of

this mitigation technique, the median can be widened either continuously along an entire corridor or at selected intersections where U-turns are likely.

TYPE OF MANEUVER		M - MINIMUM WIDTH OF MEDIAN - METERS FOR DESIGN VEHICLE						
		LENGTH OF DESIGN VEHICLE (m)						
		F	WB-17	SU	BUS	WB-15	WB-16	TDI
		5.7	15.0	9.0	12.0	16.5	19.5	25.4
INNER LANE TO INNER LANE		9	18	19	19	21	21	30
INNER LANE TO OUTER LANE		5	15	15	15	18	18	27
INNER LANE TO SHOULDER		2	12	12	12	15	15	24

FIGURE 25 AASHTO minimum median widths to accommodate U-turns (1).

Add Additional Lanes to the Divided Highway

The turning radius for U-turns can also be increased by adding additional lanes to the roadway of the divided highway into which the larger vehicle is turning. For example, a passenger car on a divided highway with a narrow median might have little difficulty making a U-turn into a roadway with two lanes, but this might be difficult or impossible for a larger vehicle. If the divided roadway were widened to three lanes in each direction of travel, however, larger vehicles might have no difficulty making U-turns. It is unlikely that U-turn demand alone would provide the justification for adding an additional lane to a divided highway but, where through traffic demands appear to justify adding an additional lane, U-turn requirements could provide further justification that could be critical in some cases, merely widening lanes rather than adding a new lane could make U-turn maneuvers easier.

Add Paved/Stabilized Shoulder to Allow Larger Vehicles to Swing Wider

The same effect as adding an additional travel lane can be achieved by providing a paved or stabilized shoulder on the outside of a divided roadway or by encouraging larger vehicles making a U-turn to use an existing paved shoulder.

Provide Median Crossover Roadways or Indirect Routes for U-Turns

Where U-turns are being made by larger vehicles at median openings with conventional left-turn lanes, safety problems may be mitigated by providing median crossovers at locations between intersections such as those shown in Figure 19. Such median crossovers are usually

directional in nature (i.e., designed for U-turns by vehicles from one direction of travel only), and the curved alignment of the crossover can assist larger vehicles in completing their U-turn. Other indirect routes can also be provided to increase the radii available to larger vehicles in making U-turn maneuvers. For example, Figure 26 illustrates the provision of jughandles for U-turns at locations where a narrow median precludes the provision of a median crossover roadway.

Prohibit U-Turn Maneuvers

Where accident patterns involving U-turn maneuvers develop, one mitigation technique is, of course, to prohibit U-turn maneuvers at that particular location. However, in such cases, consideration must be given to the alternate routes that will be used by those U-turning vehicles to reach their destination or the problem may simply be transferred to another location.

Prohibit U-Turn Maneuvers by Larger Vehicles

Another potential mitigation technique is to prohibit U-turn maneuvers by larger vehicles, but to permit passenger cars to make U-turns. There may, indeed, be locations where most drivers of larger vehicles avoid making a U-turn, but the few who try encounter problems. It is also desirable to avoid restricting passenger cars from U-turn maneuvers they can complete safely simply because a sufficient turning radius for larger vehicles is not available.

Close the Median Opening

If an accident pattern related to U-turn maneuvers cannot be eliminated in any other way, one option is to close the median opening. This, of course, prohibits all turning and crossing maneuvers through the median opening, not just U-turn maneuvers, so it should generally be considered only when a serious problem is present that cannot be corrected in any other way. Consideration must be given to the alternate routes that will be used by those U-turning vehicles to reach their destination or the problem may simply be transferred to another location.

DESIGN TECHNIQUES

The preceding discussion has focused on techniques for mitigating problems that develop related to maneuvers by larger vehicles on divided highways with narrow medians. Attention should also be given in the design of new divided highways or in major reconstruction projects to avoid introducing such problems in the first place. Design

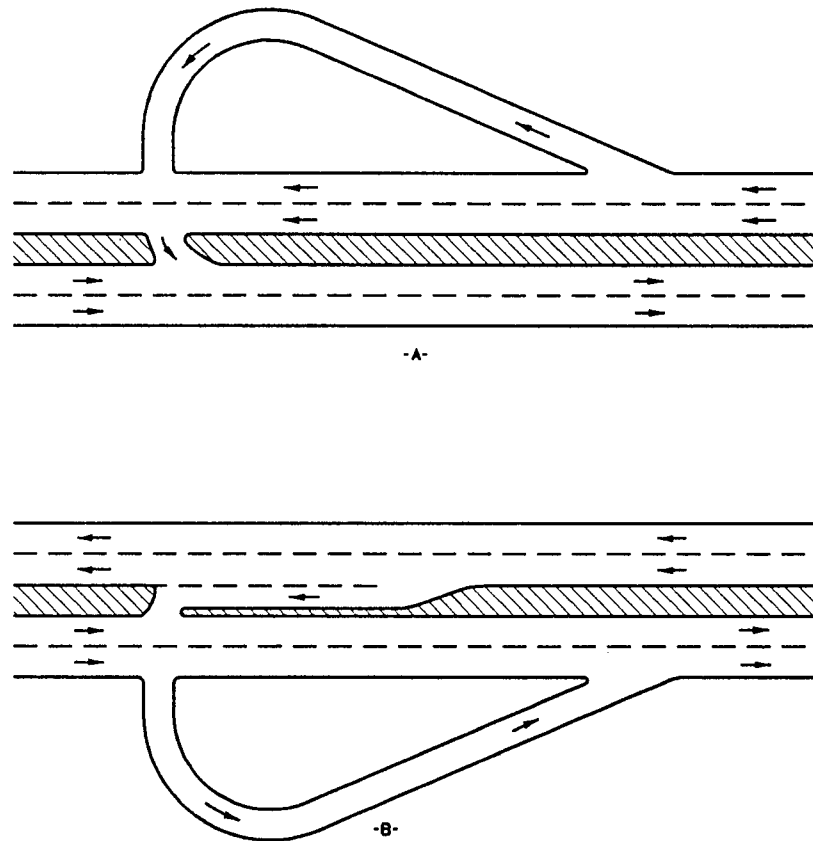


FIGURE 26 Special indirect U-turn jughandles used with narrow medians (1).

techniques to avoid problems related to larger vehicles and narrow medians can be described as follows:

- Careful study should be put into the selection of the design vehicle for a particular project from among the AASHTO design vehicles in Table 18. The choice of the design vehicle should be related to the actual mix of traffic expected to use the site. At some locations where a side road or driveway serves a facility that generates substantial truck traffic, it may be justified to use a different design vehicle for the selection of median width and design of the median opening area than is used for the project as a whole. Both the length and the turning radius of the selected design vehicle should be considered in the design of the divided highway facility.
- NCHRP Report 375 (14) found that safety at intersections on rural divided highways increases with increasing median width. The report, therefore, recommends that medians on rural divided highways should be as wide as possible. For this reason, if sufficient right-of-way is available, the provision of a median wide enough to store any specific design vehicle is likely to provide safety benefits.
- On urban and suburban divided highways, NCHRP Report 375 recommends that medians should not generally be wider than necessary to accommodate current and anticipated left-turn treatments. However, the report indicates that a wider median may be considered where larger vehicles are likely to make frequent turning or crossing maneuvers through the median opening area.
- Where any design or traffic control feature that restricts left or U-turns is provided (including raised or depressed medians, turn prohibitions, and closure of median openings) consideration should be given to the routes that will be used by those left- or U-turning vehicles to reach their destination or the problem may simply be transferred to another location. This involves consideration of the destinations of the vehicles being diverted and the alternate routes that may be used to reach those designations.
- Indirect routes involving turning roadways provided for left and U-turns, including jughandles, loops, and median crossovers like those shown in Figures 19 and 25 should be considered.

CONCLUSIONS

This chapter presents conclusions developed from the synthesis concerning traffic operational and safety problems encountered by larger vehicles at intersections and driveways on divided highways with narrow medians.

Larger vehicles, including trucks, buses, and RVs frequently encounter difficulty in traveling through the median opening area at intersections and driveways on divided highways with narrow medians. A survey of highway agencies found that 63 percent of state highway agencies and 26 percent of local highway agencies that responded had encountered traffic operational or safety problems related to larger vehicles on highways with narrow medians. Of the state highway agencies that responded to the survey, 65 percent indicated that they had experienced problems related to larger vehicles and narrow medians on rural divided highways and 85 percent indicated that they had encountered such problems on urban/suburban divided arterials.

Concerns or complaints from the trucking industry about difficulties encountered on divided highways with narrow medians were reported by 34 percent of state highway agencies and 17 percent of local highway agencies. Traffic operational and safety problems at intersections or driveways with narrow medians were reported most often concerning combination trucks (e.g., tractor-semitrailers). Traffic operational and safety problems were reported to be common, but less frequent, for school buses, single-unit trucks, RVs, and local transit buses. Intercity buses rarely encountered such problems. Traffic operational and safety problems were reported very frequently at unsignalized intersections on divided highways and commonly, but less frequently, for driveways with median openings, driveways without median openings, and intersections with signals.

Highway agencies currently use a broad range of cross sections for rural, suburban, and urban arterial highways including individual roadways, roadways divided by center TWLTLs, and roadways divided by raised or depressed medians. Each of these cross sections has advantages and disadvantages that have been summarized in this synthesis. Cross sections divided by raised or depressed medians minimize delays to through traffic on the divided highway because left turns onto or off the highway are permitted only where median openings are provided. Roadways with raised or depressed medians are also consistent with local land-use planning intended to limit strip commercial development

on many arterials; the presence of a raised or depressed median with limited median openings may make an arterial highway less attractive to strip commercial development.

Conversely, the denial of direct left-turn access to driveways or minor intersections where median openings are not provided can increase delays to traffic with destinations not located at a median opening. Vehicles that would turn left but for the presence of the median may require extra travel time to reach a median opening where a U-turn can be made further downstream on the arterial and then to return to their destination, or may choose some other indirect route requiring more time to reach their destination. Such U-turn maneuvers and indirect routings can be a source of delays and accidents involving larger vehicles.

Median widths used by highway agencies on divided arterials in both rural and urban/suburban arterials vary widely. AASHTO geometric design policies specify a minimum median width of 1.2 m (4 ft) for divided arterials, but most divided highways have wider medians and such wider medians are desirable to accommodate larger vehicles.

A recent survey of highway agencies found that minimum median widths ranged from 1 to 20 m (3 to 64 ft) on rural divided highways and from 0.3 to 9 m (1 to 30 ft) on urban/suburban divided arterials. The same survey found that desirable median widths ranged from 5 to 26 m (18 to 84 ft) on rural divided highways and from 3 to 20 m (9 to 64 ft) on urban/suburban divided highways.

A survey of highway agencies conducted for this synthesis found that highway agency assessments of minimum median widths to accommodate larger vehicles ranged from 1.2 to 38 m (4 to 125 ft) for rural divided highways and 0.6 to 31 m (2 to 100 ft) for urban/suburban divided arterials. This shows a broad range of opinion among highway agencies, with some agencies believing that nearly any median width can adequately accommodate larger vehicles, whereas others believe that only medians that are wider than the longest vehicle are sufficient.

Recent research has recommended that median widths at unsignalized intersections on rural divided highways should be as wide as possible (14). No traffic safety problems were found at rural divided highway intersections with medians of up to 44 m (144 ft) in width, so long as both roadways of the divided highway were visible to motorists

on the minor-road approaches to the intersection. Thus, where larger vehicles frequently use intersections on rural divided highways, provision of a median wide enough to store those larger vehicles is desirable.

At unsignalized intersections on urban/suburban divided highways, the same research has shown that traffic operational and safety problems may develop if the median is unnecessarily wide. The research has recommended that medians at such intersections be only as wide as necessary to accommodate current and planned left-turn treatments. However, at intersections used frequently by larger vehicles, it may be desirable to choose a median width sufficient to store a selected design vehicle with adequate clearance to the through lanes of the divided highway at both ends of the vehicle.

Research has shown that at signalized intersections on divided highways the median width should be kept to a minimum to limit traffic operational delays, unless the median is so wide that the two roadways of the divided highway operate with separate signals. Thus, the median width should be kept to the minimum necessary to accommodate current or planned left-turn treatments. There would be no need to make the median wider to accommodate any particular larger vehicle because it should not be necessary to store larger vehicles in the median at signalized intersections past the end of any given signal phase.

The following types of traffic operational and safety problems are encountered by larger vehicles at intersections and driveways on divided highways with narrow medians:

- Encroachment on through lanes by larger vehicles stopped in the median
- Left-turn maneuvers by larger vehicles entering the highway
- Inadequate storage space in the median opening area
- Maneuvers by larger vehicles crossing the highway
- Left-turn maneuvers by larger vehicles leaving the highway
- U-turn maneuvers by larger vehicles
- Inadequate storage length in left-turn lanes
- Restricted sight distance due to opposing left-turn vehicles
- Use of indirect routes to reach destinations with no median opening
- Use of indirect routes to reach destinations where a median opening is provided but the median is too narrow to accommodate larger vehicles.

This synthesis identifies a number of alternative improvement techniques that can be used by highway agencies to minimize or eliminate the traffic operational and safety problems encountered by larger vehicles. These mitigation techniques include:

- Reconstructing the highway with a median wider than the existing median
- Reconstructing the highway with a median wider than the existing median at selected intersections
- Reconstructing the highway with a median narrower than the existing median
- Removing the median
- Removing a raised or depressed median and replacing it with a flush median
- Prohibiting left-turn maneuvers
- Closing the median opening
- Reconfiguring the median to prohibit crossing maneuvers while still permitting left turns
- Requiring indirect left-turn movements
- Providing median acceleration lanes
- Removing STOP signs in the median
- Installing traffic signals
- Providing protected left-turn signal phasing
- Installing advance signing
- Installing bigger signs
- Installing better delineation
- Implementing lower speed limits
- Implementing advisory speeds on the major road
- Providing left-turn lanes on the major road
- Increasing the deceleration and storage length of existing left-turn lanes
- Offsetting opposing left-turn lanes by moving them laterally within the median
- Adding additional lanes to the divided highway
- Adding paved/stabilized shoulders to allow trucks to swing wider when making a U-turn
- Providing median crossover roadways or indirect routes for U-turns
- Prohibiting U-turn maneuvers
- Prohibiting U-turn maneuvers by larger vehicles.

The circumstances under which each of the mitigation techniques is appropriate have been discussed in chapter 4. Table 27 relates the traffic operational and safety symptoms of divided highway intersections to these mitigation techniques.

This synthesis also identifies design techniques that can be used in new construction or reconstruction projects to avoid introducing traffic operational and safety problems.

Highway agencies have a wealth of experience with projects involving alternative median treatments, including raised medians, TWLTLs, and undivided roadways. However, it is clear that site-specific factors play an important role in the choice among alternative median treatments and that these site-specific factors are not well understood. Furthermore, none of the basic research on cross sections for urban/suburban arterials, an important element of arterial access management, gives more than

cursory attention to the role of trucks in selecting an appropriate cross section. Further research on this issue should be encouraged.

A major disadvantage of access control treatments involving provisions of raised medians or the closing of existing median openings is that drivers who desire to

turn left are instead required to make U-turns at downstream median openings or to use alternative routes to reach their destinations. There are no generalized methods to quantify the expected delay to turning traffic (i.e., the additional travel time required to use an alternate route) or the safety effects of the U-turn maneuvers for use in the process of comparing and selecting design alternatives.

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APPENDIX A

Results of Highway Agency Survey

A survey of state and local highway agencies was conducted as part of the preparation of this synthesis. The purpose of the survey was to determine highway agency traffic operational and safety experience with truck operations on divided highways and divided arterial streets with narrow medians.

The survey was conducted by means of a questionnaire that was sent to all 50 state highway agencies and to 100 selected local (city and county) highway agencies. For state highway agencies, the questionnaire was directed to the Transportation Research Board representative in each state with a request that the questionnaire be forwarded to the agency's design or traffic operations staff. For local highway agencies, the questionnaires were sent to selected members of the Institute of Transportation Engineers Urban Traffic Engineering Council. The questionnaire was sent to at least one local agency engineer in each state and up to seven local agency engineers in larger states. The local agency questionnaire focused on urban/suburban highway agencies, because most divided highways in rural areas are under state rather than local jurisdiction.

The questionnaire used for the survey is presented at the end of this appendix.

RESPONSE RATE

Responses were received from 32 of the 50 state highway agencies (64 percent) and 23 of the 100 selected local highway agencies (23 percent). The response rate from state highway agencies was good, but not as high as hoped. Experience with similar surveys shows that response rates from local highway agencies are usually much lower than from state highway agencies.

OPERATIONAL OR SAFETY PROBLEMS RELATED TO NARROW MEDIANS

Question 1 of the survey asked whether each agency had encountered traffic operational or safety problems related to divided highways or streets with medians that are too narrow or are otherwise unsuited to accommodate larger vehicles (e.g., trucks and buses). The responses to this question are tabulated in Table A-1. Twenty of the 32 state highway agencies responding to the questionnaire (63 percent)

indicated that they had encountered traffic operational or safety problems related to truck operations on highways or streets with narrow medians. Thirteen of these 20 agencies (65 percent) indicated that they had encountered such problems on rural divided highways and 17 of the 20 agencies (85 percent) had encountered such problems on urban/suburban arterials. In general, larger and more urbanized states were more likely to indicate that they had encountered truck-related operational or safety problems on roads with narrow medians, whereas smaller, less urbanized states generally had not encountered such problems. However, this trend was not universal, as a few large, urbanized states indicated that they had not encountered such problems. The 20 state agencies that had experienced problems are located throughout the United States, so there is no particular regional character to the distribution of such perceived problems.

TABLE A-1
HIGHWAY AGENCY RESPONSES ON TRAFFIC OPERATIONAL OR SAFETY PROBLEMS RELATED TO NARROW MEDIANS

Traffic Operational or Safety Problems Related to Narrow Medians?	State Highway	Local Highway
Yes	20 (62.5)	6 (26.1)
No	12 (37.5)	17 (73.9)
Total	32	23

Note: Percentages shown in parentheses.

Only 6 of the 23 local agencies (26 percent) responding to the questionnaire indicated that they had encountered traffic operational or safety problems. These problems all occurred on urban/suburban arterial highways because the local agencies surveyed were all located in urban areas. These six local agencies are located in several different regions of the United States (Southeast, Midwest, and West), so there does not appear to be any particular regional character to these problems.

The responses to question 1 indicate that many, but not all, state highway agencies have experienced traffic operational and safety problems related to larger vehicles on divided highways or streets with narrow medians. Such problems have been encountered both on rural divided highways and urban/suburban arterial streets, although more agencies reported problems on arterial streets than on rural highways.

TABLE A-2

TYPES OF PROBLEMS RELATED TO LARGER VEHICLES AND NARROW MEDIANS EXPERIENCED BY HIGHWAY AGENCIES

Type of Problem	Agencies Reporting the Problem ¹
Left-turn maneuvers by larger vehicles leaving the highway	16 (61.5)
Left-turn maneuvers by larger vehicles entering the highway	19 (73.1)
Maneuvers by larger vehicles crossing the highway	17 (65.3)
U-turn maneuvers by larger vehicles	15 (57.7)
Inadequate storage length in left-turn lanes	15 (57.7)
Inadequate storage space in the median opening area	19 (73.1)
Encroachment on through lanes by larger vehicles stopped in the median	21 (80.8)
Restricted sight distance due to opposing left-turn vehicles	15 (57.7)
Use of indirect routes to reach destinations with no median opening	7 (26.9)
Use of indirect routes to reach destinations with a median opening but restricted median width	5 (19.2)

¹Percentages (shown in parentheses) are based on the total of 26 highway agencies that reported traffic operational and safety problems related to larger vehicles and narrow medians.

CONCERNS OR COMPLAINTS FROM THE TRUCKING INDUSTRY OR BUSINESSES

Question 2 of the survey asked highway agencies whether they had encountered concerns or complaints from the trucking industry or from businesses that truckers serve about access difficulties associated with narrow medians. This question was posed because, even if highway agencies have not encountered traffic operational or safety problems associated with larger vehicles and narrow medians, it is possible that truckers are encountering difficulties in entering particular business establishments. It is also possible that traffic operational and safety problems are being avoided because truckers use indirect routes to their destination to avoid making a turning or crossing maneuver through a narrow median.

Concerns or complaints from the trucking industry were reported by 11 of the 32 state highway agencies that responded to the survey (34 percent). All 11 of the state agencies that reported trucking industry concerns or complaints also reported traffic operational or safety problems in response to question 1. Stated another way, these results indicate that 11 of the 20 state highway agencies (55 percent) that reported traffic operational and safety problems also reported concerns or complaints from the trucking industry. The respondents in three additional state highway agencies indicated that they thought there had been industry complaints about isolated locations, but they had no specific knowledge.

Four of the 23 local highway agencies that responded to the survey (17 percent) reported trucking industry concerns or complaints. These four local agencies were among the six agencies that reported traffic operational and safety problems in response to question 1.

The specific trucking industry concerns and complaints that were noted by highway agencies are as follows:

- Insufficient space for trucks to stop in the median without encroaching on through traffic lanes (five agencies),
- Difficulty in accessing businesses on the opposite side of the road because of the difficulty of making U-turns or the limited number of locations where U-turns are possible (four agencies),
- Difficulty in finding breaks in traffic for trucks to make turning or crossing movements (three agencies), and
- General industry opposition to any raised median that hinders turning movements (one agency).

The remainder of the questionnaire analysis focuses on the 26 survey responses (20 from state highway agencies and 6 local highway agencies) that indicated that traffic operational or safety problems related to larger vehicles and narrow medians had been encountered.

TYPES OF PROBLEMS EXPERIENCED BY HIGHWAY AGENCIES

Question 3 asked highway agencies about the types of problems they had encountered related to larger vehicles and narrow medians. Table A-2 summarizes the responses of the 26 highway agencies that reported experiencing traffic operational and safety problems. The most common problem, reported by 81 percent of highway agencies that had experienced problems, was encroachment on through lanes by larger vehicles stopped in the median. The second and third most common problems were inadequate storage space in the median opening area and left-turn maneuvers by larger vehicles entering the highway, both reported by 73 percent of highway agencies. Each of these problems is related to narrow median widths that do not provide sufficient space in a median opening area to store a large vehicle, or a large vehicle as well as other vehicles, making

turning or crossing maneuvers. Other problems reported by 50 percent or more of these highway agencies included maneuvers by larger vehicles crossing the highway, left-turn maneuvers by large vehicles leaving the highway, U-turn maneuvers by larger vehicles, inadequate storage length in left-turn lanes, and restricted sight distance due to opposing left-turn vehicles.

Two other problems that were reported less frequently by highway agencies were use of indirect routes to reach destinations with no median opening and use of indirect routes to reach destinations with a median opening but restricted median width. These problems were reported by 27 percent and 19 percent of highway agencies, respectively. However, these are problems that may be encountered by truckers without necessarily coming to the attention of highway agencies.

No other traffic operational and safety problems specifically related to large vehicles and narrow medians were reported by highway agencies.

TYPES OF LARGER VEHICLES THAT ENCOUNTER PROBLEMS

Question 4 asked highway agencies which vehicle types have encountered problems related to narrow medians. Table A-3 summarizes the highway agency responses to this question. All but 1 of the 26 highway agencies that had reported traffic operational and safety problems related to larger vehicles and narrow medians (96 percent) reported that combination trucks, such as tractor-semi-trailers, had encountered such problems. All other vehicle types were identified by less than one-half of these highway agencies. The second most frequently cited vehicle type was school buses (42 percent). Other vehicle types noted by highway agencies were single-unit trucks (35 percent), recreational vehicles (27 percent), local transit buses (19 percent),

TABLE A-3
TYPES OF LARGER VEHICLES THAT ENCOUNTER PROBLEMS RELATED TO NARROW MEDIANS

Types of Larger Vehicles	Agencies Reporting Problems Encountered by This Vehicle Type ¹
Single-unit trucks	9 (34.6)
Combination trucks (e.g., tractor-semitrailers)	25 (96.2)
Intercity buses	2 (7.7)
Local transit buses	5 (19.2)
School buses	11 (42.3)
Recreational vehicles (e.g., motor homes)	7 (26.9)

¹Percentages (shown in parentheses) are based on the total of 26 highway agencies that reported traffic operational and safety problems related to larger vehicles and narrow medians.

and intercity buses (8 percent). It is clear from these results that the overwhelming majority of traffic operational and safety problems are related to combination trucks, although school buses and smaller trucks are also a concern.

TYPES OF LOCATIONS WHERE PROBLEMS HAVE BEEN ENCOUNTERED

Question 5 asked highway agencies to identify the types of locations where traffic operational and safety problems involving larger vehicles and narrow medians have been encountered. Table A-4 summarizes the highway agency responses to this question. The most common type of location at which problems were encountered was unsignalized intersections, where problems were noted by 81 percent of highway agencies. Traffic operational and safety problems related to narrow medians were also noted at driveways with median openings (65 percent), signalized intersections (58 percent), and driveways without median openings (50 percent).

TABLE A-4
TYPES OF LOCATIONS WHERE PROBLEMS INVOLVING LARGER VEHICLES AND NARROW MEDIANS HAVE BEEN ENCOUNTERED

Types of Locations	Agencies Reporting Problems at This Location Type ¹
Signalized intersections	15 (57.7)
Unsignalized intersections	21 (80.8)
Driveways with median openings	17 (65.3)
Driveways without median openings	13 (50.0)

¹Percentages (shown in parentheses) are based on the total of 26 highway agencies that reported traffic operational and safety problems related to larger vehicles and narrow medians.

VARIATIONS OF PROBLEMS BY TIME OF DAY

Question 6 asked highway agencies whether traffic operational and safety problems encountered by large vehicles related to narrow medians vary by time of day. Only 7 of the 26 highway agencies that had experienced traffic operational and safety problems (27 percent) indicated that these problems varied by time of day. The traffic operational and safety problems observed by the other agencies were not limited to any specific time of day. One agency noted that these problems vary by time of day in urban areas, but not in rural areas.

The time of day at which the seven agencies indicated that problems had occurred are summarized in Table A-5. The table indicates that five of these seven agencies (71 percent) had observed problems in the morning peak hour. A slightly different set of five agencies (71 percent) observed problems in the evening peak hour. Problems during daytime off-peak periods were observed by two of the

TABLE A-5
TIMES OF DAY AT WHICH PROBLEMS RELATED TO LARGER VEHICLES AND NARROW MEDIANS OCCUR

Times of Day	Agencies That Indicate Problems Occur at Particular Times of Day ¹
Morning peak hour	5 (71.4)
Evening peak hour	5 (71.4)
Daytime off-peak	2 (28.6)
Nighttime	0 (0.0)

¹Percentages (shown in parentheses) are based on the seven highway agencies that indicated traffic operational and safety problems vary by time of day.

seven agencies (29 percent). None of the seven agencies reported problems at night. One agency noted late Sunday afternoon and evening as times when traffic operational and safety problems are encountered by RVs.

MEDIAN WIDTH TO ACCOMMODATE LARGER VEHICLES

Question 7 asked highway agencies the median width they consider too narrow to adequately accommodate large vehicles. This is essentially equivalent to asking for the minimum median width that can adequately accommodate larger vehicles.

The highway agency responses to this question are summarized in Table A-6, both for rural divided highways and for urban/suburban divided arterials. All 15 responses for rural divided highways are from state highway agencies, whereas the 20 responses for urban/suburban divided arterials include 14 state agencies and 6 local agencies.

TABLE A-6
HIGHWAY AGENCY ASSESSMENTS OF MINIMUM MEDIAN WIDTH TO ACCOMMODATE LARGER VEHICLES

Descriptive Statistics	Minimum Median Width (ft)	
	Rural Divided Highways	Urban/Suburban Divided Arterials
Minimum	4	2
Maximum	125	100
Mean	58	33
15th percentile	25	12
25th percentile	30	16
Median (50th percentile)	60	25
75th percentile	70	60
85th percentile	80	60
Number of responses	15	20

This table shows that the recommended median widths for rural divided highways range from 1.2 to 38 m (4 to 125 ft). The 1.2-m (4-ft) minimum response was from a state highway agency that generally does not permit left turns from divided highways, but rather provides indirect paths for left turns (jughandles or loops). The mean width

of the responses was 17.7 m (58 ft), whereas the median response was 18.3 m (60 ft). The range of median widths from the 25th to 75th percentiles is 9.2 to 21 m (30 to 70 ft), which includes most current rural median design practice.

The recommended median widths for urban/suburban divided arterials range from 0.6 to 31 m (2 to 100 ft). The 0.6-m (2-ft) minimum response was from the state that does not generally permit direct left turns from divided arterials. The mean of the responses was 10 m (33 ft), whereas the median response was 7.6 m (25 ft). The range of median widths from the 25th to 75th percentiles is 4.9 to 18 m (16 to 60 ft), which includes most current urban/suburban median design practices. Two state highway agencies indicated that they use wider medians (equivalent to rural divided highways) in suburban areas and reserve the narrower medians noted in the table for divided arterials under urban conditions only.

SPECIFIC ACCIDENT PATTERNS OBSERVED

Question 8 asked highway agencies whether the problems they had noted resulted in any specific observed accident patterns. In response, 12 of the 26 agencies that had observed problems (46 percent) indicated that these problems had resulted in specific observed accident patterns. Ten of the 12 agencies indicated that they had taken specific steps to mitigate the observed accident patterns. Table A-7 presents the accident patterns that were observed by the responding agencies and the mitigation measures they noted.

MITIGATION MEASURES USED

To obtain more information on specific mitigation measures used by highway agencies in response to traffic operational and safety problems, question 9 asked respondents to identify which of a list of mitigation measures they had used. Table A-8 summarizes the frequency with which particular mitigation measures were used by the responding highway agencies. Where question 8 dealt with mitigation measures in response to accident patterns, question 9 addresses mitigation measures in response to either traffic operational or safety problems.

REPRESENTATIVE PROJECTS

Question 10 asked highway agencies to describe their experience with any of the changes/improvements identified in their responses to question 9 and to provide plans or sketches for any representative improvement projects. Only three agencies made statements about the effectiveness of their improvement projects:

TABLE A-7

ACCIDENT PATTERNS OBSERVED BY HIGHWAY AGENCIES AT NARROW MEDIAN INTERSECTIONS AND MITIGATION MEASURES USED

Accident Patterns	Mitigation Measures
Higher than average concentration of accidents at intersections and median openings (5 agencies)	Installed bigger signs Installed better delineation Implemented lower speed limits Used wider medians in rural areas Removed STOP signs in median Installed traffic signals Replaced intersection with interchange
Collisions between through vehicles and vehicles in median encroaching on through lanes (2 agencies)	Closed median opening Paved grass medians to provide two-way left-turn lanes
Collisions between left-turning and opposing through vehicles (2 agencies)	Offset opposing left-turn lanes by removing median Installed protected left-turn phases at signals
Collisions between U-turn and opposing through vehicles because of inability of trucks to complete the U-turn maneuver in one swing (2 agencies)	Prohibited U-turn maneuvers by larger vehicles Add stabilized shoulder to allow trucks to swing wider Closed median openings, particularly in sag vertical curves
Rear-end collisions in through lanes (1 agency)	Added deceleration lanes
Damage to KEEP RIGHT signs on ends of medians (1 agency)	Increased radius by reconstructing median noses

TABLE A-8

HIGHWAY AGENCY USE OF SPECIFIC MITIGATION MEASURES FOR TRAFFIC OPERATIONAL PROBLEMS RELATED TO LARGER VEHICLES AND NARROW MEDIANS

Mitigation Measures	Agencies Using This Mitigation Measure ¹
Reconstruct highway with wider median	4 (15.4)
Reconstruct highway with wider median only at selected intersections	7 (26.9)
Remove median	7 (26.9)
Remove median and replace with flush median	13 (50.0)
Provide left-turn lanes	19 (73.1)
Provide offset left-turn lanes	10 (43.5)
Prohibit left turns	9 (34.6)
Close median opening	15 (57.7)
Reconfigure median to prohibit crossing maneuvers while still permitting left turns	6 (23.1)
Require indirect left-turn movements (e.g., jughandles or loops)	7 (26.9)
Provide median U-turn roadways	4 (15.4)
Provide median acceleration lanes	7 (26.9)
Provide protected left-turn signal phasing	19 (73.1)
Improve signal timing at adjacent signals	11 (42.3)

¹Percentages (shown in parentheses) are based on the total of 26 highway agencies that report traffic operational and safety problems related to larger vehicles and narrow medians.

- Accident reduction of about 20 percent was observed for signalization and reconstruction projects.
- Three-lane or five-lane cross sections with two-way left-turn lanes were found to work better than a divided highway with a narrow raised median.
- Offset left-turn lanes were found to work well.

Two agencies responding to the survey identified a total of nine projects implemented to address problems encountered by larger vehicles on divided highways with narrow medians. The types of projects were as follows:

- Installation of median acceleration lane (two projects)
- Installation of offset left-turn lanes (two projects)
- Installation of jughandles for indirect left-turn movements (two projects)
- Closure of median openings (one project)
- U-turn improvement (one project)
- Installation of a roundabout (one project).

Preliminary plans were provided for three projects: (1) installation of a median acceleration lane in a 9.2-m (30-ft) median at a three-leg signalized intersection; (2) installation of a jughandle for indirect left turns at an unsignalized intersection on a divided arterial with a 6.1-m (20-ft) median; and (3) installation of offset left-turn lanes in a 6.1-m (20-ft) median at a signalized intersection.

FORMAL CASE STUDIES OR EVALUATIONS

Question 11 asked highway agencies to indicate whether they had conducted any formal case studies or evaluations of problems encountered by larger vehicles at narrow medians.

None of the responding agencies provided any formal case studies or evaluations in response to this request.

CHANGES IN GEOMETRIC DESIGN OR TRAFFIC CONTROL POLICIES

Question 12 asked whether each agency had made or was planning any changes in geometric design or traffic control policies to better accommodate larger vehicles on divided highways with narrow medians. The following recent or potential changes in policy by individual highway agencies were cited in response to this question:

- On rural bypass roadways, at-grade intersections are being constructed with 27- to 31-m (90- to 100-ft) median widths.
- Median widths of 18 m (60 ft) will be used whenever possible.
- Offset left-turn lanes are being used in roadway medians.
- Median U-turn lanes will be used on a divided highway in a rural corridor carrying recreational traffic.
- Signing may be used in advance of truck crossing locations.
- Left-turn lanes at intersections will be lengthened to provide additional storage.
- The turning radius for an AASHTO WB-18 design vehicle will be used for new construction.
- Larger curb return radii on driveways (and, in some cases, extra-wide driveways) will be used where tractor-trailer usage is high (e.g., trucking companies, freight terminals, truck stops).

National Cooperative Highway Research Program
NCHRP Synthesis Topic 29-05

**TRAFFIC OPERATIONAL AND SAFETY PROBLEMS ENCOUNTERED BY
LARGER VEHICLES ON ROADWAYS WITH NARROW MEDIANS**

QUESTIONNAIRE

The following survey on the traffic operational and safety problems encountered by larger vehicles (i.e., trucks and buses) on divided roadways with narrow medians is being conducted as part of the National Cooperative Highway Research Program (NCHRP), which is sponsored by the American Association of State Highway and Transportation Officials (AASHTO) in cooperation with the Federal Highway Administration (FHWA). Your responses to a few questions concerning your agency's operational and safety experience with truck operations on divided highways and arterial streets with narrow medians would be appreciated.

1. Has your agency encountered operational or safety problems related to divided highway medians that are too narrow or are otherwise unsuited to accommodate larger vehicles (e.g., trucks and buses)?

___ YES ___ NO.

If YES, have such problems been encountered on (please check one or both);

Rural divided highways _____

Urban/suburban divided arterials _____

2. Has your agency encountered concerns or complaints from the trucking industry or from businesses that they serve about access difficulties associated with narrow medians?

___ YES ___ NO.

If YES, please describe:

If you responded NO to both questions 1 and 2, please skip to question 13.

3. Have the problems your agency has encountered with larger vehicles and narrow medians involved any of the following issues? (please check all that apply):

Left-turn maneuvers by larger vehicles leaving the highway _____
 Left-turn maneuvers by larger vehicles entering the highway _____
 Maneuvers by larger vehicles crossing the highway _____

- U-turn maneuvers by larger vehicles _____
- Inadequate storage length in left-turn lanes _____
- Inadequate storage space in the median opening area _____
- Encroachment on through lanes by larger vehicles stopped in the median _____
- Restricted sight distance due to opposing left-turn vehicles _____
- Use of indirect routes to reach destinations with no median opening _____
- Use of indirect routes to reach destinations with a median opening but with restricted median width _____
- Other (please describe): _____

4. Which types of larger vehicles have encountered problems related to narrow medians? (please check all that apply):

- Single-unit trucks _____
- Combination trucks (e.g., tractor-semitrailers) _____
- Intercity buses _____
- Local transit buses _____
- School buses _____
- Recreational vehicles (e.g., motor homes) _____

5. At what types of locations have you encountered operational or safety problems involving larger vehicles and narrow medians? (please check all that apply):

- Signalized intersections _____
- Unsignalized intersections _____
- Driveways with median openings _____
- Driveways without median openings _____
- Other (please describe): _____

6. In your agency's experience, do the problems encountered by large vehicles related to narrow medians vary by time of day?

___ YES ___ NO.

If YES, at which times of day do large vehicles appear to have the greatest problems at narrow medians? (please check all that apply):

- Morning peak hour _____
- Evening peak hour _____
- Daytime off-peak _____
- Nighttime _____

7. What median width do you consider too narrow to adequately accommodate large vehicles?

- On rural divided highways _____ ft
- On urban/suburban divided arterials _____ ft

8. Have any of these problems resulted in specific accident patterns that your agency has observed?

___ YES ___ NO.

If YES, has your agency taken any steps to mitigate this problem?

___ YES ___ NO.

(Please explain what accident patterns were found, what data were used to diagnose these problems, and what corrective actions were taken.)

9. Has your agency made any of the following changes/improvements to mitigate problems created by larger vehicles at narrow medians? (please check all that apply):

- Reconstruct highway with wider median _____
- Reconstruct highway with wider medians only at selected intersections _____
- Remove median _____
- Remove median and replace with flush median _____
- Provide left-turn lanes _____
- Provide offset left-turn lanes _____
- Prohibit left turns _____
- Close median opening _____
- Reconfigure median to prohibit crossing maneuvers while still permitting left turns _____
- Require indirect left-turn movements (e.g., jughandles or loops) _____
- Provide median U-turn roadways _____
- Provide median acceleration lanes _____
- Provide protected left-turn signal phasing _____
- Improve signal timing at adjacent signals _____
- Other (please describe): _____

10. Please describe your agency's experience with any of the changes/improvements you checked in your response to Question 9. For example, if you have plans or sketches for any representative improvement projects, we would appreciate a copy.

11. Has your agency conducted any formal case studies or evaluations of problems encountered by larger vehicles at narrow medians?

___ YES ___ NO.

If YES, we would appreciate it if you would send us a copy of the case study or evaluation with your response.

12. Has your agency made or is your agency planning any changes in geometric design or traffic control policies to better accommodate larger vehicles on divided roadways with narrow medians?

___ YES ___ NO.

If YES, please explain:

13. May we also have the information requested below for an engineer in your agency that we may contact to obtain follow-up information?

Name: _____

Title: _____

Agency: _____

Mailing Address: _____

Telephone Number: _____ Fax Number: _____

E-mail Address: _____

Please mail questionnaire to:

Mr. Douglas W. Harwood
Principal Traffic Engineer
Midwest Research Institute
425 Volker Boulevard
Kansas City, MO 64114

If you have any questions or comments, please feel free to contact Mr. Harwood at (816) 753-7600, Ext. 1571; Fax: (816) 753-0271; E-mail: dharwood@mriresearch.org.

THANK YOU FOR YOUR ASSISTANCE

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